PROCEEDINGS OF THE I.R.E.

Television Broadcasting in the U.S.
Synchronizing Systems for Dot-Interlaced Color TV
Control Chart for Analyzing Experimental Data
Life Expectancy of Vacuum Tubes
Magnetic Recording with AC Bias
Representations of Speech Sounds
Traveling-Wave Amplifier for Medium Powers
Gain of Electromagnetic Horns
Slotted-Line Impedance Measurements
Feedback Oscillator Analysis
Spectrum Analysis of Transient Response Curves
Ionosphere Absorption at 150 Kc
Secondary-Emitting Surfaces
Poisoning of Oxide Cathodes by Sulfur (Abstract)
Abstracts and References

The health of workers in the neighborhood of radioactive materials is safeguarded by electronic instruments, such as the above Radiation Hazard Survey Meter.
FILTER SPECIALISTS
PRODUCERS OF PERMALLOY DUST TOROID COILS AND FILTERS FOR OVER A DECADE

FOR FILTERS

BROAD BAND SHARP CUT-OFF FILTER

NARROW BAND SHARP CUT-OFF FILTER

ATTENUATES 10 KC TO 30 MEGACYCLES

LOW FREQUENCY—LOW PASS FILTER

SUB-OUNCER TOROID FILTERS

Filters employing SUB-OUNCER toroids and special condensers represent the optimum in miniaturized filter performance. The band pass filter shown weighs 6 ounces.

FOR HIGH Q COILS

HQA, C, D TOROID COILS
1 3/4” Dia. x 1 1/2” High.

HQB TOROID COIL
2 1/2” L. x 1 3/4” W. x 2 1/2” H.

UNCASED TOROIDS

VARIABLE INDUCTOR
3 1/2” L. x 1 3/4” W. x 1 1/2” H.

United Transformer Co.
150 VARICK STREET NEW YORK 13, N.Y.
EXPORT DIVISION: 13 EAST 40TH STREET. NEW YORK 16, N.Y. CABLES: “ARLAB”

write for catalog PS-409
The 1951 IRE Convention

In pace with the rapid and widespread advances of the engineering and science of radio-television-and-electronics are the plans for the IRE Convention. 210 vitally important technical papers will be presented in 29 technical sessions, and 14 comprehensive symposia organized by nine of the IRE professional groups.

The entire industry, and every engineer attending will be helped to advance by these four days of meetings!

Engineering is accomplished by men! The humbly interesting contacts of the Convention help further the advances of the field. To know your fellow engineers is to help get things done, by exchange of information and finding "who knows how"! A Banquet that this year is truly different from menu to program—a President's Luncheon with special tables for the Professional Groups—a "get-together" Cocktail Party all further these ends.

The Radio Engineering Show

267 Manufacturers will bring their 1951 Advances in better products, components and apparatus to a single meeting place. Grand Central Palace in New York City. Thousands of IRE members and visiting engineers may see them. Such a "show" saves time and spreads information. In no other way can you see and learn so much in four days!

The exhibit method is the finest form of product presentation. Here the manufacturers can properly prepare his demonstrations—and adequately man his exhibit with his own competent engineers to answer your questions—doing much for you and himself, economically. Come and see these great 1951 Advances.

Remember these days, March 19-22, Monday through Thursday, and these places: Grand Central Palace; and the Waldorf-Astoria, our new hotel headquarters.

"IRE Meetings and Shows Accelerate Electronic Progress"
Sprague-Herlec Cera-mite Capacitors are a "must" for modern television circuits.

Now available in both temperature-compensating (TC) and general application (GA) types, Cera-mites meet most application needs in the 10 mmf to 15,000 mmf capacitance range.

These miniature capacitors offer set designers maximum space economy, ease of mounting, and improved very-high-frequency performance.

The flat disc with uni-directional lead construction has minimum self-inductance and a higher self-resonant frequency than a tubular design; hence improved v-h-f bypass efficiency.

Sprague-Herlec Engineering Bulletin 601B gives the complete list of standard ratings as well as performance specifications. Write for your copy today!
How to be sure you get the Best Capacitor

YOU CAN test the paper for density . . . thickness . . . porosity . . .
power factor . . . chloride content . . . dielectric constant . . .
dielectric strength.

And then test the foil for thickness . . . purity . . . softness of the
anneal . . . freedom from oil . . . cleanliness of surface . . . absolute
smoothness.

And then test the liquid dielectric for specific gravity . . . viscosity
. . . power factor . . . color . . . acidity . . . flash point . . . dielectric
strength . . . dielectric constant . . . insulation resistance . . . water
content.

And after that, test every single finished capacitor for shorts,
grounds, and opens at overvoltage between terminals and between
terminals and case . . . and measure the capacitance of every single
unit . . . and then check every single capacitor to see that it has a
leak-proof hermetic seal.

OR YOU CAN buy General Electric capacitors . . . product of
outstanding research and know-how . . . which have already passed
every one of these tests

. . . on the materials when they were made,
. . . and again before they were used.
. . . and on the capacitors during manufacture.
. . . and then, finally, on every single capacitor before shipment.

For full information on types, ratings, dimensions, types of mount-
ing, and prices of capacitors, address the nearest General Electric
Sales Office or Apparatus Department, General Electric Company,
Schenectady 5, N. Y.

GENERAL ELECTRIC

3 A
At Bell Telephone Laboratories, radio scientists devised their latest microwave lens by copying the molecular action of optical lenses in focusing light. The result was a radically new type of lens—the array of metal strips shown in the illustration. Giant metal strip lenses are used in the new microwave link for telephone and television between New York and Chicago.

The scientists went on to discover that the very same type of lens could also focus sound...thus help, too, in the study of sound radiation...another field of great importance to your telephone system.

The study of the basic laws of waves and vibrations is just another example of research which turns into practical telephone equipment at Bell Telephone Laboratories...helping to bring you high value for your telephone dollar.

Waves from the sound source at left are focused by the lens at center. In front of the lens, a moving arm (not shown) scans the wave field with a tiny microphone and neon lamp. The microphone picks up sound energy and sends it through amplifiers to the lamp. The lamp glows brightly where sound level is high, dims where it is low. This new technique pictures accurately the focusing effect of the lens. Similar lenses efficiently focus microwaves in radio relay transmission.
A tiny telephone type—the Guardian Series 695 D.C. Relay has distinguished itself in wartime communications equipment. For inter-plane—intra plane—ground to plane—ship to shore radio—walkie talkie—field telephone equipment—the Guardian Series 695 D.C. is unequaled. Contrary to conventional design, armature on this relay is formed outward, away from coil, permitting use of a longer coil without increasing overall length of the unit. Armature hinges on a frictionless bearing which requires no lubrication. Proper balance of copper winding and volume of iron on field piece result in maximum flux density without oversaturation of iron. Series 695 D.C. Relay is capable of carrying up to 6 single pole, single throw contact combinations. Can be hermetically sealed as a standard unit in Lug Header type housing or, to specification, in A. N. Connector, Screw Terminal, or Lug Header type housings.

WRITE OR WIRE... FREE CATALOG, SPECIFIC RECOMMENDATIONS, NO OBLIGATION.

GUARDIAN ELECTRIC
1628-B W. WALNUT STREET
CHICAGO 12, ILLINOIS
A COMPLETE LINE OF RELAYS SERVING AMERICAN INDUSTRY

PROCEEDINGS OF THE I.R.E.  February, 1951
TRUSCON... a name you can build on

world leader in better radio tower engineering

Truscon experience in radio tower engineering is world wide... meeting all types of topographical and meteorological conditions... and supplying many different tower types—guyed or self-supporting... tapered or uniform in cross-section... for AM, FM or TV transmission.

Your phone call or letter to any convenient Truscon district office, or to our home office in Youngstown, will bring you immediate, capable engineering assistance. Call or write today.

TRUSCON® STEEL COMPANY Youngstown 1, Ohio
Subsidiary of Republic Steel Corporation

PROCEEDINGS OF THE I.R.E. February, 1951
**Specifications**

- **-hp- 460B Fast Pulse Amplifier**
  - **Frequency Response**: Closely matches Gaussian curve. Hi 3 db point is approx. 140 mc. If 3 db point is approx. 50 kc into 200-ohm load.
  - **Maximum Output Voltage**: High bias approx. 125 v. negative open circuit. Normal bias (linear amplification) approx. 8 v. peak into 200-ohm load or 16 v. peak open circuit, pos. or neg. pulses.
  - **Gain**: Approx. 15 db into 200-ohm load.
  - **Input Impedance**: Approx. 200 ohms.
  - **Rise Time**: Approx. 0.0026 μsec.
  - **Delay**: Approx. 0.016 μsec.
  - **Duty Cycle**: 0.10 max. for 125 v. output pulse.
  - **Non Linearity**: See Figure 1.
  - **Mounting**: 5½" x 9½" x 6" deep.
  - **Power Supply**: 115 v. 50/60 cps. 35 watts.
  - **Price**: $225.00 f.o.b. factory.

- **-hp- 460A Wide-Band Amplifier**
  - **Specifications same as Model 460B except**
  - **Maximum Output Voltage**: Approx. 8 v. peak open circuit. 4.75 v. peak into 200-ohm load.
  - **Gain**: Approx. 20 db with 200-ohm load.
  - **Delay**: Approx. 0.013 μsec.
  - **Price**: $85.00 f.o.b. factory.

- **-hp- 460A Accessories**
  - **46A-16A Patch Cord**: 200-ohms, 2' long. $18.50.
  - **46A-16B Patch Cord**: 200-ohms, 6' long. $25.50.
  - **46A-95A Panel Jack**: For 200-ohm cables, low capacitance. 1½" dia. $7.50.
  - **46A-95B Cable Plug**: For 200-ohm cables, low capacitance. $7.50.
  - **812-52 Cable—200-ohm cable in lengths to specification. Per foot $1.75.**
  - **46A-95C 50-ohm Adaptor—Type N connector for coupling 50-ohm line into -hp- amplifiers. $15.00.
  - **46A-95D Adaptor—Bayonet sleeve for connecting -hp- 410A VTVAm to output of 460A/B amplifiers. $15.00.
  - **46A-95E Connector Sleeve—Joins two 46A-95B Cable Plugs. $7.50.
  - **46A-95F Adaptor—For connecting to EXPe CRT. $10.00.**
  - **46A-95G Adaptor—For connecting to Tektronix type 511 oscilloscope. $12.50.**

**Here at last** is complete instrumentation for true amplification of fast pulses at high power levels sufficient to operate scalers or counting meters, cathode ray tubes, or to give more than 100 mc bandwidth to your present oscilloscope. New -hp- 460B Fast-Pulse Amplifiers, in cascade with -hp- 460A Wide-Band Amplifiers, amplify up to 125 volts, open circuit (limited duty cycle). This permits full deflection of 5XP cathode ray tubes, or 2-inch deflection of SCP tubes. Ultra-short rise time of 0.0026 μsec, combined with zero overshoot, assures distortion-free amplification of pulses faster than 0.01 μsec.

New -hp- 460B Amplifier, cascaded with -hp- 460A provides linear amplification of 16 volts peak output and pulse amplification of 125 volts output (slight nlinearity). This combination provides maximum usefulness in fast-pulse study for nuclear radiation work, television or VHF research; for increasing frequency range of your oscilloscope, or general wide-band laboratory amplification. In addition to the above instrumentation, -hp- also offers series 46A accessories—a complete set of 200 ohm cables, adapters and fittings for inter-connections of amplifiers or patching to oscilloscopes.

**Get complete details. Write direct or see your -hp- sales representative.**

**HEWLETT-PACKARD COMPANY**

21770 Page Mill Road • Palo Alto, California, U.S.A.
Sales Representatives in all principal cities.

Export: Frazar & Hansen, Ltd., San Francisco, New York, Los Angeles
Specialization in resistors lets IRC concentrate on research and quality control to a greater degree than any other supplier.

Result: IRC exploration anticipates future resistor needs—improves existing products—and controls quality and uniformity in every IRC unit. Largest resistor manufacturer in the world, IRC attracts the finest of engineering talent. We're using more of such talent than ever, now, to keep step with today's electronic requirements—while we plan for tomorrow's advances.

**FLAT POWER WIRE WOUND RESISTORS**

For high-wattage dissipation in limited-space applications, IRC Type FRW Flat Wire Wound Resistors have higher space-power ratios than standard tubular units. FRW's can be mounted vertically or horizontally—singly or in stacks. Non-magnetic mounting brackets permit easy, economical mounting, aid in heat distribution along the entire length, and transfer internal heat to the chassis. Available in 9 sizes—fixed and adjustable. Send for full details in Bulletin C-1.
is important

DEPOSITED CARBON PRECISTORS
A unique combination of accuracy, stability and economy makes IRC Deposited Carbon PRECISTORS ideal for applications where carbon compositions are unsuitable or wire-wound precisions too expensive. Instrumentation, advanced electronics and critical television circuits also benefit from their wide range of values, low voltage coefficient, excellent frequency characteristics, predictable temperature characteristics, high voltage rating, low noise level and small size. Coupon brings full particulars in Bulletin B-4.

VOLTMETER MULTIPLIERS
Sealed-precision IRC Type MF Resistors are completely impervious to moisture—have proved themselves dependable voltmeter multipliers for use under the most severe humidity conditions. Each multiplier consists of a number of IRC Precision Resistors, mounted, interconnected, and encased in a glazed, hermetically sealed ceramic tube. MF's are compact, rugged, stable, easy to install, and may be used with very little drain on the power supply. Individual precision resistors may be either inductive or noninductive, so that they may be used on AC as well as DC. Mail coupon for full data in Bulletin D-2.

HIGH OHMIC RESISTORS
Engineered for high voltage applications where high resistance and power are required, IRC Type MVX Resistors are particularly suited to many types of television and electronic circuits. Unique application of IRC's proven filament resistance coating in helical turns on a ceramic tube provides a conducting path of long, effective length. Result: A unit of high resistance value with resistance materials having relatively low specific resistance. Type MVX's have 2 watt rating, are exceptionally stable—permit the use of high voltage on the resistor while keeping voltage per unit length of path comparatively low. Send coupon for complete details in Bulletin G-2.

INTERNATIONAL RESISTANCE CO.
405 N. BROAD ST., PHILADELPHIA 8, PA.

Please send me complete information on the items checked below:

☐ Flat Wire Wound Resistors (C-1) ☐ Deposited Carbon PRECISTORS (B-4)
☐ High Voltage Resistors (G-2) ☐ Voltmeter Multipliers (D-2)

☐ Name and address of local IRC Distributor

NAME: .................................................................
TITLE: ...............................................................
COMPANY ..........................................................  
ADDRESS .............................................................
CITY ................................................................. ZONE: ............ STATE: ..................
Lower losses with higher efficiency and lower operating temperatures
Lighter weight, smaller sizes for more compact construction, lower costs of finished equipment
Much higher permeability
Less corona effect
Lower cost

Technically, Stackpole Ceramag Cores are molded from a metallic oxide powder mixture which, when properly handled during processing, promotes cubic crystal growth. This results in a non-metallic material having low eddy current loss and exceptionally high permeability.

Practically, Stackpole's skill in the highly critical fabrication of these cores in production quantities has resulted in lower costs and higher standards of performance and dependability for the nation's leading television receivers.

Besides the more popular standard Ceramag core types illustrated above, many specials are regularly supplied.
Let's Put the Chill on a Hot Subject . . .

As you read this message engineers the country over are hard at work planning, experimenting on fused hermetic sealing for their company's electrical product.

When the subject of a so-called glass terminal comes up (and it's bound to) they're apt to talk in terms of thermal shock. That's where Fusite Hermetic Terminals come in.

Take the interfusion of steel and inorganic glass that is a Fusite terminal. Apply the sizzling heat of a soldering or welding operation. And if you want to be ornery, shove it right out on the shipping dock on a zero day.

What happens?

Absolutely nothing. Your seal remains as tight as your production skill made it. All Terminals remain as smooth, as rugged, and uniform as only Fusite makes them.

Would you like to know more, or see samples? Write to Dept. E.

TERMINAL ILLUSTRATED 908HTO—For plug-in to standard "Octal" sockets. Available with two to eight hollow tube electrodes.

THE FUSITE CORPORATION
CARTHAGE AT HANNAFORD, NORWOOD, CINCINNATI 12, OHIO
and now--
the magic link
for closed circuit tv

Actually a miniature closed-circuit television transmitter. Takes signal directly from any standard camera chain, modulates a carrier frequency of either Channel 2 or 3, and feeds via cable directly through the antenna posts of standard TV receivers. Receivers operate exactly as though tuned to a telecast on that Channel.

Performance superior to other forms of transmission. Audio and video reception absolutely free from outside interference. Truly, the MAGIC LINK for closed-circuit television.

Ideal for use in industrial television applications, for field demonstrations of TV receivers, for studio use, for sales meetings, and countless other uses. Does away with expensive, bulky equipment and circuitry modification of receivers.

First with the Finest in Television

ALLEN B. DU MONT LABORATORIES, INC.
Television Transmitter Division, Clifton, N.J.
Cleveland Container Company

5201 Barberton Ave., Cleveland 2, Ohio

Plants and Sales Offices at Plymouth, Minn., Chicago, Detroit, Ogdenburg, N.Y., Jamesburg, N.J.

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New York Area: R. T. Murray, 614 Central Ave., East Orange, N. J.


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CLEVELITE* and COSMALITE*

PHENOLIC TUBING

Meets the Most Exacting Specifications!

A Grade for Every Need:

Cleveland

Grade E . . . . . Improved post cure fabrication and stapling.
Grade EX . . . . . Special grade for TV deflection yoke sleeve.
Grade EE . . . . . Improved general purpose.
Grade EEX . . . . . Superior electrical and moisture absorption properties.
Grade EEE . . . . . Critical electrical and high voltage applications.
Grade XAX . . . . . Special grade for government phenolic specifications.

Cosmalite

Grade SP . . . . Post cure fabrication and stapling.
Grade SS . . . . General purpose.
Grade SSP . . . . General purpose—punching grade.
Grade SLF . . . . Thin wall tubing—high dielectric and compression strength.

CLEVELAND PHENOLIC TUBING

The First Choice of the Radio and Television Industries.
Excellent Service and Prompt Deliveries Assured.

*Trade Marks
Outstanding Advantages of the new Mallory Spiral Inductuner

1. A single control for easy selection and fine tuning of any television or FM channel.
2. Easily adapted to UHF converter use.
3. Excellent stability eliminates frequency drift.
4. Supplied in two-, three- or four-section designs.
5. Far more quiet operation; permits high signal-to-noise ratio in front end designs.
6. Free from microphonics.
7. Greater selectivity on high frequency channels.
8. Eliminates "bunching" of high band channels.
9. Simplifies front end design and production.
10. Reduces assembly costs.
11. Choice of: 6 turn unit continuously tunes from channels 2 to 13; 4 turn unit tunes only channels 2 to 6, FM, 7 to 13; 3 turn unit tunes only the 12 television channels.

Mallory TV Front End Limits Oscillator Radiation

Mallory engineering has accomplished the development of a TV Front End Assembly which avoids interference by the receiver with nearby sets and other electronic equipment.

Built around the four-tuned circuit Spiral Inductuner*, this new front end is designed to restrict radiation from the oscillator. In addition, the oscillator and converter are shielded from the RF amplifier. And, each section of the Inductuner is provided with its own special shielding. Thus, Mallory now offers TV manufacturers a front end that is ready to perform within the strict standards contemplated for oscillator radiation.

That's service beyond the sale!

The Mallory Front End is universally adaptable. It features higher gain, and lower signal-to-noise ratio. Designed around the Inductuner, it is available with or without indexing provisions, in 3 and 4 revolution designs. Also available in 6 turns without the indexing feature.

*Reg. trade mark of P. R. Mallory & Co., Inc. for inductance tuning devices covered by Mallory-Wave patents.

Television Tuners, Special Switches, Controls and Resistors

SERVING INDUSTRY WITH

Electromechanical Products
  Resolvers
  Switches
  TV Tuners
  Vibrators

Electrochemical Products
  Capacitors
  Rectifiers
  Mercury Dry Batteries

Metallurgical Products
  Contacts
  Special Metals
  Welding Materials

MALLORY

P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

PROCEEDINGS OF THE I.R.E.  February, 1951
A New Concept in Precision Potentiometers...

THE MODEL J

Helipot

Precise Mechanical Concentricity
High Electrical Accuracy
Ball Bearing Construction
Independent Phasing

...combined with mass-production economies!

If it's a tough potentiometer problem, bring it to Helipot —for Helipot has facilities and know-how unequalled in the industry for mass-producing precision potentiometers with advanced operating and electrical features.

This recently-developed 'Model J' Helipot, for example, combines several revolutionary advancements never before available in the potentiometer field...

Precise Mechanical Concentricity

Modern servo mechanisms and computer hook-ups require high mechanical precision to assure uniform accuracy when connected to servo motors through close-tolerance gears and couplings.

In the "Model J," close concentricity between mounting surface and shaft is assured by a unique mounting arrangement. The unit can be aligned on either of two wide-base flange registers and secured with three screws from the front of the panel... or it can be secured with adjustable clamps from the rear of the panel to permit angular phasing. Or if preferred, it can be equipped with the conventional single-hole bushing type of mounting.

In addition to accurate mounting alignment, exact rotational alignment is assured by the long-life, precision-type ball bearings upon which the shaft rotates. Precise initial alignment coupled with negligible wear mean high sustained accuracy.

High Electrical Accuracy

Helipot products have long been noted for their unusually high electrical accuracy and the "Model J" embodies the latest advancements of Helipot engineering in this field.

For example, tap connections are made by a new Helipot welding technique whereby the tap is connected to only ONE turn of the resistance winding. This unique process eliminates "shorted section" problems!

High linearity is also assured by Helipot's advanced production methods. Standard "Model J" linearity accuracies are guaranteed within ±0.05%. On special order, accuracies to ±0.15% (capacities of 5000 ohms and up) have been obtained.

Ball Bearing Construction

The shaft of each "Model J" is carefully mounted on precision-type ball bearings that not only assure sustained rotational accuracy, but also provide the constant low-torque operation so essential for servo and computer applications. Starting torque is only % of an inch-ounce (± .25 in.-oz.)—running torque, of course, is even less.

Independent Phasing

When using the "Model J" in ganged multiple assemblies, each section can be independently phased electrically or mechanically—even after installation on the panel—by means of hidden internal clamps controlled from outside the housing. Phasing is simple, quick, accurate!

Mass-Production Economies

In addition to its many other unique features, Helipot engineers have developed unusual techniques that permit mass-production economies in manufacturing the "Model J". Actual price depends upon the number of taps required, special features, etc.... but with all its unique features, you will find the "Model J" very moderate in cost.

Wide Choice of Designs

The "Model J" Helipot is available in a wide selection of standard resistance ranges—50, 100, 1,000, 5,000, 10,000, 20,000, 30,000 and 50,000 ohms... in single- or double-shaft designs... with choice of many special features to meet virtually any requirement within its operating field.

*Write for Bulletin 107 which gives complete data and price information on the versatile "Model J" Helipot

THE HELIPO T CORPORATION
South Pasadena, California
A New Tube For
HIGH-POWER VHF TV

Eimac
4W20000A
Water-Cooled Power Tetrode
★ 20 Kw Peak Sync. Output
★ 5 Mc. Bandwidth
★ 216 Mc. Operation
★ LOW COST

For the practical approach to high-power TV through channel 13, here is the tube . . . the new Eimac 4W20000A power tetrode.

Among the features of the 4W20000A are a unipotential cathode of thoriated tungsten heated by electron bombardment, a water-cooled anode rated at 20 kw dissipation, and coaxially arranged terminals.

This new tube's potential applications are not limited to TV service. Data on typical operation in class-C telegraphy or FM telephony as well as class-B linear TV amplifier service are included in a comprehensive data sheet . . . available for the asking.

Eitel-McCullough, Inc.
San Bruno, California

SEE THE 4W20000A
at the March IRE Show, Booth 36

PROCEEDINGS OF THE I.R.E. February, 1951
CERAMIC DISK CAPACITORS

Hi-Q Ceramic Disk Capacitors are being used by the millions by television receiver manufacturers who demand the utmost in performance.

Unit cost, time and labor may be saved by using several of the multiple capacity Hi-Q Disks where applicable in your television circuit. Multiple capacities having a common ground are available in standard units as shown in the chart below. Hi-Q Disks are coated with a non-hygroscopic phenolic to insure protection against moisture and high humidities. Hi-Q Disks like all other Hi-Q components assure you of the highest quality workmanship at the lowest possible cost.

Our Engineers are ready and willing to discuss the application of these highly efficient, dependable capacitors in your circuits. Write today for your FREE copy of the new Hi-Q Datalog.

<table>
<thead>
<tr>
<th>Type</th>
<th>A Diameter</th>
<th>B Lead Width</th>
<th>C Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.P.D. .00047</td>
<td>3/16&quot; max.</td>
<td>3/16&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. .0008</td>
<td>3/16&quot; max.</td>
<td>3/16&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. .001</td>
<td>3/8&quot; max.</td>
<td>3/8&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. .0015</td>
<td>3/8&quot; max.</td>
<td>3/8&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. .002</td>
<td>3/16&quot; max.</td>
<td>3/16&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. .004</td>
<td>1 1/32&quot; max.</td>
<td>1 1/32&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. .005</td>
<td>3/16&quot; max.</td>
<td>3/16&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. .01</td>
<td>3/16&quot; max.</td>
<td>3/16&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. 2x.001</td>
<td>1 1/32&quot; max.</td>
<td>1 1/32&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. 2x.0015</td>
<td>1 1/32&quot; max.</td>
<td>1 1/32&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. 2x.002</td>
<td>3/16&quot; max.</td>
<td>3/16&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. 2x.003</td>
<td>3/16&quot; max.</td>
<td>3/16&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. 2x.004</td>
<td>3/16&quot; max.</td>
<td>3/16&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. 3x.0015</td>
<td>3/16&quot; max.</td>
<td>3/16&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
<tr>
<td>B.P.D. 3x.002</td>
<td>3/16&quot; max.</td>
<td>3/16&quot; ± 1/16&quot;</td>
<td>5/32&quot; max.</td>
</tr>
</tbody>
</table>

Insulation: Durez and Wax impregnated. Leads: 22 gauge pure tinned dead soft copper. Capacity: Guaranteed minimum as stamped. All capacitance measurements made at 75°C at 1 KC at not over 5 volts RMS. Test Voltage: 1500 volts D.C.


Hi-Q Electrical Reactance Corp.
OLEAN, N.Y.

SALES OFFICES: New York, Philadelphia
Detroit, Chicago, Los Angeles

PLANTS: Olean, N.Y., Franklinville, N.Y.
Jessup, Pa., Myrtle Beach, S. C.
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

Aircraft Signal Generator

A signal generator for complete testing of airborne omnirange and localizer receivers in aircraft or on the bench has been introduced by the Aircraft Radio Corp., Boonton, N. J.

The unit, designated as Type H-14, has a frequency range of 108 to 118 Mc, and can be used for all necessary quantitative bench tests. It provides facilities for testing 24 omni courses, plus left-center-right checks on both amplitude and phase localizers. The output for outside checks is 1 volt into 52 ohm line, and for bench checks, 0 to 10,000 \( \mu V \).

New Tape Recorder

A high-fidelity magnetic tape recorder, with a range of 15,000 cps on half-track tape recorded at 7\( \frac{1}{4} \) inches per second is in production at Ampex Electric Corp., 131 Howard Ave., San Carlos, Calif.

The capacity of this Model 400 is 132 minutes on a single 10-inch reel.
Other features include three magnetic heads shielded in a single housing, a built-in vu meter, and a single control switch for forward, rewind, and record. The machine also provides 15 inches per second tape speed by simply turning a switch. At 7\( \frac{1}{4} \) inches per second flutter and wow is less than 0.25 per cent; frequency response is \( \pm 4 \) db, 30 to 15,000 cps. At 15 inches per second flutter and wow is less than 0.2 per cent; frequency response is \( \pm 2 \) db, 50 to 15,000 cps.

(Continued on page 22A)
Center, on black background, are the eight standard sizes of Arnold Tape-Wound Toroids. Around them are a number of other cores of special nature produced for individual needs.

Arnold Tape-Wound Toroidal Cores

Applications
Magnetic Amplifiers
Pulse Transformers
Non-Linear Retard Coils
and Transformers
Peaking Strips, and many other specialized applications.

Range of Sizes
Arnold Tape-Wound Toroids are available in eight sizes of standard cores—all furnished encased in molded nylon containers, and ranging in size from \( \frac{1}{2} \)" to \( 2\frac{1}{2} \)" I.D., \( \frac{1}{2} \)" to 3" O.D., and \( \frac{1}{4} \)" to \( \frac{1}{2} \)" high.

Range of Types
These standard core sizes are available in each of the three magnetic materials named, made from either .004", .003" or .001" tape, as required.

In addition to the standard toroids described at left, Arnold Tape-Wound Cores are available in special sizes manufactured to meet your requirements—toroidal, rectangular or square. Toroidal cores are supplied in protective cases.

* Manufactured under licensing arrangements with Western Electric Company.
LITTLE DEVIL COMPOSITION RESISTORS

Resistance and wattage are clearly marked on every one of these tiny, rugged insulated composition resistors. Three sizes: ½, 1 and 2-watt in all RMA resistances. Tolerance ±5% and ±10%.

CLOSE CONTROL RHEOSTATS

Inspect permanently smooth, close control. Widely used in industry. All ceramic, vitreous enameled: 25, 50, 75, 100, 150, 225, 300, 500, 750, and 1000-watt sizes.

DUMMY ANTENNA RESISTORS

For loading transmitters or other r.f. sources. New, rugged, vitreous enameled units are practically non-reactive within their recommended frequency range. 100 And 250-watt sizes, 52 to 600 ohms, ±5%.

If it's made by OHMITE

it's DEPENDABLE!

To countless thousands of technical men all over the world—engineers, designers, and servicemen—the name OHMITE has become synonymous with dependability. There is good reason for this overwhelming opinion. Every OHMITE product is carefully designed and constructed to give extra performance and long life under severe service conditions. When you need dependable resistance components, play safe and specify OHMITE.

OHMITE MANUFACTURING CO., 4861 Flournoy St., Chicago 44, Ill.

Be Right with OHMITE®
In the price of the El-Menco CM-15 capacitor, the cost of materials is small — for few materials are used. It's the know-how of putting these minute quantities of materials together that really counts.

Tiny as it is, the El-Menco CM-15 high-capacity fixed mica condenser exceeds the strict requirements of the Army and Navy. It is tested for dielectric strength at double its working voltage before leaving the factory — for insulation resistance and capacity value. You can always depend on this mighty midget — even under the most critical operating conditions and climate extremes.

**ALWAYS SPECIFY EL-MENCO CAPACITORS**

**CM-15 MINIATURE CAPACITOR**
Actual Size 9/32" x 1/2" x 3/16"
For Television, Radio and other Electronic Applications.
2 mmf. to 420 mmf. cap. at 500v DCw.
2 mmf. to 525 mmf. cap. at 300v DCw.
Temp. Co-efficient ± 50 parts per million per degree C for most capacity values.
6-dot color coded.

**THE ELECTRO MOTIVE MFG. CO., Inc.**
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**MOLDED MICA CAPACITORS**
**MICA TRIMMER CAPACITORS**

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**ARCO ELECTRONICS, INC.** 103 Lafayette St., New York, N. Y.—Sole Agent for Jobbers and Distributors in U.S. and Canada

PROCEEDINGS OF THE I.R.E. February, 1951
A Better Product through "Sound" Research

Magneencoder
High Fidelity Tape Recorders For Industry

NOISE ANALYSIS • PROCESS CONTROL
VIBRATION TESTS • TELEMETERING

Used by more engineers than all other professional tape recorders combined

Write for NEW CATALOG
Magnecord, Inc., Dept P-2
360 N. Michigan Ave., Chicago 1, Ill.
Send me further information on Magnecord tape recorders for industrial "Sound" Research.

News—New Products
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 18A)

New Amplifier
A new wide-range, low-distortion amplifier system A-20-5 is available from The Electronic Workshop, 351 Bleecker St., New York 14, N. Y.

The four input channels, including an equalizer-pre-amplifier, of any of the available magnetic phonograph cartridges, have independent level adjustments. A four-position treble cut-off filter reduces high-frequency noise and distortion. A loudness-compensated volume control is provided, as well as separate bass and treble controls giving 18-dB boost or cut. The treble control equalizes for high-frequency recording characteristics.

A noise suppressor can be conveniently connected into the system to be effective on all channels. A recorder output which is unaffected by settings of the tone and volume controls is included.

The 18 dB of feedback in the amplifier affords excellent loudspeaker damping and long tube life. Distortion at 20 watts is less than 1 per cent. Full power is delivered over the entire audio range.

A somewhat simplified system, the S-20 is also available.

Television Deflector Yoke Core
A high-permeability core for deflection of wide-angle, large-screen, kinescopes is available from Westinghouse Electric Corp., P. O. Box 2099, Pittsburgh 30, Pa.

Made of Hiperil, a cold-rolled, grain-oriented electrical steel, the core has low reluctance at all flux densities.

The core is wound and bonded in circular form from a continuous strip of 5-mil material. It is then cut into two "C" shaped pieces for assembly around the deflection coils. The firm claims that the extremely thin laminations plus superior magnetic characteristics of the steel results in improved linearity and sharper pictures. The cores are rugged and completely free from magnetic instability due to change in temperature.

The core is available in sizes to suit the application.

(Continued on page 23A)
News—New Products
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.
(Continued from page 22A)

Plug-In Electronic Chassis
To meet a variety of requirements for compact, lightweight electronic assemblies, Avion Instrument Corp., 121 E. 24 St., New York 10, N. Y. has designed a universal electronic chassis for use in servo mechanisms, pulse and flip-flop circuits, analog computers, and similar devices. Up to eight subminiature tubes can be mounted and wired.

The assembly mounts in a metal case, filled with a potting compound, which provides mechanical support for the components. Input and output leads are brought to a standard octal tube base, for connection to associated equipment. Operating weight is 12 ounces.

The chassis is designed to operate in temperatures ranging from -50° C to +80° C. It meets specification AN-E-19 with respect to condition of altitude, humidity, and vibration.

Typical assembly is a direct-coupled basic amplifier having closed-loop characteristics as follows: output, with no load, -125 to 275 volts and, with 10 ohm load, -40 to 40 volts; output impedance, looking into amplifier, 1 ohm (approx.); linearity, variation over entire output range, less than 10 mv; gain is determined by choice of external resistors, maximum useful gain, limited by drift, 25, (approx.); drift, referred to input, 20 mv (approx.); frequency response 3 db down at 100 cps; operating voltages must be regulated to ±1 per cent.

Video Distribution Amplifier
The Type 1311 video distribution amplifier which consists of five separate isolation amplifiers and an electronically regulated power supply is in production at Tel-Instrument Co., Inc., 50 Paterson Ave., East Rutherford, N. J.
(Continued on page 74A)

Cables
Amphenol coaxial cables made with Teflon dielectric have low loss and perform satisfactorily at temperatures as high as 500° F. Covering the Teflon dielectric are two silver coated shields and two wrappings of Teflon tape. The jacket consists of two fibre glass braids impregnated with silicone varnish which is oven baked to provide maximum moisture and abrasion resistance.

Connectors
Because impedance specifications of Amphenol RF Connectors can be depended on, no line unbalance is inserted, nor is the standing-wave ratio increased. Amphenol RF Connectors meet the exacting requirements of laboratory applications—have longer leakage paths, lower loss.

The 82 series connectors illustrated are weatherproof type HN connectors for use with 50 ohm cable. These connectors have full 4Kv. rating when used with Silicone Compound and may be used with 70 ohm cables when impedance is not critical.

The 83 series UHF connectors illustrated are low cost general purpose connectors ideal for laboratory applications. Not constant impedance, but suitable for general RF transmission below 160 megacycles.

Teflon inserts are standard on the connectors illustrated and will be supplied with any AMPHENOL RF connector on special order.
SHALLCROSS MATCHES YOUR Precision Resistor Requirements!

...for real dependability on STANDARD INDUSTRIAL USES
...over 40 economical standard types and sizes, each available in numerous mechanical and electrical adaptations. Write for Shallcross Data Bulletin R3A.

...for JAN EQUIPMENT
Shallcross is in constant touch with the latest military precision resistor requirements. The present line includes 13 types designed for JAN characteristic "B" and 4 types for characteristic "A".

...for MINIATURIZATION PROGRAMS
For years, Shallcross has led the way in the production of truly dependable close-tolerance, high-stability resistors in miniature sizes. Standard and hermetically sealed types are available.

...for SPECIAL ASSEMBLIES
Shallcross regularly produces hundreds of special precision resistor types including precision power resistors, resistors with axial or radial leads and multi-unit strip resistors (illustrated) with either inductive or non-inductive windings.

...for HIGH-STABILITY APPLICATIONS
Many Shallcross Akra-Ohm resistors are available with guaranteed tolerance to 0.01% and stability to 0.003%. Matched pairs and sets are supplied to close tolerances.

SHALLCROSS MANUFACTURING COMPANY COLLINGDALE, PA.

WIDE-RANGE, DIRECT READING CAPACITOR ANALYZER
A laboratory-type Capacitor Analyzer meeting the need for a highly accurate, wide-range, direct-reading measuring instrument capable of determining the essential characteristics of capacitors has been announced by the Shallcross Manufacturing Co. This versatile instrument will determine capacitance values between 5mmf. and 12,000 mfd.; insulation resistance from 1.1 to 12,000 megohms; also leakage current, dielectric strength, and percentage power factor. A divided panel carrying an outline of the operating instructions makes it readily possible to use the instrument without reference to an instruction book. The Shallcross analyzer operates on 110 volt, 60-cycle alternating current. Literature giving full details will gladly be sent on request to the Shallcross Manufacturing Company, Collingdale, Pa.

MULTI-PURPOSE TRANSMISSION TEST SET
In addition to measuring the electrical characteristics of telephone lines and equipment the new Shallcross multi-purpose transmission test set may be used for efficiency tests on local and common battery telephone lines and sets, carbon microphones, receivers, and magnetic microphones. It also provides a fast, efficient means of testing capacitors, generators, ringers, insulation resistance, dials, and continuity. Key switches and dials are used to select and control the test circuits. The 693 Transmission Test Set is powered by external batteries. It features compact, substantial construction and is fully portable, thus making it ideal for either field or laboratory use. Details may be obtained from the Shallcross Manufacturing Company, Collingdale, Pennsylvania.
Production facilities, already the largest in the steatite industry, are being rapidly expanded to take care of your needs. Plant No. 3 is just going into production. All plants are running 24 hours a day, 7 days a week. Plant No. 5 is on the way.

Current deliveries are not satisfactory to you or to us. We were swamped with rearmament orders for the last quarter of 1950. But great strides are being made toward taking care of your requirements for AlSiMag custom made technical ceramics.

Every effort is being made to keep American Lava Corporation your most dependable source for quality and for delivery according to promise.
WELLER was getting a twist in the rod when it was installed in the assembled gun. Other tempers were tried and tested. Then a copper rod of a slightly harder temper than the first was recommended. That was it! Proper temper was the key. Proper temper was also the key to the .291 dia. copper rod used for the Soldering tip itself. For this, too, had to retain its rigidity and yet remain soft enough to be coined, punched, and formed without fracture.

"In addition to being extremely helpful in arriving at the proper tempers, Revere also recommended that we specify our rod in multiple lengths, and thus save considerably on scrap. They were also helpful in solving the problem of attaching the brass sleeve to the secondary rod in our Soldering Gun," the Weller Manufacturing Company tells us.

So you see, Revere's interest in your problem does not stop with the recommendation of its products. Perhaps Revere can help you. Why not take your current problem to the nearest Revere Sales Office and see?

Revere Copper Rod replaces Secondary Coil in Soldering Gun Transformer... reduces number of parts, makes for a speedier, more efficient assembly... also makes possible a lighter, more compact unit of increased capacity.
THIS IS THE REASON
CLARE SEALED RELAYS
Can’t Leak!

Pictured here are ten CLARE Sealed Relays from which every trace of moisture and gas is being removed by a high vacuum pump.

After the first pumping, the enclosures are flushed with dry nitrogen and again pumped down to a few microns pressure. While under this extreme vacuum, enclosures and seals are tested for leaks by means of the mass spectrometer (right). This device can detect a leak so small that it would take 31 years for one cubic centimeter of air to pass through it.

Containers are next filled with dry nitrogen to a pressure of at least one atmosphere. When the evacuating tubes are pinched off, the enclosures are hermetically sealed.

More than forty different series of CLARE hermetically sealed relays ... immune to every type of climatic or environmental conditions ... are now available to relay users. Innumerable variations of coil and contact specifications are possible.

If your relay requirement calls for the utmost in relay dependability under difficult operating conditions, get in touch with the CLARE sales engineer nearest you or C. P. CLARE & CO., 4719 West Sunnyside Avenue, Chicago 30, Illinois. In Canada: Canadian Line Materials Ltd., Toronto 13. Cable address: CLARELAY.

Write for 36-page Clare Bulletin No. 114

CLARE RELAYS...

First in the Industrial Field
The Type H-14 Signal Generator, 108-118 megacycles, provides a standard signal source for the complete testing of VHF airborne omnirange and localizer receivers in aircraft or on the bench. It provides for testing 24 omni courses, plus left-center-right checks on both amplitude and phase localizers. Aircraft may be checked out quickly and accurately just before take-off. RF output for ramp checks, 1 volt into 52 ohm line and for bench checks, 0-10,000 microvolts. Provision for external voice or other modulation. AF output available for bench maintenance and trouble shooting.

Price: $885.00 net, f.a.b., Boonton, N. J.

TYPE H-10—Microwave Test Set; 23,500-24,500 Megacycles

Provides source of cw or pulse frequency-modulated RF, power level -37 to -90 dbm. RF power meter measures levels from +7 to +30 dbm. Frequency meter for measuring output or input RF accurate to better than 20 mc. Primary purpose of the H-10 is to measure receiver sensitivity, band-width, frequency, recovery time, and overload characteristics, plus transmitter power and frequency. Recommended as a standard source of RF for research or production testing. Equal to military TS-223/AP.

Price: $1692.00 net, f.a.b., Boonton, N. J.

TYPE H-12—VHF Signal Generator; 900-2100 Megacycles

Provides source of cw or pulse amplitude-modulated RF, power level 0 to -120 dbm. Internal pulse circuits with controls for width, delay, and rate, and provision for external pulsing. Single dial tuning, frequency calibration accurate to better than 1%. Built to Navy specifications for research and production testing. Equal to military TS-119/U.

Price: $1950.00 net, f.a.b., Boonton, N. J.

WRITE TODAY for descriptive literature on A.R.C. Signal Generators or airborne LF and VHF communication and navigation equipment, CAA Type Certificated for transport or private use.
Look into this
PROFESSIONAL
Telecast Projector
and see years of
Dependable Service

The GPL Model PA-100 — a 16-mm Studio Projector with the basic features and performance reliability of the famous Simplex 35-mm Theatre Projectors.

Sharper Pictures . . . Finer Sound
From Any Film in Your Studio

The importance of 16-mm film in television programming has called for new standards of projection quality and dependability. The GPL Model PA-100 is the first projector designed and built specifically for television studio use. It is a heavy-duty film chain projector for operation with any full-storage type film pick-up.

The professional, sprocket-type intermittent, similar to that used in the finest 35-mm equipment, is quiet and trouble-free. It provides a vertical stability of better than 0.2% over years of service. Film is protected — tests show more than 4,000 passages without noticeable film wear.

The high quality optical system resolves better than 90 lines per mm, with illumination so uniform that corner brightness is at least 90% of center. With a 1,000 watt light source, the projector delivers 100 foot-candles to the camera tube. The sound system provides a frequency response truly flat to 7,000 cps, with flutter less than 0.2%.

The Model PA-100 is one of a complete line of GPL 16-mm television studio and theatre projectors built to highest 35-mm standards.

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General Precision Laboratory
INCORPORATED
PLEASANTVILLE NEW YORK
TV Camera Chains • TV Film Chains • TV Field and Studio Equipment • Theatre TV Equipment
ESSEX ELECTRONICS
Manufacturers of coils, chokes and transformers
Station Street and Springfield Avenue
Berkeley Heights, N. J. — Summit 6-642

December 21, 1950

Antara Products Division
General Electric Corporation
399 Riverside Street
New York 14, N. Y.

Gentlemen:

Miniaturization is a word that has become ever more important in our business. Over the past four years we have received one assignment after another of this type. The solutions to these problems do not always go by formula; they are not exactly simple, but in each and every occasion — G & F Carbonyl Iron Powders have been one of our major tools in the successful completion of these assignments.

A typical application was for the translation receivers which permit a United Nations delegate to select the language in which he wishes to hear any talk...Another was for the tuning coils on a hearing-aid, and the radio-receiving attachment. Another was for I.F. coils for a tiny personal receiver. And the nation's armor campaign — to which we hope we are making full contribution — calls for miniature coils.

These, too, we are developing with the help of your product.

At all times, our design work is aimed at top quantity production of top quality items. In every assignment of this type, we rely on the fully dependable properties of Carbonyl Iron Powders.

Sincerely yours,

[Signature]

Bernard M. Smith
President

ESSEX PERMEABILITY-TUNED
I.F. COIL for personal radio
(455 kc.)—measuring \( \frac{1}{2} \)" x \( \frac{1}{2} \)" x 1\( \frac{1}{2} \)". In spite of its small size, there is no sacrifice in performance.

ESSEX PERMEABILITY-TUNED
R.F. TRANSFORMER for
United Nations translation receiver—measuring \( \frac{3}{4} \)" in diameter and \( \frac{5}{8} \)" in height. Same type of construction has been made in 262 kc. I.F. Transformer—measuring \( \frac{1}{2} \)" x \( \frac{1}{2} \)".

G A & F Carbonyl
Each and every problem of MINIATURIZATION solved with the help of CARBONYL IRON POWDERS

Essex Electronics ranks today as one of the major suppliers of coils to the leading makers of receiving sets. Their reputation is based upon sound engineering and efficient production. With ten years of experience in this field, Essex Electronics testifies that G A & F Carbonyl Iron Powders have been one of the major tools in the successful completion of their many assignments.

Other makers—of both cores and coils—have testified that it costs less to work with these top quality materials and that major gains are effected in both weight reduction and increased efficiency. We urge you to ask your core maker, your coil winder, your industrial designer, how G A & F Carbonyl Iron Powders can improve the performance of the equipment you manufacture. It will cost you nothing to get the facts.

THIS FREE BOOK — fully illustrated, with performance charts and application data — will help any radio engineer or electronics manufacturer to step up quality, while saving real money. Kindly address your request to Department 22.

ANTARA® PRODUCTS
DIVISION OF
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435 HUDSON STREET • NEW YORK 14, NEW YORK

Iron Powders...
Performance-Proved in active duty

For civilian and military electronic designs... RCA preferred-type receiving tubes offer these important advantages...

FLEXIBILITY—RCA preferred-type receiving tubes are chosen for the advantages they offer from engineering and equipment production viewpoints. They cover an extremely wide variety of tube applications in civilian and military equipment...and offer the engineer flexibility in circuit design.

PERFORMANCE—These types have demonstrated their reliability in equipment of widely divergent designs. Proved in service, they are the logical types for future designs.

ECONOMY—This group of 44 tube types represents more than half of RCA's current receiving tube volume. By concentrating production on these few types having wide application, substantial savings are realized in manufacturing costs which are passed on to customers...and quality and performance capability are sustained at a high level.

STANDARDIZATION—By concentrating on RCA preferred receiving-tube types, the equipment manufacturer also benefits by his ability to standardize on component parts...resulting in substantial purchasing and stocking economies.
PROCEEDINGS OF THE I.R.E.

February, 1951

I. R. E.

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Volume 39

Number 2

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Jorgen Rybner, Vice-President—1951

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* Numerals in parenthesis following Directors' names designate Region number.
Jorgen Rybner
VICE-PRESIDENT, 1951

Jorgen Rybner was born at Frederiksberg, Denmark, on November 26, 1902. He was graduated as an electrical engineer, specializing in telecommunications, from the Royal Technical University of Denmark in 1926, and worked as a private assistant to Professor P. O. Pedersen at the university for 18 months, carrying out most of the computation work for Professor Pedersen’s famous book, “The Propagation of Radio Waves.”

During 1927-1928, Mr. Rybner spent a year in the United States, studying radio techniques with Professor Morecroft at Columbia University. He did part-time work in the propagation department of the Bell Laboratories, Inc. He also worked in the laboratory of the General Electric Company at Schenectady, N. Y.

He was associated with the Geodetic Institute of Denmark until 1939, serving as chief of the technical department, and he took part in the longitude determination of the Baltic Geodetic Commission 1929, carrying out extensive studies of the theory of seismographs, on which he published several papers.

In 1939, the chair of telecommunications at the Royal Technical University of Denmark held by Professor Pedersen since 1907, was doubled, and Mr. Rybner obtained the new professorship.

He has published, besides a number of scientific papers, a series of textbooks in Danish, covering telegraph and telephone techniques, including switching and application of probability, radio techniques, electronic amplifiers, network and transmission lines, and advanced books on filter theory and on the general theory of circle diagrams. Publications with English and Danish text include his “Nomograms of Complex Hyperbolic Functions,” 1947, as well as “Table for Use in the Addition of Complex Numbers,” 1949.

In 1948–1949, Professor Rybner paid another visit to the United States to study communication theory and advanced network theory at Massachusetts Institute of Technology, Boston, Mass., during the fall term. He also spent three weeks at Bell Telephone Laboratories, Murray Hill, N. J., and Holmdel, N. Y., with visits to the Watson Scientific Computing Laboratory, New York, N. Y., and Cornell University, Ithaca, N. Y.

Since 1933, he has been a teacher of telecommunications for signal officers at the Army Officers’ School.

He was elected a member of the Danish Academy of Technical Sciences in 1937, and was president of the Danish National Committee of the International Scientific Radio Union (URSI) in 1948. He has been a chairman of the board of directors of the Radio Receiver Laboratory of the Academy since 1944. He was decorated with the Knight’s order of Danebrog in 1948. Mr. Rybner has been a member of the IRE since 1926.
The dimensions—or certain other characteristics—of physical things may have chosen values. But if such values are selected from an orderly and adequate list of "preferred numbers" a certain degree of simplification, interchangeability, uniformity, convenience, and economy will result.

As Preferred Numbers and their advantages have been described at length elsewhere, it will suffice here to say that use of the system by even one manufacturer will improve his efficiency of operation, and that wider use by a whole industry, or many industries, brings benefits in geometric proportion to the extent of use. The subject has had active study for about thirty years, but in spite of this lengthy period, has not made great progress toward adoption by American industry.

The Preferred Numbers activity began just after World War I, a period when high ideals inspired the thinking elements of mankind. Even the government and international relations, international amity, seemed within reach. In the thirty years that have passed—enough to have brought impressive results, it would seem—progress has been disappointingly small. The League of Nations, expected to bring peace to the world, instead saw a second World War, and its successor, the United Nations is dealing with a third. Similarly, Preferred Numbers has not made the progress which its obvious advantages make it reasonable to expect.

It seems to me that the factors which have determined the amount of progress toward world peace, or lack of it, are the same ones which have limited the degree of accomplishment in standardization, and that it is easier to see some of these factors in the broad field of international relations than in the narrow field of product design, in spite of the vastly greater scope of the former. The greatest obstacle to international peace agreement is the unwillingness of nations to limit "national sovereignty" to the slightest extent. Each nation insists upon full rights to have and to do whatever it wants. Little attention is paid to the long term benefits which would accrue to each and to all by the establishment of unselfish, cooperative practices. Few realize that large, permanent benefits can be derived from small temporary sacrifices, and that such benefits are obtainable only in that way. Most want to eat the cake and have it, too. Consequently, petty bickering continues and so do the resulting wars.

The same attitude has existed in the design field in relation to Preferred Numbers. It is clear that the same numbers must be used by everyone. If each company or industry, has its own private list of numbers, the benefits will be greatly limited. Nevertheless, various organizations have seen fit not to adopt the ASA Preferred Numbers, but instead have set up their own lists of numbers. They have done this because their own practices of the moment seemed to be accommodated better by lists different from the ASA Standard. I emphasize "of the moment" because that is the heart of the matter, the seat of the trouble, the crux of the situation. For example, some years ago, the Radio-Television Manufacturers Association found it desirable to standardize the values of resistors. The ASA Preferred Numbers Standard was considered, but judged not to suit the manufacturing conditions and the buying practices of the resistor field at the moment, whereas a special series of numbers suited better. The special series was adopted and, since it was an official RTMA list, it has been utilized by later RTMA committees for other applications than resistors, although adopted originally because of seeming advantages for resistors. Ironically, the original advantages have largely disappeared through changes in resistor manufacturing conditions. But the irregular standard remains, and in fact is now being proposed for universal application in the radio-electronic industry. We in the industry, of course, feel that radio-electronics is the outstanding element in the American industrial scene, but it is at least a wee bit unfortunate that electronics, just now entering into increasingly important and intimate relationships with all other elements of industry, exercises its "sovereignty," sets its own Standard, and exchanges the greater good for the appeal of the immediate.

Another point which seems to be overlooked by most standardization committees is that a standard must have much of the aspect of an ideal if it is to be worthy while, and that if it cannot be used immediately for some practical reason, it need not be used immediately. As time goes on, with effort to use the standard wherever conveniently possible, the first practical objections lessen, and the standard becomes more and more universally usable. After five, ten, or twenty years, the standard is wholly acceptable and its benefits are had. A good standard is a goal to shoot at, not a ratification of old or existing practice. On the other hand, if standardization work operates on the basis of setting up standards with primary attention to the operating practices of the moment—so that everything every manufacturer is doing will be "standard" immediately—little is accomplished toward the proper objective of maximum simplification. It is not simplification of current practice to standardize all of current practice.

The extreme to which overlooking this basic principle naturally leads, is exemplified by the proposals now active in the work to establish a Standard for Preferred Voltages, 100 volts and under. The proposals call for standardizing more than ninety values between zero and one hundred! The original committee "ideal" list called for twenty-three values, which is big enough, but as each industry element added the values it is using currently, the list grew until nearly every number up to one hundred is proposed as standard. That surely is the height of something or other, and one might ask "How absurd can we get?" The answer to that one is easy, however. It is found in the list of current television picture tube sizes!

In the long, difficult period ahead of us, when our industrial economy will have to bear strains greater than ever before experienced, the benefits to be obtained by standardization and simplification will be needed. Preferred Numbers can help much, if they are attempted with understanding, unselfishness, and co-operation. It must be realized that there is only one list of Preferred Numbers and that must be the national standard. Individual industry lists are not Preferred Numbers and should not be so called—they are private numbers and bring a little amount of benefit or temporary advantage, but little of the large scale benefits which will result from national, widespread, inter-industry use of one list. The production capability of this country, great as it is, is finite, not infinite, and the tough task before us demands maximum efficiency to assure success.

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1 ASA American Standard Z 17.1-1936.

**Preferred Numbers**

**ARTHUR VAN DYCK**
Television Broadcasting in the United States, 1927-1950*

DONALD G. FINK†, FELLOW, IRE

A study of the wishes of representative portions of the membership of The Institute of Radio Engineers has led to a plan to present to the readers of these PROCEEDINGS a series of tutorial papers on a wide variety of topics of both present and historical interest. These papers are to be educational in nature, of exceptional clarity, and prepared in each case by an authority in the corresponding field. It is believed that they will as well be appealing and interesting to others than experts in that field.

The procurement of these tutorial papers, and their individual recommended approval for publication, are carried out by the Subcommittee on Tutorial Papers (under the Chairmanship of Professor Ernst Weber) of the IRE Committee on Education (under the Chairmanship of Professor Herbert J. Reich). The first tutorial paper of what is hoped to be an extensive series is here presented.—The Editor.

TELEVISION broadcasting in America began in 1927, when the Federal Radio Commission issued the first television license to Charles F. Jenkins authorizing broadcast transmissions from a station in the suburbs of Washington, D. C. Prior to that time, development of television techniques was not open to public participation. V. K. Zworykin applied for a patent on his iconoscope, which may fairly be called the cornerstone of modern television, in 1925. In 1923, Jenkins in America and John Baird in England had demonstrated the transmission of crude images over wires. Early in 1927 the Bell Telephone Laboratories demonstrated a low-definition picture over wire circuits, between New York and Washington. But the concept of providing broadcast emissions, available to experimenters not otherwise connected with the transmitting organization, did not gain wide currency in America until 1929. In that year some 22 stations were authorized by the Federal Radio Commission to broad visual images.

The earliest stations had wide latitude in choice of frequency, almost any frequency above 1,500 kc being permitted if no interference was caused to other services. But this latitude was soon withdrawn, as the short-wave region became crowded with other, more vital services. In 1929, emissions were limited to a bandwidth of 100 kc, within the regions of 2.0–2.3 Mc and 2.75–2.95 Mc. The powers employed varied from 100 w to 20 kw, the majority of stations operating at 5 kw.

The quality of the early images were primitive, judged by any standard. The pictures were commonly transmitted at a rate of 20 per second. At this rate the number of picture elements capable of being transmitted by double sidebands in a 100-ke band is limited to 5,000. Equal resolution in vertical and horizontal dimensions was achieved within the band limits by employing a square image of about 70 lines, but the preferred figure was 60 lines.

Many of the major American television stations of the present day can trace their origin to this early period. The National Broadcasting Company's station in New York was first licensed as W2XBS in July, 1928, and has since evolved from the 2,000 to 2,100-ke band to the 66 to 72-Mc band, from 60-line pictures to 525-line pictures. In 1942 the call letters W2XBS were withdrawn in favor of the “commercial” call letters WNBX. Similarly, the Columbia Broadcasting System station in New York, now WCBS-TV, started in July, 1931, as W2XAX. This station operated with 60-line pictures, 20 per second, for a total of 2,500 hours in the period ending February, 1933. The General Electric station in Schenectady operated on similar standards, with 20-kw power from 1929 to 1932.

In 1931 it was evident that progress could not be made on the restricted channels of the 2-Mc band, and the trend toward higher frequencies began. One of the earliest to apply for permission to use frequencies above 40 Mc was the Don Lee Broadcasting System in Los Angeles, Calif. In December, 1931, the license of station W6XAO was granted to this organization, authorizing the use of the bands 43–46, 48.5–50.3, and 60–80 Mc. In 1941 this station became a commercial station with the call letters KTSX, operating on 54-60-Mc with a regular public program service.

Permission to use the 43-80-Mc bands was granted to several other stations, including NBC's W2XF and W2XBT in New York, Jenkins's W3XC in Wheaton, Md., W1XG in Boston, and W8XF in Pontiac, Mich. In 1933 and 1934 several additional vhf stations were licensed to use the bands 42–56 and 60–86 Mc. In 1936, all activity in the 2-Mc band ceased and all vhf stations were placed in the bands 42–56 and 60–86 Mc.

In 1937, the frequency allocation was set up for the first time on the basis of channels 6 Mc wide. Nineteen such channels were set up between 44 and 294 Mc. The present allocation comprises 12 channels, each 6 Mc wide, in two groups 54–88 Mc and 174–216 Mc.

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Evolution of High-Definition Standards

Shortly after permission to operate in the vhf bands was given, attention was focused on purely electronic methods of scanning and cathode-ray tubes for reproduction. Dr. Zworykin had demonstrated a cathode-ray receiver before The Institute of Radio Engineers in Rochester, N. Y., in November, 1929. In 1932, an “all-electronic” system was demonstrated by RCA, transmitting 240-line images from New York to Camden, near Philadelphia, over an air-line distance of about 80 miles, with one intermediate relay point at Arney’s Mount, N. J. This was one of the earliest demonstrations of cathode-ray equipment, but the term “all-electronic” was something of a misnomer, since no satisfactory electronic synchronizing circuits had been developed, and the synchronizing pulses were derived by passing light to a photocell through apertures in a whirling disk. In 1934 P. T. Farnsworth announced a new electronic camera tube, the image dissector.

In 1934, the march toward higher definition got properly under way. Each transmitter was free to employ any scanning method, but between 1932 and 1934 agreement was reached that interlaced transmission, based on the “odd-line” principle, was the simplest and most satisfactory method of avoiding flicker in the reproduced images. The first “odd-line” value chosen was 343, an odd number composed of odd factors (343 = 7 x 7 x 7). From this root sprang many other choices, all tending toward greater definition in the pictures, all odd numbers, composed of odd factors. The majority opinion was that no more than 441 lines could be accommodated in a picture sent by double-sideband methods within the limits of a 6-Mc channel. The dissenting opinion was that it would be better to err on the high side in the number of lines, with consequent excessive definition in the vertical dimension, in the hope that better utilization of bandwidth would be possible as time went on. This dissenting opinion was in fact justified in 1939, when vestigial-sideband transmission was proved feasible and adopted as standard. The 441-line figure then proved too small for a 6-Mc channel and the standard was eventually changed (in 1941) to 525 lines, the value presently specified in the FCC regulations.

The foregoing paragraphs may indicate that the adoption of standards in the United States was accompanied by not a little dissension in the ranks. This must be admitted. In fact, the five-year period from 1936, when official sanction for public programs was given in the United Kingdom, to 1941, when similar sanction was granted in America, was characterized by a very vigorous debate on standards.

The debate finally came to an end in the meetings of the nine panels of the National Television System Committee (NTSC). This group of 168 television specialists, in the period from August, 1940, to March, 1941, devoted 4,000 man-hours to meetings, witnessed 25 demonstrations of the comparative merits of different proposals, and finally left behind them a record of reports and minutes some 600,000 words in length. Out of this monumental effort came virtually complete agreement on a set of 22 standards which were presented to the Federal Communications Commission for approval and adoption. This approval was granted, and commercial operation of television broadcast stations was authorized, to be effective July 1, 1941. The stage was set for a rapid advance. On December 7, 1941, the United States entered the war and the state of the art was frozen by lack of man-power and materials. Thereafter, until 1945, commercial broadcasting continued, but at a “bare-subsistence” level. The FCC required a minimum of 15 hours per week of public programs from each station before the war; after Pearl Harbor this was reduced to four hours per week.

In 1944–1945 a thorough review of the standards was conducted by the Television Panel of the Radio Technical Planning Board (RTPB). The standards were reaffirmed by this group, and no change has since occurred.

Evolution of Program Service

Prior to 1936, the American public was an incidental partner to the television enterprise. But in that year, the broadcasting of programs especially designed for public consumption began, although no regular source of receivers was available and no official sanction had been given for other than experimental transmissions. The occasion was one of considerable international competition between England and the United States. The first move came from the British Broadcasting Corporation. Plans for the opening of the London station in Alexandra Palace were announced early in 1936. This was the cue for the RCA-NBC transmitter to “get busy.” On June 29, 1936, RCA started a field test of its television system with 100 of its engineers in and around New York as the observers. The images were transmitted by double sideband, at 343 lines, 30 frames per second. Film was used copiously in the early stages. But by November 6 of that year, the New York Times announced “the first complete program of entertainment over the NBC system,” viewed enthusiastically by the press. Four days before, on November 2, the Alexandra Palace station had begun a regular public service. The American service was not public in the same sense, and did not become so for five years.

By 1938 the RCA field test had progressed to the point where its directors were ready to take a step in the direction of inviting the public to participate actively. It was announced in October, 1938, that, coincidentally with the opening of the New York World’s Fair in May, 1939, regular public service would be offered.

In the meantime, vestigial-sideband transmission had been adopted as standard by the Television Committee of the Radio Manufacturers’ Association and had been incorporated in the NBC transmitter. The scanning
pattern had been increased to 441 lines, and the effective video band to 4 Mc. In February, 1940, the Federal Communications Commission adopted rules permitting “limited” commercial operation of stations.

The stage seemed set. The NBC transmitter was offering 10 to 15 hours of program a week, including elaborate dramatic presentations from the studios, regular outside rebroadcasts of sporting events of every description, educational programs and films. But in April, 1940, the FCC retracted the offer of limited commercialization, following an announcement by RCA that receivers would be offered to the public in greater volume and at reduced prices. The FCC stated that this action by RCA tended to freeze the then accepted standards, those formulated by the Radio Manufacturers Association, without official sanction from the Government. This action effectively held up further progress until the standards had been studied and essentially reaffirmed by the National Television System Committee. In July, 1941, the impasse was cleared, and television broadcasting for the public officially began.

The American Television Channel

The standard 6-Mc channel assigned to television broadcast stations in the United States is intended for vestigial-sideband transmission. At the lower frequency limit of the channel, the emission is required to be substantially zero, actually no more than one per cent of the picture-carrier amplitude. At a point 0.5 Mc higher in frequency, the sideband emission has full amplitude. The picture carrier itself is located 1.25 Mc above the lower channel edge, and occupies an asymmetrical position with respect to the channel limits. Thus only a portion of the lower sideband is transmitted, hence the term “vestigial-sideband transmission.” The upper sideband is transmitted fully over a region 4 Mc wide, i.e., it maintains maximum amplitude to a point 5.25 Mc above the lower channel edge. At this point the sideband energy is attenuated with increasing frequency until, at a point 5.75 Mc above the lower channel edge, it is attenuated to one per cent of the carrier amplitude. The carrier of the associated sound transmission is placed at this point. The remaining 0.25 Mc of the channel is reserved as a guard band.

This arrangement of carriers and sidebands was originally devised in 1938 and has persisted substantially without change through the deliberations of the National Television System Committee and those of the Radio Technical Planning Board. The vestigial-sideband principle permits a maximum unattenuated vision frequency of 4 Mc and permits attenuated transmission of vision signals up to a maximum of 4.5 Mc. In comparison, the double-sideband system permits a maximum vision frequency of 2.5 Mc. The vestigial-sideband transmission thus offers an increase in pictorial detail of 80 per cent, with substantial improvement in picture quality.

The wide spacing between carriers (4.5 Mc) was chosen in preference to the alternative narrow spacing (1.25 Mc) which would be possible if the sound carrier were transferred from the high frequency edge of the channel to the low frequency edge. The wide spacing produces a high-frequency beat frequency which is outside the limits of the vision frequency band and hence has little or no visible effect. The narrow spacing would produce a beat note within the video band.

The vestigial-sideband system is intended to operate with a receiver whose response characteristic increases linearly with frequency from 0.5 to 2.0 Mc above the lower edge of the channel. This “slope” region corresponds to the portion of the transmitter spectrum where both sidebands are transmitted. By virtue of the sloping receiver response the picture carrier is attenuated to one half, and the sum of the two sideband voltages is constant throughout the region, and equal to the value of sideband voltage at higher frequencies outside the “slope” region. Thus the video-frequency voltage developed at the output of the demodulator is the same for all sideband frequencies.

The ratio of sound-carrier power (radiated by the sound radiator) to picture-carrier power (radiated by the picture radiator) has been set up within the limits 0.5 and 1.50. The general range has been chosen to provide approximately equal areas of coverage of the sound and picture signals. The sound power is lower than the picture power because the sound transmission employs frequency modulation, with an inherent signal-to-noise ratio superior to that of amplitude modulation. Account has been taken, in setting up this ratio, of the fact that interference (particularly impulsive noise) in the sound channel is usually more objectionable than interference arising from the same noise source in the picture channel.

The Scanning Specifications

The standard American television picture is scanned in 525 lines from the beginning of one frame to the beginning of the next. Each frame is broken up into two fields of 262.5 lines each. The half-line portion at the end of a field causes the lines of one field to fall between the lines of the previous field. Hence an odd number of lines was chosen to give this half-line relationship between fields. The value 525 consists of odd integral factors (525 = 7 x 5 x 5 x 3). This permits multivibrators or counting circuits in the synchronization generator (used to divide from the line frequency of 15,750 cps to the frame frequency of 30 cps) to operate in the most stable condition.

The frame frequency is 30 per second interlaced two-to-one. The aspect ratio of the scanning pattern (ratio of width to height) is 4/3, to agree with the ratio previously adopted as standard for motion-picture projection. The FCC standards specify that the active scanning of the picture shall occur at uniform velocity from left to right horizontally and top to bottom vertically.
The choice of 525 lines was made from among several proposed values, including 495 and 507 lines. Assuming 4.25 Mc as the maximum usable video frequency, equal vertical and horizontal resolution at 30 frames per second is obtained with a scanning pattern of about 500 lines, which would indicate that all the proposed values are equally suitable. The number 507 has the disadvantage of two large integral factors which require two of the frequency-dividing circuits in the synchronizing signal generator to count by a factor of 13. The choice between 495 and 525 was finally made on the basis of fineness of line structure, which indicates a slight preference for the higher number of lines. The value of 441 lines was discarded as it did not make full use of the maximum available video frequency.

**Sound Signal Standards**

A major difference between British and American television practice lies in the method of modulation employed for the sound transmission. The American standard specifies frequency modulation with a maximum frequency deviation, corresponding to the maximum audio level, of 25 kc either side of the unmodulated carrier frequency. Frequency modulation, employing a spectrum considerably wider than that required for the corresponding amplitude-modulated signal, has been shown to offer a substantially higher signal-to-noise ratio than that offered by amplitude modulation. This advantage obtains over all types of noise, provided only that the peak signal voltage is at least twice the peak noise voltage. Since natural atmospherics are rarely present in the vhf spectrum, the principal advantage of frequency-modulated transmission is the mitigation of impulse noises such as is generated by automobile ignition systems, and noise generated in tubes and circuit elements of the receiver.

To assist in the reproduction of the upper register of the audible spectrum, it has been customary in frequency-modulated sound transmissions to introduce audio pre-emphasis at the transmitter. The standard pre-emphasis characteristic is that of a series resistive-inductive impedance whose time-constant (resistance times inductance) is 75 microseconds. The converse de-emphasis is inserted in the receiver (usually by a resistive-capacitive impedance of the same time-constant). The advantage of such pre-emphasis lies in the fact that the sound power associated with the higher register is generally lower than that of the lower register and hence is less efficiently transmitted with respect to the noise level. Artificial emphasis and de-emphasis thus add to the over-all signal-noise ratio, by reducing the noise level in the upper register.

The remaining standard is the direction of polarization of the electric vector of the radiated wave. This was chosen as horizontal as early as 1938, and although polarization has been the subject of intensive investigation by the NTSC and the RTPB the advantage of the horizontal direction has been consistently upheld.

**Rules Governing Allocation of Television Broadcasting Facilities**

As the demand for broadcasting facilities has consistently exceeded the supply, it has been necessary for the FCC to set up equitable rules whereby the available portions of the spectrum may be allocated to serve the public interest.

A conflict in allocation arises, by definition, when interference occurs among stations. The interference is defined in terms of (1) the signal level required to give satisfactory service in an area from the station serving that area, and (2) the level of signal which creates interference in that area, arising from another station on the same channel in an adjacent area. The problem of interference between stations in the same area but assigned to adjacent channels must also be considered.

The basic level of service is defined as a field strength which must be equalled or exceeded over 50 per cent of the distance along a radial line from the transmitter. The field strength thus specified for built-up city areas and business districts is 5 millivolts per meter. For residential and rural areas the specified field strength is one-tenth as great, or 500 microvolts per meter. These figures properly surpass the figure of 50 microvolts per meter commonly regarded by engineers as the lower limit for "marginal service," in the absence of man-made sources of noise.

The applicant for a television construction permit or license must show that his proposed transmitter will offer service in accordance with the above rules, and must estimate the population lying within the 5-mv/m and 0.5-mv/m contours.

The interference ratio (ratio of desired signal to undesired signal) which must be equalled or exceeded within the service area has been set at 100:1 for stations on the same channel and 2:1 for stations on adjacent channels. This is in keeping with the commonly-held engineering opinion that an interfering signal must be at least 40 db below the desired signal if it is to have negligible effect. For adjacent-channel interference, the selectivity of the receiver circuits will introduce sufficient additional rejection if the interfering signal voltage does not exceed one-half the desired signal voltage. It is the practice of the FCC to avoid assigning adjacent channels in the same metropolitan area; otherwise the 2:1 ratio would be met in but a small portion of the normal service area.

The problem of finding sufficient facilities for television without interference is most critical in the highly populated areas along the eastern seaboard. In general an allocation plan to provide sufficient service to the cities of Boston, Providence, Hartford, New York, Philadelphia, Baltimore, and Washington will take care of all other population centers in North America.

**Postwar Activity**

The postwar period has been marked by a very substantial expansion of the television service. At present
(December, 1950) the areas covered by television signals include 63 major population centers, in which 107 stations offer service to a potential audience in excess of 50,000,000. The expansion has emphasized the shortage of spectrum space for television stations and has brought into sharp focus the problem of interference between stations.

In 1945, at the close of the war, about 10,000 receivers had been produced and sold to the public. Nine stations were operating in five cities, four of them on a fully commercial basis. Postwar production did not get under way, owing to shortages of materials and components, until the spring of 1946. In that year, 6,500 receivers were produced by the six manufacturers then in the business. Three years later (1949), the production was 2,400,000 sets, according to figures compiled by members of the Radio Manufacturers Association. Production by non-RMA companies accounted for approximately 450,000 additional receivers in that year. Over 100 companies participated in the 1949 production. Production in 1950 was approximately 6,000,000 receivers.

The trends in receiver design have been toward larger pictures, fewer tubes and simplification of controls. The smallest screen size is 2½ inches in diameter, offered in a 1948 model no longer in production. The largest direct-view tube was an all-glass tube of 20 inches diameter, now replaced by a 19-inch metal-cone tube. From 1946 to 1948 the most popular model was the 10-inch set, but in 1949 this model gave way to the 12½-inch size. The 16-inch tube took first place in 1950.

Projection pictures ranging from 9 by 12 inches to 18 by 24 inches have been offered in domestic receivers, although production of this type of receiver has been small compared with the direct-view type. Projection equipment for large audiences, ranging in screen size from 6 by 8 feet to the full theater screen of 18 by 24 feet has also been produced.

Reduction in the tube complement of receivers has averaged about 25 per cent since 1946. The first large-scale-production chassis was a 10-inch model employing 30 tubes. In 1948, a 7-inch model was offered with 16 tubes. Current models employ from 22 to 24 tubes. Substantially all receivers having screen diameter greater than 7 inches employ magnetic deflection of the picture tube.

Simplification of controls has resulted from improvement in the stability of circuits and components, particularly those used for tuning and for synchronization of scanning. The majority of receivers currently in production employ the intercarrier circuit, in which a sound intermediate frequency of 4.5 Mc is developed by frequency conversion at the picture second detector. The most popular value of picture intermediate frequency is 25.75 Mc, but plans for changing this to 45.75 Mc have been announced by many manufacturers and the latter value may eventually be adopted as standard by all manufacturers.

Expansion of Broadcast Facilities

By the end of 1946, 10 stations were in operation, and in that year 38 construction permits for additional stations were granted by the FCC. By the fall of 1948, 54 stations were operating, construction of an additional 70 stations had been authorized, and 310 applications for construction permits had been filed.

Beginning in the spring of 1948, the FCC received complaints that excessive interference was occurring between stations on the same channel, as well as between stations occupying adjacent channels. The co-channel interference takes the form of horizontal bars, which move upward or downward through the image of the desired station. These bars, known as "venetian-blind" interference, are caused by the heterodyne beat between the carriers of the stations. The beat frequency can have values from a few cycles per second to several thousand cycles per second, under the frequency tolerances permitted by the FCC regulations.

The interference extends over an appreciable portion of the service area of each station, for a majority of the operating hours, when the stations were separated by less than approximately 200 miles. It is explained by tropospheric propagation which produces signal strengths much higher than had been anticipated when the allocation plan was devised. Since the then-existing allocation plan called for a minimum spacing of 150 miles, and exceptions to the rule as small as 95 miles had been allowed, the FCC decided to call a halt on further expansion of broadcasting facilities until the cause and extent of the interference could be studied. Accordingly, in September, 1948, the Commission issued a "freeze" order, prohibiting construction of new stations for an indefinite period. The order did not prohibit completion of the 70 stations then under construction, but held up any further action on the 310 applications for construction permits. The freeze order was still on the books, as of December, 1950. At present nearly 400 applications for new stations are on the books of the FCC.

Meanwhile, the means of accommodating this large number of stations, while minimizing interference, have been under almost continuous study in a series of conferences and hearings before the FCC, from September, 1948, to the present. Two approaches have been investigated: (1) the reduction of co-channel interference by control of the interfering carriers, and (2) the extension of the television spectrum into the ultra-high frequencies.

Two techniques of interference reduction have been developed, carrier synchronization and carrier-offset operation. The second of these is now in wide use among co-channel stations in the east and midwest sections of the country.

In the carrier synchronization scheme, the two carriers are received in a monitor station approximately midway between the stations, and their frequencies compared
in a frequency discriminator. A signal representative of the frequency difference is sent over a telephone line to one of the stations, where it actuates a control circuit connected to the quartz-crystal frequency control. By this means, the carriers of the two stations are kept rigidly locked together in precise phase relationship. Since the beat frequency between the carriers is thereby reduced to zero, the venetian-blind interference is removed. The strength of the interfering signal may then be allowed to increase by about 17 db on the average before the image content of the undesired signal becomes objectionably apparent. This reduction in interference would permit co-channel stations to be located at a distance of separation of about 150 miles, compared to about 210 miles for the same degree of interference with carriers unsynchronized.

The cost of the monitoring station and the telephone lines necessary in the carrier synchronization method led to the development of a simpler system known as carrier offset. In this method, the carrier of one co-channel station is purposely separated from that of the others by 10.5 Kc, plus or minus the 0.002 per cent tolerance allowed by the FCC regulations. The average beat frequency of 10.5 Kc produces a large number of venetian-blind bars, each occupying about three adjacent scanning lines. Since each interference bar is thereby confined to the space occupied by two successive lines in a single field scanning, the average tone produced tends toward a neutral gray, and the effect is subjectively much less annoying than if the carriers were within a few hundred cycles of one another, as is usually the case between unsynchronized carriers.

Actually, the greatest reduction of interference is obtained when the offset frequency is 7.875 kc, that is, one-half the line scanning frequency, and no improvement is noted when the offset is 15.750 kc, the line scanning frequency. The half-line frequency would be used in the offset system, were it not for the fact that three or more co-channel stations are often involved in a single interference area. The insertion of 7.875 kc offset between all stations would then result in nearly zero or 15.750 kc offset (no interference reduction) between certain pairs in the group. The 10.5-kc figure was chosen as a compromise, permitting several stations to operate with carrier offset in the same area. The average interference reduction, relative to the unsynchronized case, is about the same as the carrier synchronization method. No wire line or monitor is needed: the crystal control frequency of a particular station is merely chosen to produce a carrier 10.5 kc higher or lower than that of the neighboring stations.

The investigation of ultra-high frequencies for television broadcasting has centered on the frequency range from 475 to 890 Mc, a region of the spectrum previously set aside by the FCC for experimental television stations. In planning to turn over all or part of this band to commercial broadcasting, several decisions have to be weighed: (1) what standards of transmission to adopt, including the question of whether the service should be in black-and-white, in color, or both; (2) the bandwidth of the channels, and consequently the number of channels available in a given portion of the band; and (3) whether to assign ultra-high-frequency (uhf) stations to cities already possessing vhf stations, or to separate the two services geographically as much as possible.

Since the demand for additional black-and-white stations is so great, it has been conceded that at least part of the uhf band must be turned over to the black-and-white service. Moreover, to make the additional service available to owners of existing receivers at the least expense, the standards of transmission, including the channel width of 6 Mc, should be identical to those of the vhf service. This latter requirement exists even if the uhf stations are to be confined to cities not now served by vhf stations, since owners of existing receivers may move from a vhf city to a uhf city.

This leaves unsettled the question of whether color service should also be provided in the uhf band. Prior to 1948, all planning for commercial color television was on the basis of channels 12 to 16 Mc wide, and there seemed to be no room for a national allocation of such channels, even if the whole of the uhf band were used. But since that time color service on 6-Mc channels has been authorized, as outlined below, and it is now planned that color transmissions be offered by black-and-white stations on 6-Mc vhf and uhf channels.

The third question, whether or not to mix uhf and vhf assignments in a given locality, arises from the fact that the propagation conditions affecting uhf service indicate that the primary service area of a uhf station would be appreciably smaller than that of a vhf station of equal radiated power. Field tests conducted in Washington, D. C., and Bridgeport, Conn., have confirmed this assumption, at least to the extent of indicating that the shadowing effect of obstructions on uhf channels is much sharper than on vhf channels. Out to perhaps 25 miles, the service on the two bands is expected to be nearly equivalent, except for shadow effects, but beyond this limit, and out to the radio horizon, the vhf station would provide a better grade of service.

If these preliminary findings hold true generally, the licensee of a uhf station would find himself at a competitive disadvantage with respect to the licensees of vhf stations in his locality, and this would be particularly true if the potential audience of the stations extends in any substantial density beyond the 25-mile limit. In such cases, it may be questioned whether broadcasters would wish to make the investment in a uhf station.

On the other hand, if no vhf assignments are made in certain cities, the potential viewers located beyond the range of a uhf station might be denied service which otherwise could be rendered by a vhf station.

The uhf allocation proposed by the FCC in the Fall of 1949 envisages 42 additional 6-Mc channels, starting at 475 Mc or 500 Mc, and extending upward to 727
Theater Television

Throughout the development of television as a medium of home entertainment there has existed a parallel effort directed toward a system suitable for large audiences in theaters. The earliest demonstration of large-screen television was conducted by E. F. W. Alexanderson in Schenectady in 1929, using the scanning disk method to project 60-line images. But the low optical efficiency of this system did not permit a sufficiently bright picture to be projected when the number of lines was increased to 525.

Attention then turned on the method of projecting the image formed on the face of a cathode-ray tube. Since large lens apertures were required, refractive projection lenses proved exorbitantly expensive for projecting images of theater size. A more efficient system using reflective optics, based on the Schmidt telescope, was finally adopted as the basis for direct projection. In the Schmidt system, the image is reflected from a spherical mirror through an aspherical correction plate which removes spherical aberration. The first demonstration of a Schmidt projector was held by RCA at the New Yorker Theater in New York on January 24, 1941. The equipment employed a seven-inch picture tube with a second anode voltage of 70,000. A highlight brightness of about 5 foot-lamberts was achieved on a 15-by-20 foot screen.

In an attempt to achieve greater brightness on larger screens (film projectors produce about 10 foot-lamberts on screens as large as 18 by 24 feet), the intermediate film method was developed. In this process, the image on a picture tube is photographed on motion picture film, which is processed immediately and passed through the conventional film projector. The processing time has been reduced to less than one minute, so the loss of immediacy is not important, except possibly in sporting events. The film serves as a permanent record of the performance and permits repeat showings of programs. The first demonstration of the intermediate film method was given at the Paramount Theater in New York on April 14, 1948. This equipment has since been used to televise to the theater audience such events as the national political conventions in 1948 and the Joe Louis-Joe Walcott prize fight.

Color Television

The recent history of color television in the United States starts in 1940, when the Columbia Broadcasting System, demonstrated a 343-line 120-field system employing sequentially-scanned fields in three primary colors. The system as then proposed used a 6-Mc channel, and experimental broadcasts were made in the 50-to-56-Mc channel then occupied by the CBS black-and-white transmitter. This work was interrupted by the war. Later, in 1946, the standards were changed to 525 lines, 144 fields, to provide higher resolution and greater freedom from flicker. These values required a channel 16 Mc wide. To bring the channel width more in line with existing 6-Mc black-and-white service, the channel was later reduced to 12 Mc and the number of lines was reduced to 441. The 144-per-second field rate was retained to avoid flicker. This system was proposed by CBS for commercial use in the ultra-high frequencies in 1946, but in March, 1947, the FCC denied the CBS petition on the ground that art had not advanced sufficiently to justify adopting standards at that time.

By 1948, the CBS system had been shifted to a 6-Mc channel, employing 405 lines, 144-fields, but otherwise similar to the previous proposals. At first this system was shown only on a "closed circuit" basis (i.e., not broadcast) but in the summer of 1949 the FCC asked for information concerning the possibility of immediate introduction of color service on 6-Mc channels, and the CBS proposed their system for this purpose.

The CBS system is known as the field sequential system, since the color sequence is introduced by changing the color at the completion of each scanning field. The high field rate of 144 per second is necessary to avoid flicker at image brightness (in the highlights) up to about 25 foot-lamberts. Since the system uses the same bandwidth as the black-and-white system, the total number of resolvable picture elements in the color image is in the inverse ratio of the field scanning rates, or 60/144 = 0.42, that is, 42 per cent of the resolution of the standard black-and-white resolution image. This loss of resolution, plus the fact that existing receivers would have to be converted to new line- and fieldscanning rates to permit reception of the color signals, have been urged as disadvantages of the field-sequential system.

As early as 1946, the desirability of providing color service on scanning standards identical to those of black-and-white service, thus minimizing obsolescence of existing equipment, was manifest. In that year the Radio Corporation of America announced the so-called simultaneous system, in which three entirely separate and complete images, each scanned at 525 lines, 60 fields, were produced in the three primary colors by three camera tubes, in optical and electrical register. For color service, the three signals, radiated in three adjacent subchannels occupying a total band about 15 Mc wide, were applied to separate picture tubes, and the images combined, in register, by projection on a common viewing screen. The black-and-white version of the color transmission would be available to existing receivers by tuning to the green channel which contains most of the tonal information of the color image. Since this channel, as well as the red and blue ones, is based on 525-line, 60-field scanning, no change in the equipment, beyond a uhf antenna and radio-frequency converter to
tune to new channels, would be required. Later a technique known as mixed highs (which allowed reduction in the bandwidth required for the red and blue images) permitted this system to operate on a 12-Mc channel. When attention was directed, in 1948, toward the 6-Mc color service, the simultaneous system was discontinued, and work on the dot-sequential system was instituted.

The dot-sequential system introduces the color sequence by changing the color between successive picture elements (dots) along each line. This permits a second interface between dots to be added to the conventional line interface. A color image transmitted by this method at the black-and-white standard of 60 fields per second has a flicker performance equal to that of the black-and-white system, that is, high light brightness above 100 foot-lamberts is permissible without evident flicker. The image structure is divided among the sets of interlaced lines and the sets of interlaced dots in such a way that all points on the image are scanned in all colors 15 times per second.

The dot-sequential system is particularly adapted to transmission by the time-multiplex method, which is considerably more efficient in its use of the spectrum than is the continuous modulation method employed in black-and-white system and the other proposed color systems. In fact, time-multiplex transmission provides nearly two-to-one improvement in resolution for a given bandwidth, i.e., the image detail is equal to that provided by continuous modulation over an 8-Mc band, when transmission occurs by time multiplex over a 4-Mc band. By this technique it is possible to transmit a color image, within a 6-Mc channel, having nearly as high resolution, and equal freedom from flicker, as a black-and-white image transmitted by continuous modulation over the same channel. Moreover, the scanning rates of the dot-sequential color system are identical to those of the black-and-white system so obsolescence of existing equipment is avoided.

The time multiplex transmission is achieved by sampling in sequence the outputs of three camera tubes (which televise the scene simultaneously in the three primary colors) at a rate of 3.6 Mc. Sinewaves in three-phase relationship are developed from this sampling process, each representative of the scanning of alternate dots along the lines of the respective images. The sinewaves are combined vectorially into a single sinewave which is radiated as a sideband component separated 3.6 Mc from the picture carrier. At the receiver, the combined sinewave is sampled by an electronic switch synchronized with the sampling switch at the transmitter (the synchronization is accomplished by short bursts of 3.6 Mc sinewave inserted on the sync pedestal during the horizontal blanking period).

The separated sinewaves resulting from this process control three electron guns in a tricolor picture tube. The viewing screen of the tricolor tube consists of several hundred thousand dots of phosphor material arranged in groups of three. One phosphor dot in each group fluoresces with red light, the second with blue light, and the third with green. The area of the three phosphor dots as a group corresponds to the area of a single picture element. Accordingly, each picture element may be caused to assume the desired combination of primary colors by sequential excitation of the phosphor dots within its area. The three electron guns are so positioned that the electron beam of one gun can excite only the red phosphor dots, the second gun only blue dots, and the third only green dots. A single-gun type of tube, in which the beam traverses a spiral in impinging on the screen and hence can excite one phosphor dot to the exclusion of the other two in the group, has also been demonstrated.

The terminal apparatus (camera and picture-reproducing equipment) of the dot-sequential system is more complicated than that of the field-sequential system. Moreover, it is vital that the transmission system cover the full video frequency range up to and including the sampling frequency of 3.6 Mc; if this frequency is not transmitted, the color values are lost and a rendition in tones of gray results.

The third color television system considered by the FCC is the line-sequential system developed by Color Television, Inc. In this system the color sequence is introduced by a change in color at the end of each scanning line. The scanning rates are 525-lines, 60-fields, as in the black-and-white system and dot-sequential color system. The color sequence is obtained by focusing on the mosaic of an image orthicon, three congruent images side by side, in the three primary colors. The group of three images is scanned at one third the usual line scanning rate (15,750/3 = 5,250 cps). Each horizontal passage of the scanning beam crosses three images, so the lines are scanned at 15,750 cps in the sequence red, green, blue. Since the number of lines per frame (525) is exactly divisible by three, it would follow that a given line in the scanning pattern would always be scanned in the same color, and the rendition of solid tones would display very poor vertical resolution. To avoid this effect, the colors are commutated by a special sync signal which causes a vertical shift of certain lines. In this manner every line is scanned in three colors at a rate of 10 per second. This rate is sufficiently low to create interline flicker and line crawl.

On October 11, 1950, the FCC announced its decision to adopt the CBS field-sequential color system, and stated that it would authorize commercial color broadcasts using this system on and after November 20, 1950.

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Analysis of Synchronizing Systems for Dot-Interlaced Color Television*

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IN DESIGNING a “dot interlace” system1 of color television, synchronizing problems over and above those of ordinary black-and-white television are encountered. A “dot” system consists essentially of a three-channel time division multiplex system with one channel devoted to the transmission of each primary color. This involves sampling each color at the transmitting end of the system at approximately a 3-Mc rate, transmitting information so derived to the receiver, separating this information by resampling at the same 3-Mc rate and applying it to control the three colors displayed on the cathode-ray tube. Thus a sample of each color is obtained on every third pulse. In order to avoid deleterious color distortion, the sampling frequency in the receiver must be closely synchronized in phase with that of the transmitter.

In the receiver we have the problem of first synchronizing the frame, then the line, and finally the dots within each line. The first two of these are common to both color and black-and-white television and since these problems are relatively well understood, less attention will be given to them than to dot synchronizing. There appear to be no smaller tolerances required for frame and line synchronizing in color television than in black-and-white. A continuous-wave 3-Mc wave could be transmitted, picked out by frequency separation, and used for synchronizing purposes. This has obvious disadvantages, however. A better scheme, the one which will be considered here, consists in transmitting a burst of 3-Mc carrier during horizontal sync pulse. This burst together with the sync pulse may be separated from the video in the usual way by clipping. The 3-Mc information may then be separated from the pulse by filtering or by gating. Alternatively, one could first gate out the 3-Mc burst and then filter. The clipped pulse and burst may be applied directly to the conventional pulse afc system without difficulty. However, the pulse must be removed in some way before the burst is applied to a sine-wave afc system.

Assuming that the 3-Mc burst has been in some way separated, it is necessary to consider what mechanism will be used to effect synchronization. Since the tolerances on the stability of the transmitted synchronizing wave will largely determine the mechanism to be used, these will be established. It will be assumed that all synchronizing frequencies in the transmitter are crystal-controlled so that it may be expected that variations in the 3-Mc frequency will not exceed ±50 cps when switching from station to station. Furthermore, the drift in frequency of a given crystal will be so small as to be negligible. Also, the ratio between the dotting frequency and the line frequency is so chosen that there is no necessity to shift the phase of the dotting frequency at the end of each line or frame. Under these conditions three possible synchronizing devices appear possible: first, a simple high-Q filter (e.g., a crystal filter) which picks out the 3-Mc component, amplifies it, and applies it directly as the sampling wave; second, a locked sine-wave oscillator controlled in frequency by the 3-Mc burst; third, an afc system which controls the frequency of a sine-wave oscillator. Since any sync system must operate satisfactorily under bad fluctuation noise conditions, it must be realized that this requirement will ultimately determine the choice of system.

If, in order to achieve good noise protection, the simple filter device is narrowed down, the point will eventually be reached where the slope of the phase characteristic becomes so large that shifts in frequency such as may be encountered in switching from station to station will cause such an intolerably large static phase error that a manual frequency trimmer must be used. Furthermore, lock-in time on sudden phase transi-

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tions may be too long. This dilemma is common to any sync system in various degrees; that is, if the system is designed to ignore noise fluctuations it tends also to ignore variations from any source.

All three of the possible systems will track variations in phase and frequency with varying degrees of fidelity. The locked oscillator may have some advantage over the simple filter in that its effective bandwidth varies directly as the voltage of the applied synchronizing signal, although its chief merit appears to be in the fact that it is a Q multiplier.\(^2\) Automatic-frequency-control sync would appear to be the most efficient of the three since it separates the functions of phase detection, filtering and amplifying, and generation of the correct synchronizing signal, thus permitting the parameters in each part of the system to be adjusted for optimum performance. The validity of these statements requires some proof and this will now be undertaken. The simple tuned circuit will be compared quantitatively with afc sync, since it is believed that locked oscillator performance lies somewhere between these two.

Since crystal frequency control is assumed used in the transmitter, the problem essentially reduces to the calculation of phase error introduced by random noise, and the static phase error caused by a shift of frequency when station switching. The delay in tracking a phase shift caused by station switching is not believed to be important.

The characteristics of each system which will keep the phase error due to random noise alone below 5\(^\circ\) will now be determined, and then the respective static phase errors caused by transients of frequency will be found. This will be done for various signal-to-noise ratios in the intermediate frequency and will furnish a measure of the fidelity of the two systems. The average carrier power-to-noise ratio in the intermediate frequency will be used where the carrier is measured at the sync tips.

If the carrier burst occupies 4 \(\mu\)seconds out of 64 \(\mu\)seconds, when gated, clipped, and filtered, it will yield a sinusoid of amplitude \((C/128)\beta\) where \(C\) is the amplitude of the intermediate-frequency carrier during the sync pulse and \(\beta\) is the modulation suppression term derived in Appendix A.

The noise power out of a filter of total bandwidth 2\(\gamma\) will be \(2\gamma F_0\) where \(F_0\) is the amplitude of the noise-power spectrum at 3 Mc as derived in Appendix A and 2\(\gamma\) is the equivalent noise bandwidth of the filter. 2\(\gamma\) will turn out to be so small compared with the 4-Mc video bandwidth that the power spectrum may be considered flat across it. When noise is added to a sinusoid, the phase of the sinusoid becomes indeterminate to a degree. It is shown in Appendix C that in such a case, the rms value of the phase error due to noise alone is \(\sqrt{\psi_0}/Q\) where \(\psi_0\) is the total noise power added to the sinusoid, and \(Q\) is the amplitude of the sinusoid. Thus if it is desired that the rms value of the phase error due to noise alone be less than 5\(^\circ\),

\[
\frac{\sqrt{2\gamma F_0}}{Q} < \frac{5}{57.3}
\]

Using the values of \(F_0\) from Appendix A and considering the filter to be a single-tuned circuit it is found that the half bandwidth \(\alpha\) must be less than 22, 85, and 135 cps, respectively, for intermediate-frequency signal-to-noise ratios of 1, 3, and 5.

To calculate the static phase error, the filter is again taken to be a single-tuned circuit and the maximum frequency deviation to be \(\pm\) 50 cps. Then the slope of the phase characteristic at resonance is

\[
\frac{d\theta}{d\omega} \bigg|_{\omega=\omega_0} = \frac{1}{\alpha}
\]

where \(\alpha\) is the half bandwidth. Thus measuring frequency deviation from resonance, one has \(d\theta = \omega/\alpha\). This yields a phase shift of 2.3, 0.6, and 0.37 radians for intermediate-frequency signal-to-noise ratios of 1, 3, and 5. This amount of phase shift obviously requires an auxiliary manual phase control. If the allowable rms phase error is 10\(^\circ\), then the bandwidths become 88, 340, and 540 cps, respectively, and the static phase shift becomes 33\(^\circ\), 8.4\(^\circ\), and 5.3\(^\circ\). The picture probably becomes unusable for a carrier-to-noise ratio in the intermediate frequency of about 2, so that if these phase errors can be tolerated in the sampling frequency, then the receiver can be operated without auxiliary manual hold control. The transient caused by a sudden step of phase in the input to the filter will have the time constant of the filter. This will occur when switching stations, but it is not considered to be important.

To determine the characteristics of the afc synchronizing system, the configuration of Fig. 1 is assumed.

![Fig. 1—Automatic-frequency-control servo loop.](image)

The incoming sync information after detection and separation is fed into a phase comparator where its phase is compared with that of the free-running oscillator which determines the frequency of the receiver sync. Thus the incoming phase information is denoted by \(\phi(t)\). Out of the phase comparator comes an error current \(i(t)\) which passes through a filter \(Z(p)\) before correcting the oscillator whose output is \(\phi_0(t)\). Then out of the phase detector there is obtained

\[
i(t) = K_1[\phi(t) - \phi_0(t)]
\]

where \(K_1\) is the sensitivity parameter of the phase comparator and is taken to be a constant. From the filter \(Z(p)\) there is a voltage \(e(t)\) which defined by

---

\[ e(p) = Z(p)i(p). \]

It is assumed that the voltage controlling the oscillator is held at a bias which yields the nominal sync frequency so that the voltage applied here results in deviation about that frequency. It is further assumed that the instantaneous deviation of oscillator frequency from the nominal value is directly proportional to \( e(t) \).

Then

\[ \frac{d\phi_0}{dt} = K_2 e \]

where \( K_2 \) is the sensitivity constant of the oscillator.

Since the phase comparator is a nonlinear device, \( K_1 \) is not an absolute constant but depends somewhat on the input signal and noise level. However, when measured or otherwise determined for a particular signal and noise, it will not vary much for reasonably small deviations from that value of signal and noise. Presumably, in designing an AFC sync system one must first decide the lowest signal-to-noise ratio under which the system is to operate satisfactorily. The design is then optimized for that condition with the expectation that performance will be better when the noise level falls. \( K_2 \) will be essentially constant for small values of \( e(t) \) for sine-wave oscillators controlled by reactance tubes or for blocking oscillators. Then, solving these equations in the frequency domain, it is seen that

\[ \phi_0(p) = \frac{K_1 K_2 Z(p)}{p + K_1 K_2 Z(p)} \phi_1(p). \]

If \( Z(p) \) is taken as a simple \( RC \) low-pass filter,

\[ Z(p) = \frac{1}{p + \alpha} \]

Then

\[ \phi_0(p) = \frac{A_i}{p^2 + \alpha p + A_i} \phi_1(p) \]

where \( A_i = K_1 K_2 A_i \). Thus the over-all gain function of the system is given by

\[ Z_o(p) = \frac{A_i}{p^2 + \alpha p + A_i} \]

Now consider the effect on the system of introducing signals such as a step of phase or a step of frequency. These situations will exist when stations are switched. The output phase is given by a Laplace transform, thus

\[ \phi_o(t) = \frac{A_i}{2\pi} \int_{-\infty}^{\infty} \frac{g(p)e^{pt}dp}{p^2 + \alpha p + A_i} \]

where \( g(p) \) is the spectrum of the input \( \phi_1(t) \). In the case of a step of phase of magnitude \( I_o \),

\[ \phi_o(t) = \frac{A_i I_o}{2\pi} \int_{-\infty}^{\infty} \frac{e^{pt}dp}{p[p^2 + \alpha p + A_i]} \]

where

\[ p^2 + \alpha p + A_i = (p - p_1)(p - p_2) \]

and

\[ p_1 = -\alpha + \sqrt{\alpha^2 - 4A_i}, \quad p_2 = -\alpha - \sqrt{\alpha^2 - 4A_i}. \]

These roots are always in the left half plane and may be complex or real depending on \( \alpha^2 - 4A_i \) being less than or greater than zero. In the former case, there is no oscillatory approach to the final tracking position while the latter provides a hunting approach. Operation at or near the critically damped position when \( 4A_i = \alpha^2 \) is generally preferred. In case the system is under-damped, the output is

\[ \phi_0(t) = I_o \left[ 1 - \frac{e^{-(\alpha t)}(\cos \beta - \frac{\alpha}{\beta} \sin \beta t)}{\beta} \right] \]

where \( \beta = \sqrt{4A_i - \alpha^2} \). This will reduce to the critically damped case when \( \beta = 0 \). \( \phi_0(t) \) can be written as

\[ \phi_0(t) = I_o \left[ 1 - \frac{2\sqrt{A_i} e^{-\alpha t} \cos (\frac{\beta}{2} t - \tan^{-1}\frac{\alpha}{\beta})}{\beta} \right] \]

The output then is as shown in Fig. 2.

![Fig. 2—Output of AFC system to a step of phase.](image)

The actual crossing of the line occurs at

\[ t = \frac{2}{\beta} \left( \frac{\pi}{2} + \tan^{-1}\frac{\alpha}{\beta} \right) \]

so that if this crossing is taken as a measure of lock-in time, it appears that the lock-in time can be made small by making \( \alpha \) large and \( \beta \) large. However, the overshoot becomes larger in such a case, so that a reasonable compromise must be made between fast lock-in time and initial overshoot. By minimizing the error \( i(t) \) \( \xi_i \) in the mean square sense, it can easily be shown to vary as \( 1/\alpha \) so that in this sense, optimum tracking is obtained by making \( \alpha \) as large as possible. All of this is in the absence of noise. It may be further noted that the output actually tracks \( I_o \) regardless of loop gain or filter bandwidth and that tracking time is independent of the magnitude of the phase error. To maintain an oscillatory approach, \( 4A_i > \alpha^2 \). If for example \( 4A_i \) is taken to be equal to \( 2\alpha^2 \) and \( 4\alpha^2 \), respectively, the first overshoot is 4 per cent and 16 per cent, which gives an idea of the
magnitude of the oscillation. The magnitude of the first
overshoot is $f_0(1 + e^{-r_0\alpha})$. These oscillations have been
observed experimentally.

Now suppose that the input signal is in correct phase
but off in frequency by a fixed amount, due to oscillator
drift or station switching. Then beginning at $t = 0$, 
$\phi_i(t) = \omega_0 t$ where $\omega_0$ is the frequency difference. Then 
$g(p) = \omega_0/p^2$ and

$$\phi_0(t) = \frac{2\alpha}{\beta} e^{-\alpha/2 \alpha} \cos \left[ \frac{\beta t}{2} - \tan^{-1} \left( \frac{\alpha^2 - 2A_1}{\alpha\beta} \right) \right]$$

$$+ \omega_0 t - \omega_0 t.$$ 

This last function is asymptotic to $\omega_0 - (\omega_0\alpha/A_1)$ so that there
is a static phase error $\omega_0 \alpha/A_1$. This static phase
error results in a static shift in the output $e(t)$ applied to the
oscillator which is just enough to change its frequency by $\omega_0$. One notes that this error is $\omega_0/ R K_1 K_2$ and is thus independent of the capacity of the filter. The
output is as shown in Fig. 3.

![Fig. 3—Output of acf system to a step of frequency.](image)

In general, in designing an acf system, it is necessary to
consider the necessity of tracking relatively low
variations in the incoming signal in the presence of noise
as well as the more severe transients such as steps of
frequency and phase. Having decided upon a typical
input signal to be tracked with optimum fidelity in the
presence of a given noise level, an attempt would then be
made to find the parameters which would minimize the
error in some sense. This objective leads naturally
to the theory of Wiener* in which an attempt is made to find
the filter which will minimize the difference between
input and output in the mean square sense. In principle,
this procedure is straightforward. However, it will gen-
erally yield a filter characteristic which is not physically
realizable and must therefore be approximated. It is
therefore the practice of servomechanisms to start with a
servo of a given type having adjustable parameters. The
mean square error can then be computed directly and the
parameters adjusted to minimize it. For our pur-
poses here the simple low-pass filter heretofore assumed
is believed adequate. An additional degree of freedom

* H. M. James, N. B. Nichols, and R. S. Phillips, "Theory of
Servomechanisms," Radiation Laboratory Series, vol. 25, McGraw-

with some improvement in performance can be
obtained by starting off with a double time-constant filter.
However, this complicates the calculations considerably
and will not be gone into here.

The output of the servo as a convolution integral can be
given as

$$\phi_0(t) = \int_0^\infty [\phi_i(t - \tau) + \phi_N(t - \tau)] K(\tau) d\tau$$

where $\phi_N$ is the noise assumed to enter the system with
$\phi_i(t)$ and $K(\tau)$ is the characteristic transient of the
servo system. The phase error is given by

$$\frac{i(t)}{K_1} = \phi_i(t) - \phi_0(t)$$

$$= \phi_i(t) - \int_0^\infty [\phi_i(t - \tau) + \phi_N(t - \tau)] K(\tau) d\tau.$$ 

Assuming no error in the incoming signal, the phase
error becomes

$$\frac{i(t)}{K_1} = -\int_0^\infty \phi_N(t - \tau) K(\tau) d\tau.$$ 

Thus using Plancherel's theorem, the mean-square
phase error due to noise alone is

$$\frac{1}{4\pi} \int_{-\infty}^\infty F_i(\omega) |Z_0(\omega)|^2 d\omega$$

where $F_i(\omega)$ is the phase noise power spectrum and
$Z_0(\omega)$ the over-all servo gain function. The above con-
siderations are quite general and apply to any acf sys-
tem of the type considered here. It may be assumed that
the bandwidth of $Z_0(\omega)$ will be so small compared to 4
Mc that $F_i(\omega)$ can be considered flat across it. There-
fore, the mean-squared phase error is

$$\frac{1}{4\pi} F_i \int_{-\infty}^\infty |Z_0(\omega)|^2 d\omega = \frac{F_i}{4\pi} \int_{-\infty}^\infty \frac{A_1^2 \alpha \omega}{(A_1 - \omega^2) + \alpha^2 \omega^2}$$

$$= \frac{F_i A_1}{4\pi}.$$ 

It may be observed here that in trying to minimize this
error, the static phase error $\omega_0 \alpha/A_1$ is made large so that
a compromise must be struck between the two. Since
this result will be evaluated for $4A_1 = \alpha^2$, little error is
caused here by taking the integral to $\infty$.

Now consider that the acf is applied to the 3-Mc
carrier. First the burst is put through a narrow tun-
circuit to pick out the 3-Mc sine wave. No phase in-
formation is lost by this maneuver. This filter must be
wide enough so that an objectionable phase shift does
not develop here. Then a sine wave plus noise is put into
the phase detector. The power spectrum of the phase
noise is, as shown in Appendix A,

$$F_i(\omega) = \frac{2F_0}{Q^2}, \quad 0 < \omega < \gamma$$
where $Q$ is the amplitude of the sinusoid, $2\gamma$ the bandwidth of the phasemeter, and $F_0$ the power spectrum of the video noise at 3 Mc.

Now we wish to compare the simple filter with the a.c.f. by constraining them to have the same r.m.s. phase noise error and then comparing the ensuing static phase error. If the phase noise errors are equated, it is found that $\alpha_1=\alpha_2$ where $\alpha_1$ is the half bandwidth of the simple filter, and $\alpha_2$ the half bandwidth of the filter in the a.c.f. loop. Then the static phase error for the a.c.f. case is $\omega_0\alpha_1=\omega_0/\alpha_2$ which is identical with the result for the simple filter, independent of the relationship between $\alpha_1$ and $\alpha_2$. If a double time-constant filter is used in the a.c.f. loop, it can be shown that for equal static phase errors, the noise error in the double time-constant case can always be made less than that for the single time-constant filter. In such a case, there will then be improvement in performance over the case analyzed here at some reduction in lock-in time.

It will now be shown how the foregoing analysis may be applied to pulsed sync systems, although specific calculations will not be carried through, since such systems are not the primary interest here.

Consider the conventional black-and-white a.c.f. pulse sync system. Here the sync information is not provided continuously but intermittently so that there is a little difficulty in defining phase in a sense that may be compared with the continuous case. The position of incoming pulses is determined in a conventional balanced phase detector by feeding back part of the sawtooth output of the oscillator in the fashion shown in Fig. 4.

[Diagram of a balanced pulse phase comparator]

In effect, the pulse is caused to ride on each of two sawteeth which differ only in polarity. In each case the pulse top is then clipped at a fixed (ideally) bias level and the two clipped pulses subtracted. The difference is the output of the phase detector. At the center position there is no output, hence the term balanced-phase detector. If the slope of the sawtooth is $d$, then the height of the output pulse is $2dx$ where $x$ is the deviation of the pulse from its proper position. If the pulses are to the left of the center point, the polarity of the output (as well as any noise present) is reversed. Thus the output of this phase detector consists of pulses of current of varying amplitude and polarity. If, at time $t=0$, the frequency of the oscillator is correct but there exists a constant phase error, then the input to the servo consists of a sequence of pulses of the same height and polarity.

To make this type of input signal fit in with the previously derived equations describing the servomechanism, it is convenient to observe that the time constant of the over-all servo will be large compared to the time between pulses (of the order of 15 to 1) so that one may without appreciable error spread the area of the input pulse over the entire interval $0$ to $T$. This provides a continuous input to the servo. The area of the error pulse is $2dxW$, where $W$ is its width. The equivalent pulse after spreading then has a height $(2dxW/T)$. $x$ is defined as the phase error. The quantity $2dxW/T$ has the dimensions of amperes per unit phase error and is therefore defined as the sensitivity constant $K_1$ of the phase detector. Under these assumptions all of the preceding results on tracking, lock-in time, and so forth, are valid.

If the sync pulses are not gated, as is generally the case in black-and-white television, there is some difficulty in calculating the noise output of such a phase detector. To design for the worst condition, one would presumably assume the video at black level and then calculate the noise output of the device. This can be done only by numerical methods and will not be gone into here. In practice, the clipping levels of the two diodes in the balanced phase detector are allowed to set themselves. These levels are determined by the pulse signal level, the noise level, the pulse signal position, the diode internal resistance, and the diode plate load resistance. For a given input signal-to-noise ratio and with the input pulse at the neutral position, a solution can be found for the proper plate load resistor to position the clipping level where desired. For small errors in phase then the clipping level will not deviate much from the optimum value. The height of the sync pulse is $C/4$ where $(C/4) > 2dx$ in all cases. Ideally, clipping should be done at $(C/4) - dx$ since at this level full indication of phase error is obtained while the clipping level is as high as possible to avoid picking up noise. Presumably then, the clipping level is established for the minimum signal at which the device is expected to operate satisfactorily and suffers a design somewhat less than optimum at the higher signal-to-noise ratios. The plate load resistor thus determined affects the value of $\alpha$ in the filter following the phase detector but the capacity there can be varied within limits to adjust $\alpha$ for optimum value in terms of tracking, and so forth.

**Appendix A**

In the usual sync system, the sync tips are passed into the video and separated there by clipping. The top 25 per cent of the peak carrier may be devoted to hori-
every-line of 63.5 µseconds. The usable burst of carrier is probably 4 µseconds long and C/4 volts in amplitude where \( C \) is the intermediate-frequency carrier amplitude during sync pulse. It is assumed that this burst has been gated so that no noise appears in the sync system except during the burst itself. The noise in the intermediate frequency may be assumed to have a normal first probability density function of the form.

\[
W_1(I) = \frac{1}{\sqrt{2\pi\psi_0}} e^{-I^2/(2\psi_0^2)}
\]

where \( I \) is the instantaneous noise current and \( \psi_0 \) the average noise power. If the second detector is an envelope tracer, the density function of noise alone in the video is no longer normal but has a Rayleigh distribution

\[
W_1(R) = \frac{R}{\psi_0} e^{-R^2/2\psi_0^2}
\]

where \( R \) is the voltage of the envelope and \( \psi_0 \) the intermediate-frequency noise. If an unmodulated carrier \( C \) is added to the intermediate-frequency, the probability density function then becomes

\[
W_1(R) = \frac{R}{\psi_0} e^{-(R^2+C^2)/2\psi_0^2} \left( \frac{RC}{\psi_0} \right) I_1(C) \tag{1}
\]

when \( I_1 \) is the modified Bessel function. This density function does not depend on the position of the carrier in the intermediate-frequency pass band. To a first approximation, the continuous part of the noise power spectrum \( F(f) \) of a sine wave and noise in the video following an envelope is given by

\[
F(f) = \pi^2 h_{11}^2 \left[ W(f_x) + W(f_q+f) \right] + \pi^2 \int_{a}^{\infty} W(x)W(f-x)dx \tag{2}
\]

where

\[
\begin{align*}
h_{11} &= \frac{1}{2} \left( \frac{y}{\pi} \right)^{1/2} I_1(1/2; 2; -y) \\
h_{02} &= (2\pi\psi_0)^{-1/2} I_1(1/2; 1; -y) \\
y &= \frac{C^2}{\psi_0}
\end{align*}
\]

\( I_1(\alpha; \beta; y) \) is the hypergeometric function. The first part of \( F(f) \) is due to the modulation products of signal and noise while the second part is due to the intermodulation of the noise alone. In the case of vestigial side-band transmission, there is only half of the first part of this, namely, \( W(f_q+f) \) where now \( f \) extends over the entire intermediate-frequency and video bandwidth. If \( W(f) \) is flat, = \( W_0 \), the noise power spectrum in the video is as shown in Fig. 5.

Here

\[
A = (ch_0)^2 \left( \frac{BW^2}{4C^2} \right) = \frac{W_0}{8} (ch_0^2) \frac{1}{\left( \frac{S}{N} \right)_{1f}}
\]

The values of \( ch_0^2 \) and \( h_0^2 \) are obtained from the curves in the literature. As the signal becomes larger compared with the noise, the contribution due to noise intermodulation drops off until ultimately the noise rides on top of the signal and the spectrum in the video has the same shape as in the intermediate frequency. On the other hand, for zero signal, the spectrum becomes triangular.

![Fig. 5—Power spectrum of sine wave plus noise in the video.](image)

The above shows the power spectrum of the noise alone. As is generally known, when the noise power becomes comparable to that of the signal, the second detector causes a suppression of modulation. Since the modulation index of the carrier burst is small \((1, 8)\), the preceding result concerning noise-power spectrum is not altered perceptibly by the addition of the modulation. However, it is necessary to know the extent of modulation suppression and it is convenient, since the modulation index is small, to use the procedure of Ragazzini. The input to the detector can be written

\[
e(t) = C \cos \omega_0 t + mc \cos (\omega_0 + \omega) t \\
+ \sum_{n=0}^{\infty} c_n \cos (\omega_n t + \phi_n)
\]

where the last term encompasses all noise components with random phase angles \( \phi_n \). Then the envelope can be written as

\[
E(t) \cong \left[ C^2 + m^2C^2 + 2\psi_0 + 2mC^2 \cos \omega_1 t \right]^{1/2}
\]

where \( \psi_0 \) is the entire intermediate-frequency noise power. This is approximately

\[
E(t) = \sqrt{C^2 + 2\psi_0 \left( 1 + \frac{mC^2 \cos \omega_1 t}{C^2 + 2\psi_0} \right)}
\]

4 See page 148 of footnote reference 5.

Thus the detected signal has the amplitude
\[
\frac{mC^2}{\sqrt{C^2 + 2\psi_0}} = \frac{mC}{\sqrt{1 + \frac{2\psi_0}{C^2}}}
\]
and the modulation suppression is
\[
\sqrt{\frac{1}{1 + \left(\frac{S}{N}\right)_{d_t}}}
\]

For \(S/N_d = 1, 3,\) and \(5,\) the suppression factor becomes \(0.71, 0.87,\) and \(0.91.\)

Now, if in the video, the burst and associated noise is simply gated, it is possible, as is shown in Appendix B, to find the signal-to-noise ratio of the 3-Mc sine wave and noise as it leaves the filter. However, some improvement can be made by clipping as well as gating. As shown in Appendix B, the noise spectrum at 3 Mc is, to a first approximation, reduced by the gating factor. The noise may be further reduced by clipping at 3-4C since this does not reduce the signal but does reduce the noise. Numerical integration of the second density function (1) shows that the total de-suppressed noise power is reduced from 0.63\(\psi_0\) to 0.50\(\psi_0\), 0.83\(\psi_0\) to 0.52\(\psi_0\), and 0.93\(\psi_0\) to 0.61\(\psi_0\), respectively, for input signal-to-noise ratios of 1, 3, and 5. Thus assuming that the spectral distribution does not change materially in shape, the power spectrum level at 3 Mc can be found.

Utilizing the results of (2), this is to be found to be 0.027\(W_0\), 0.032\(W_0\), and 0.037\(W_0\), respectively. Since \(\psi_0\) the total intermediate-frequency noise \(= BW_0\) this may be written
\[
\frac{0.027\psi_0}{B}, \quad \frac{0.032\psi_0}{B}, \quad \frac{0.037\psi_0}{B}.
\]

**APPENDIX B**

If we have an ideal gate which opens and closes at intervals \(T\), it may be represented as the time function shown in Fig. 6. To gate noise this time function is multiplied by the noise-voltage time function. It is desired then to find the power spectrum of the product. The autocorrelation of the product is the product of the separate autocorrelations since the two time functions are independent. To each autocorrelation function corresponds, by Fourier transform (Wiener's theorem), the power spectrum of the original time function, Thus,

\[
G(\omega) = \int_0^\infty R(\tau) \cos \omega \tau d\tau
\]

\[
R(\tau) = \frac{1}{2\pi} \int_0^{\infty} G(\omega) \cos \omega \tau d\omega
\]

where \(G(\omega)\) is the power spectrum and \(R(\tau)\) the unnormalized autocorrelation function. The spectrum of the product of two autocorrelation functions (time functions in the power domain) is given by the complex convolution integral. Thus the power spectrum of the two original time functions is given by

\[
G(\omega) = \int_0^\infty F_1(\omega - \tau) F_2(\tau) d\tau
\]

where \(F_1(\omega)\) is the power spectrum of the noise, say, and \(F_2(\omega)\) is the power spectrum of the gating pulses. For the simple gate assumed, the result is given by

\[
F(\omega) = \frac{d^2}{T^2} \sum_{n=-\infty}^{\infty} \left( \frac{n\pi d}{T} \right)^2 G_1(\omega - \frac{2\pi n}{T}).
\]

This sum may be approximated by an integral

\[
F(\omega) \approx \frac{d^2}{T^2} \int_{-\infty}^{\infty} \left( \frac{n\pi d}{T} \right)^2 G_1(\omega - \frac{2\pi n}{T}) dn
\]

which is valid when the gating frequency is small compared to the bandwidth of the noise, so that successive \(G_1(\omega)\) s overlap substantially.

If \(G_1(\omega)\) is constant and \(= G_{1d}\)

\[
F_1(\omega) = \frac{G_{1d}d^2}{T^2} \left[ 1 + 2 \sum_{n=1}^{\infty} \left( \frac{n\pi d}{T} \right)^2 \right] = \frac{G_{1d}d}{T}
\]

showing that the noise spectrum and the total noise power are each reduced by the gating factor \(d/T\). By the same argument one may show that for any spectrum \(G_i(\omega)\), the total noise power is reduced by \(d/T\).

It may be of some interest to observe here that when gates are used in the sense of samplers of a video signal, the signal-to-noise ratio after gating does not depend on the gating factor \(d/T\) in any way, provided that the noise bandwidth is limited to \(\omega_0\) prior to sampling where \(\omega_0\) is the highest video frequency sampled. This is apparently not generally realized but may be easily shown with the aid of the above formulas.

In the application used here, the gating frequency is small compared with a bandwidth of 4 Mc so that the integral approximation is valid. Under these conditions, it is not hard to show that to a first approximation the
spectrum at 3 Mc is also reduced by $d/T$ when the total power is reduced by that amount.

**Appendix C**

In the case of normally distributed noise in a range of frequencies that is small compared to the center frequency, the noise current may be written after the method of Rice\(^4\) as

$$I_n = \sum_{n=1}^{N} C_n \cos (\omega_n t + \phi_n)$$

$$= \sum_{n=1}^{N} C_n \cos [(\omega_n - q)t + \phi_n + qt]$$

$$= I_e \cos qt - I_s \sin qt$$

where

$$I_e = \sum_{n=1}^{N} C_n \cos [(\omega_n - q)t + \phi_n]$$

$$I_s = \sum_{n=1}^{N} C_n \sin [(\omega_n - q)t + \phi_n].$$

Here $q$ is the center frequency of the band,

$$\omega_n = 2\pi f_n, \quad f_n = n \Delta f, \quad C_n = 2F(f_n)\Delta f.$$  

$F(f)$ is the noise power spectrum. $I_e$ and $I_s$ are normally distributed and each have the rms value $\sqrt{\psi_0}$. If a sinusoid $Q \cos qt$ is added to the noise,

$$I = Q \cos qt + I_n$$

$$= (Q + I_s) \cos qt - I_s \sin qt$$

$$= R \cos (qt + \theta)$$

where $R$ is the envelope and $\theta$ the phase. Then

$$\theta = \tan^{-1} \left( \frac{I_s}{I_e + Q} \right) = \frac{I_s}{Q} \; \text{if} \; Q \gg \sqrt{\psi_0}$$

and under these conditions the density function for $\theta$ may immediately be written as

$$W_\theta(\theta) = \frac{Q}{\sqrt{2\pi} \psi_0} e^{-\frac{\theta^2}{2\psi_0}}.$$  

Then the rms phase deviation from that of the sinusoid is $\sqrt{\psi_0}/Q$ radians. From the representation of noise in the Fourier series, it is evident that $I_e$ behaves like a noise current whose power spectrum is concentrated in the power part of the power spectrum and is, in fact,

$$F_1(\omega) = F(\omega_f + \omega) + F(\omega_f - \omega)$$

where $F(\omega)$ is the power spectrum of $I_n$. Thus if

$$F(\omega) = \begin{cases} F_0 = \frac{\psi_0}{B} & \text{for} \; \omega_0 - \frac{\beta}{2} < \omega < \omega_0 + \frac{\beta}{2} \\ 0 & \text{elsewhere} \end{cases}$$

then

$$F_1(\omega) = \begin{cases} \frac{2F_0}{Q^2}, & 0 < \omega < \frac{\beta}{2} \\ 0 & \text{elsewhere} \end{cases}$$

The noise in the video is not normally distributed. However, if a narrow filter at 3 Mc is inserted, randomness is restored and the noise out of the filter can be considered normal, so that the preceding argument can be applied. The filter may be assumed so narrow that the noise spectrum picked out by it will be flat. However, the level of the noise power at 3 Mc must be determined.

Using the results of Appendix B, it can be shown without difficulty that the condition $Q \gg \sqrt{\psi_0}$ is satisfied for the three values of $S/N_{int}$ assumed. A filter 2 kc wide will quite satisfactorily pick out the 3-Mc carrier without the adjacent sidebands which are 15 kc away. This filter width does not give rise to any appreciable static phase error in itself due to changes in frequency and provides a $Q$ suitably larger than $\sqrt{\psi_0}$.

It is of interest to note here that the phase noise-power spectrum has the dimensions of time so that when integrated over $\omega$, it yields phase in radians. The phase correlation may also be easily calculated from the phase power spectrum, being given by Wiener’s theorem as

$$R(\tau) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) \cos \omega \tau dw.$$  

In the case of a uniform spectrum of width $\gamma$ this yields

$$R(\tau) = \frac{F_0 \gamma}{4\pi} \frac{\sin \frac{\gamma \tau}{2}}{\gamma^2}$$

showing that phase correlation due to noise does not become small until

$$\tau = \frac{2\pi}{\gamma}.$$  

The Control Chart as a Tool for Analyzing Experimental Data*

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Summary—The statistical methods that have been developed for use in quality control are a powerful tool in the interpretation of laboratory experiments where only a small amount of data is available. An understanding of these methods also permits more logical planning of experiments and improves what we might call "the efficiency of experimentation." One of the simplest and most broadly useful of these tools is the control chart. It is easy to understand and use and in many cases can take the place of more laborious and complicated methods of analysis.

ONE OF THE simplest and most useful tools for statistical analysis is the control chart. As originally developed by Shewhart, the control chart was primarily a tool for the production man who dealt with large numbers of repetitive operations. In recent years, Shewhart and others have been giving much thought to the question: "Can the simple statistical tools that have been proved so valuable in quality control in the factory be just as useful in research and development work, in laboratory experimentation?" The answer is yes.

It is the purpose of this paper to give a very brief description of the control chart and point out how the experimenter can use it in his laboratory. He may not be an expert statistician. But he wants to make most of the analysis by himself and call in the expert only on the more difficult problems. He needs a technique that is not cloaked in mathematical symbolism. He needs a method of analysis that can be applied in a straightforward manner, and that can be explained to others who, like himself, are not steeped in statistical lore. He is more interested in relations and interpretations that lead to sound and useful judgments than he is in mathematical elegance or numerical precision.

The control chart pays its way as a simple and efficient method of analyzing and summarizing our data. Then it pays a bonus. It tells us when our data are good and when not. It tells us when we have enough data and when we need more. It tells us when our methods can be improved and when we have reached the limit in refining them along any particular line. It points a finger at those spots in our development where concentrated effort will do the most good.

In appearance, the control chart is a simple plotting of points and guide lines. Typically it is a double chart like that in Fig. 1. The abscissa is some independent variable such as observer, the number of the subgroup or setup, or ambient conditions. Often it is simply a serial number representing the order in which the experiment is carried out. The ordinate is the characteristic of interest: some physical property of an alloy under study, or the transconductance of a tube of new design.

In plotting our control chart, we group our data into small rational subgroups. The "small" means, preferably, 4 or 5, although we sometimes use subgroups as small as 2 or as large as 6 or more. The "rational" means that we have reason to believe the members of a subgroup are alike because they involve the same calibration setting, or the same bottle of reagent, or simply because they represent work all done at about the same time. The "rational" also means that we have reason to suspect that the subgroups might be different from each other, because they represent different observers, or different calibrations, or simply different days.

We treat the few observations in each subgroup as a set and we compute and plot their range $R$ and their average $\bar{X}$. The range is the difference between the largest and smallest, and is a measure of dispersion. The average is the usual arithmetic mean. The range and the average are the points on the control chart.

On our control chart we draw two central lines, one
at the average of the ranges \( \bar{R} \); one at the average of the averages, which is the grand average \( \overline{\overline{X}} \).

On the control chart we also draw limit lines.

\[
\text{lim } R = D_2 \bar{R} \quad \text{or} \quad D_4 \bar{R} \\
\text{lim } \overline{\overline{X}} = \overline{X} \pm A_2 \bar{R}
\]

where \( D_2, D_4, \) and \( A_2 \) are factors that we find in published tables, just as we find sines or logarithms. They depend on the number of observations in each subgroup.

The central line on the average chart represents the average in the usual sense. It is the average strength of our plastic, the average permeability of our iron, or the average \( g_n \) of our tubes.

The central line on our range chart tells us what dispersion to expect. If these data represent reliable information about a stable process, then we expect future observations to have a root-mean-square deviation \( \sigma \) of about

\[
\sigma = \bar{R}/d_2
\]

where \( d_2 \) is another factor from the tables, and depends on the subgroups size. We expect nearly all future observations to lie between \( \overline{\overline{X}} \pm 3\sigma \) and \( \overline{\overline{X}} - 3\sigma \).

The limit lines tell us something about the reliability and stability. If we have points outside limits we should question the reliability and stability. Points outside, outages, tell us that our experimental process is probably being affected by differences in calibration, by the mood of the observer, or by the intrusion of some foreign influence. Outages tell us that our measurements are being affected by some identifiable or assignable cause for variation—a cause not normally present—a cause that stands out above that system of causes that produce the variations inherent in our process. Outages tell us that our experiment is in trouble and tell us when it got that way. This information is most important in tracking down and eliminating that trouble.

If there are no outages, this indicates that the variations we observe are due to a mass of minor causes, and not to any one or two causes that are important or even identifiable. So we know that we should not waste time tinkering with the process in an effort at improvement. For this indication to be reliable, we should have something like 25 consecutive subgroups all within limits.

As a corollary to this, the limit lines sometimes tell us when to abandon a particular process or type of experimentation. The limits which the process gives us for itself may be wider than we can tolerate. But if we have enough points all inside limits, with no outage, and still want something better, we must make a fundamental change in the process.

We should emphasize the fact that these limits are not based on any customer's requirements, or on management's stated objectives, or on what some old hand

tells us we ought to be able to do. They are based on the measurements we have just made on the process we are working with. By these limits the process itself tells us what to expect from it in the future.

The control chart is a system of bookkeeping for studying the causes of variation. We use it to analyze the same data we would analyze by any other method. It helps us draw the same conclusions we ought to draw by whatever method we use. It is simple and straightforward.

Let us consider a couple of simple illustrations of how the control chart might be useful in laboratory work. Suppose we have a paper design for a new type of vacuum tube. We make a small batch of tubes according to this design—4 or 5, or maybe 8 or 10. We measure their characteristics. For this illustration, let us confine our attention to the trans-conductance \( g_m \). Perhaps our first models do not turn out as well as we had hoped. We revise our design and make another lot. It is still pretty poor, but we think we are beginning to see what is wrong so we try again. This time we get something worth while. This is the familiar history of experimental progress. Finally, after more trials, we arrive at a design that we think may be satisfactory. We take it to the production man and the customer for their opinions.

They like it, and the eight tubes we made according to the last design look good. Then comes the inevitable question, shot at us in two forms. From the user: "How much variation will I have to put up with?" From the producer: "How tight tolerances must I meet?"

Fig. 2 shows a simple historical record of all the tubes we have made. In preparing this hypothetical example, it was assumed that nine different designs, \( A, B, \cdots J \)

![Fig. 2—Historical record. Individual points.](image)

on the chart, were tried and that the later ones were the better ones. The \( g_m \) varies all the way from 950 to 2,270. It is not apparent from this chart just what variation is to be expected.

Now let us put these same data in control-chart form as shown in Fig. 3. Some of our design lots contained four tubes. Others contained eight and we have treated such a lot as two subgroups of four. Altogether, we have thirteen subgroups of four. Design changes have been made between subgroups so that any subgroup relates to a single design.

---

From the control chart of averages we see, as was assumed in the illustration, that designs A, B, and D give significantly low $g_n$ while designs C, F, G, and J give significantly high $g_n$.

These control charts should, of course, have been plotted day by day as our work progressed. In the early stages, we would have used tentative values, based on the data available then, for the central lines and limits. These control charts should have been used to guide each step in our development. They would have helped us to evaluate the intended effects of our design changes. They would have helped us recognize unintended effects which we might desire either to avoid or to use. They would have helped us to recognize and eliminate extraneous effects that might interfere with our experimentation.

The range control chart does its share in this guiding of the course of our work. It also helps us answer that question about variations or tolerances. Every time we changed our design we may have changed our design average. If we computed a single dispersion on the basis of all the tubes lumped together, that dispersion would probably describe principally our design changes. But within each subgroup of four there was no design change. The range of each subgroup represents the dispersion that is present with constant design. We have thirteen such ranges, and from their average we can form an estimate of the inherent dispersion that exists when the design is not changed, and that is based on an over-all sample of 52 tubes and not merely on the eight tubes of the final design.

One may well ask: But may not these intentional design changes have produced changes in inherent dispersion just as they did in the average? The answer obviously is: Yes, they may have. Fortunately, it is rather common experience that they do not. But let us not take this for granted. Let us go back to the limit line and the outages on our range chart. In this illustration it was assumed that there were no outages. This is an indication that there was no significant change in dispersion, due either to the design changes or to extraneous causes. We may, therefore, take the average range as a measure of dispersion with some confidence.

But suppose that for some subgroups the range is outside limits. This may indicate that this design tends to give greater inherent variation than the others and may cause us to abandon this design. Or it may indicate the intrusion of some foreign influence into our model building or our measurements. In either case, we would not include the range of this subgroup in the basis of our estimate of dispersion.

We may compare this method to the analysis of variance. The latter also gives us a measure of the changes that our designs have introduced and a measure of the inherent or residual dispersion that exists with a fixed design. The analysis of variance, however, makes no use of limits and outages. The analysis of variance assumes that the residual variation is constant. It waves no red flags when the inherent dispersion changes or when extraneous influences interfere. It does not tell us to ignore certain subgroups in estimating the residual dispersion.

In planning this series of experiments we would have used our knowledge of our intended method of analysis to plan the size of our subgroups, to plan the essential similarity of items within any one subgroup, and to plan specific changes between subgroups.

Now consider an example in which statistics play a more important part in planning an experiment. Suppose we are working on a 3-stage intermediate-frequency amplifier for a television receiver and want to determine experimentally the variation in gain that is to be expected from variation in certain components. This gain depends, among other things, on the $g_n$'s of the three tubes. We might get the three worst tubes we can find, and the three best tubes we can find, and try each set in our circuit. This is unrealistic and may be unnecessarily pessimistic. From our knowledge of the dispersion of this type of tube, and by the use of known statistical factors we can write down the $g_n$ for each tube in an idealized sample of nine. We know, for example, that, on the average, the largest value in a sample of nine from a normal universe will be 1.48 $\sigma$ above the universe average. Let us get a number of tubes from the stockroom, measure each, and select the nine which most nearly correspond to the idealized sample. We also know the expected values of the three averages we would get by an idealized sampling process which gave us three sets of three tubes each. So we divide our nine tubes into three sets of three each whose averages most nearly correspond to those expected.

\[ g_n \]
averages. This is illustrated in Fig. 4. We put each of these three sets of tubes in our circuit and measure the resulting gain.

There are probably some other circuit elements that are important to the gain of the amplifier—perhaps the three biasing resistors. Here again, we can pick three similarly selected sets of biasing resistors to form purposeful samples just as we did with the tubes. We would build three amplifier circuits, one with each set of resistors. Then we would test each set of tubes in each circuit.

We might make each test at three supply voltages: rated voltage, 10-per cent high and 10-per cent low. This gives us a total of 27 gain measurements to be made.

This gives us no guarantee against errors in judgment as to the most important variables nor against the intrusion of other factors into our experiment. But this kind of logical planning will increase the amount of information and the reliability of the information that we get from a given amount of effort and equipment.

Note that this planning assumed that we knew the dispersion of the tubes and of the resistors. This means that the supplier of our components has been keeping control charts of his product and that he can and will give us his pertinent quality data. With this co-operation from our supplier we can make enormous improvements in the efficiency of our experimentation.

After we make the measurements we must analyze the data. We might do this in the conventional manner by the analysis of variance. Our assumed experiment involves a three-way classification according to transconductance, cathode resistor, and supply voltage. We have no explicit replication, that is, no simple repetition, but each measurement is affected by the residual dispersion that we would observe if we made simple repetitive observations under each condition. The analysis of variance gives us quantitative measures of the three main effects. It tells us, for example, how much variation in gain was related to the variation in transconductance. It also gives us quantitative measures of the interactions, such as the effect that variation in biasing resistors had on the dispersion due to variation in transconductance. And it gives us a quantitative measure of the residual dispersion.

We can get comparable information from an analysis by the control-chart method. We can get it more readily, and we can get it in a form that the ordinary engineer can understand. Let us outline a schedule for such an analysis. Part of such a schedule is shown in Table I. Columns $a$, $b$, and $c$ give the values of the three independent parameters, and these are arranged in some logical order such as that indicated. In our example these are transconductance and biasing resistors, in each case the average of the three used, together with the supply

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>Analysis of Variation by Control-Chart Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>$b$</td>
</tr>
<tr>
<td>$(g_{a})$</td>
<td>$(K_{a})$</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>$X_{a}$</td>
<td>$R_{a}$</td>
</tr>
</tbody>
</table>

Note—$a$, $b$, and $c$ are independent parameters. $X$ is quantity measured. $R_{a}$ is range of subgroup in which $c$ is only variable parameter. $X_{a}$ is similar average. $R_{a}^{*}$ is range of a subgroup of $X_{a}$ in which $b$ is only variable parameter. Similarly $X_{a}^{*}$, $R_{a}^{*}$, and $X_{a}^{*}$, $a_{n}$, $a_{h}$, and $a_{m}$ are estimates of main effect dispersions. $a_{n}$ is estimate of residual dispersion. $d_{u}$ and factors for computing limits are taken from published tables.

\[
\begin{align*}
\sqrt{\sigma_{a}^{2} + \sigma_{c}^{2}} &= R_{a} / d_{u} \\
\sqrt{\sigma_{a}^{2} + (\sigma_{a}^{2} + \sigma_{c}^{2})/3} &= R_{a}^{*} / d_{u} \\
\sqrt{\sigma_{a}^{2} + (\sigma_{a}^{2} + \sigma_{c}^{2})/3} &= R_{c}^{*} / d_{u}
\end{align*}
\] (1) (2) (3)

Rearrange primary data similarly in orders $b$, $c$, $a$ and $c$, $a$, $b$. Obtain two solutions each for $a_{n}$, $a_{h}$, and $a_{m}$. Average each pair. Obtain three solutions for $a_{n}$. Average. Significant interactions and unstable residuals appear as ranges outside limits. Significant main differences appear as averages outside limits.
voltage. In the table we have called the three values of each parameter simply 1, 2, and 3. We might have called them $g_1$, $g_2$, $g_3$. In column $d$ is the observed quantity in which we are interested, the gain. These 27 measurements, in the order shown, fall into nine subgroups within each of which voltage is the only variable parameter. These are rational subgroups in so far as the transconductance and biasing resistor are constant within groups but variable between groups.

In column $e$ are the ranges of these subgroups. They represent a combination of two dispersions, one the inherent variation that would be present if we attempted simple repetitive measurements, the other the variation that is due to the variation in voltage. This is stated in (1) of Table I. We have called these ranges $R_e$ since column $e$ contains the only variable parameter in the subgroup.

We also compute the averages of each of the nine subgroups, as shown in column $f$. In these averages $\bar{X}_e$, the effects of the two causes just mentioned have been reduced by the averaging process. We can divide these averages $\bar{X}_e$ into secondary groups so that $g_m$ is constant within any secondary group but variable between secondary groups. The ranges of these secondary groups $R_m$ are shown in column $g$. The average of these ranges represents the dispersion due to biasing resistors, in combination with the dispersion already measured and here reduced by the first averaging process. This is shown in (2). Equations (1) and (2) may now be easily solved for the dispersion due to resistors alone.

By carrying out this last process with a different grouping of our first averages, $\bar{X}_e$ in column $f$, so that the resistors are constant within each new secondary group, we find the dispersion due to $g_m$ alone. This is indicated in column $j$ and (3). The ranges used here are called $R_m$.

Then we go back to our original data and rearrange it so tubes are the only variables in our first subgroups. We repeat the analysis as outlined above and obtain the dispersions due to resistors and voltage. Similarly, with another rearrangement of the original data, we obtain the dispersions due to voltage and tubes.

We now have two determinations or, more properly, two estimates of each main effect $\sigma_m, \sigma_g$ and $\sigma_e$. Because of sampling fluctuation, and because we have ignored the interactions, these two determinations may not be in perfect agreement with each other or with that made by an analysis of variance. Some experience has indicated that the average of these two determinations is a useful estimate of the main effect.

Finally, we compute the residual dispersion. We had determined it in combination with each main effect. We now know these main effects, we subtract them out and average the three remaining determinations to obtain an estimate of the residual dispersion.

So far we have ignored the interactions. We have no numerical values for them, such as the analysis of variance gives. But at each stage of our analysis we will have computed control-chart limits for all the subgroup and secondary ranges and averages mentioned, and for the secondary group averages, $\bar{X}_g$ in column $h$ and $\bar{X}_m$ in column $k$. Outages in our ranges tell us which interactions are significant just as outages in our averages tell us which main effects are significant.

These interactions may be shown by a mass chart of outages, as in Table II. Here, in Part A, are all the subgroup ranges $R_e$ of column $e$. This table is a rectangular array with the ranges for one set of tubes in one column and the ranges for another set of tubes in another column. That puts the ranges for one set of resistors in one row and the ranges for another set of resistors in another row. Part B is a similar table for the averages of column $f$.

### Table II

**Mass Chart of Outages**

(From an experiment similar to that outlined in Table I.)

**A. Ranges for 7 Voltages**

<table>
<thead>
<tr>
<th>Tubes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>$R_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistors</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**B. Averages for 7 Voltages**

<table>
<thead>
<tr>
<th>Tubes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>$R_m$</th>
<th>$\bar{X}_g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistors</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^1$ = Values above upper limits. — = Values below lower limits.

Now this is to be a study of outages. So, on these charts, we write no numerical values. If a range or average is within limits we leave a blank. It is outside limits and high, we write a short vertical bar. If it is an outage and low, we write a short horizontal bar. On work sheets, we can use blue circles for high values and red circles for low values.

The data for Table II were taken from an experiment that had nothing to do with amplifiers. It has been relabeled to fit the hypothetical example of Table I. There were eleven sets of tubes, ten sets of resistors, and measurements were made at seven different voltages.

Part A shows a large number of range outrages for
In Part B, showing outages of averages, we see that the higher-numbered tubes give higher gain and that the lower-numbered resistors give lower gain. These are main effects.

It has been mentioned that data of this type could be studied by the analysis of variance. The control-chart method has its advantages. For one thing, it requires less work. Some experience indicates that the control chart method takes less than half the time required for an analysis of variance.

More important is the ability of the control chart to pinpoint troubles and to test the validity of the assumptions made.

A large number of outages on our control charts, arranged in some logical pattern, gives us good indication of both the existence and the nature of real differences or real interactions. A fair number of outages, scattered over the whole experiment in an irregular fashion, usually indicates poor experimentation—sloppy work. A small number of outages, particularly if they can be traced back to a few pieces of primary data, indicates that these observations were abnormal—"wild shots."

The analysis of variance assumes a stable residual dispersion and then forgets it. The control chart sets a trap for instability and waves a red flag when it appears. The analysis of variance assumes that certain interactions are possible and ignores all others. The control chart method makes an initial assumption of no interaction and then highlights any interaction that comes along.

The control chart continually invites us to examine the quality of our experimentation and furnishes us with the means for making that examination.

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**Statistical Evaluation of Life Expectancy of Vacuum Tubes Designed for Long-Life Operation**

**ELEANOR M. McELWEE†**

*Summary—Life-test data on subminiature vacuum tubes designed for 5,000 hours are analyzed statistically and an equation is derived for the curve of life survival percentages. Correlation of individual types to the general curve is found to be extremely high. Controls are determined for normal 500-hour life tests which assure rated long-life quality and are presented as a method for evaluating life expectancy before completion of long-life tests. Life test samples of lots of tubes released by this 500-hour plan were continued in operation for 5,000 hours, and the results are shown to be satisfactory.*

**In Recent Years,** the expanding field of industrial applications of vacuum tubes has contributed to an increased demand for greater reliability over a longer period of time. As in response to this demand, engineers throughout the industry have attempted to design a line of electron tubes which might safely be rated far beyond the customary 500 hours used to evaluate the life of radio receiving tubes. The innovations in design and processing which produced the longer-life tubes, although undoubtedly of tremendous interest, are not within the scope of this paper. The problem with which we are concerned is one introduced by the development of such tubes—that of evaluating "long-life" quality within a reasonable length of time. It is obviously impractical for tube manufacturers to conduct life tests for 5,000 hours before release of lots of tubes, or for customers to wait seven to eight months for delivery. The efforts of many engineers were therefore applied to the search for a life test plan which would effectively measure 5,000-hour quality within the normal 500-hour life test period.

The life of a vacuum tube is commonly understood to be the length of time it will operate within a specified range of characteristics. Thus a tube is considered to have reached the end of life when it becomes inoperable for any reason, or when its characteristics fall outside the end point limits specified for the particular type. The normal life rating of 500 hours did not guarantee, however, that each tube had a minimum life of 500 hours, nor even that the average life of a group of tubes would be 500 hours. As defined in the JAN-1A specification, a 500-hour rating guarantees an aggregate useful life of at least 80 per cent of the total rated life. For example, a group of five tubes would have a total rated life of 2,500 tube hours. These tubes would pass the JAN specification if their total operation within specified limits was 2,000 tube hours or better. This total figure could be amassed in any one of a number of ways; e.g., by all tubes operating for 400 hours, by one failure immediately and four good to 500 hours, by two tubes good to 250 hours and three good to 500 hours, and so on. What is actually required is an average life of at least 80 per cent of the rating for any group of tubes life-tested for...
the specified time. For the purpose of better understanding of this paper, it will be assumed that a 5,000-hour life rating is applied in the same manner; i.e., that the 80 per cent limit will apply to a 5,000-hour, rather than a 500-hour test point, and that the average life of any group of tubes must be at least 4,000, rather than 400 hours.

It was apparent in the beginning that there were two approaches to the problem of a shorter life test: (1) an accelerated test which would be equivalent to 5,000 hours of normal operation, or (2) statistical controls on a normal 500-hour life test which would adequately predict 5,000-hour quality. Considerable time and effort were expended in the attempt to set up a reliable accelerated test. Various changes were made in voltages, currents and/or power dissipations in the hope of discovering a test exactly ten times as rigorous as normal operation. Unfortunately, it was impossible to determine test conditions which would accelerate normal tube failures without introducing contributory factors not present in normal operation. Several tests were found satisfactory for individual types of failures; e.g., cycling tests to determine the quality of heaters, immersion test for air leaks, fatigue test for shorts or poor welds, etc. However, it remained impossible to obtain satisfactory correlation between emission deterioration resulting from any accelerated test, and that resulting from normal operation. Consequently, the emphasis was transferred to statistical analysis in the hope of determining a consistent pattern to which the quality control method could be applied.

The first step in the statistical analysis of data was logically a survey of the occurrence of failures in operation with relation to time. In order to include results on as many tubes as possible, the initial survey was made on life test samples of early subminiature indirectly heated cathode-type vacuum tubes, rated for normal 500-hour operation. Failures per 500-hour period were listed for a heterogeneous group of 1,864 vacuum tubes, and the average life percentage1 at the end of each period was calculated in accordance with the JAN specification, as shown in Table I. The ratio between these percentages seemed to indicate that they would follow the exponential curve \( y = ab^x \), where \( y \) = average life percentage, \( x \) = hours of life expressed in thousands of hours, and \( a \) and \( b \) are constants denoting the \( y \) intercept and the slope of the line, respectively. In order to determine the goodness of fit of the empirical curve \( y = ab^x \), or the straight line \( \log y = \log a + x \log b \), the

1 Average life percentage at \( X \) hours = \( \sum (\text{life hours for each tube}) / X \) (number of tubes started) \times 100.

E.g., if 5 tubes were started on life, one failed at 700 hours, 4 remained good past 1,000 hours, the average life percentage at 1,000 hours would be

\[ \frac{3(1000)}{7(1000)} \times 100 = 94 \text{ per cent.} \]

2 The life for any individual tube shall be a maximum of \( X \) hours.

By substituting the given values of \( x \), computed values of \( y \) are obtained, and \( y \) residuals are found by subtraction. From the statistical formula for the standard error of estimate,

\[ S_y = \frac{\sum (y \text{ observed} - y \text{ computed})^2}{\text{the number of observations}} \]

\[ S_y = (4.05406)^{1/2}. \]

The index of correlation of the curve is determined by the formula

\[ \rho_{xy} = \left(1 - \frac{S_y^2}{\sigma_y^2}\right)^{1/2}, \]

where \( S_y \) is the standard error of estimate of the curve, and \( \sigma_y \) is the standard deviation of the observed values of \( y \). Substituting,

\[ \rho_{xy} = \left(1 - \frac{4.05406}{173.333}\right) \]

\[ \rho_{xy} = 0.988. \]

The high degree of correlation obtained was a positive indication that the empirical equation \( y = ab^x \) was a close representation of these data, at least. In order to verify the results of this first experiment, the same method was followed with two additional groups of data. For a group of 1,240 vacuum tubes of various types, most of which were experimental tubes designed for a longer life rating, the calculated curve was \( y = 98.2 (0.966)^x \). The index of correlation with observed data was 0.998. For a group of 130 tubes of six types released as 5,000-hour tubes, the equation of the calculated curve was \( y = 98.3 (0.973)^x \); the index of correlation was 0.995. Both the observed data and the calculated curve are plotted for each group in Fig. 1.

With the acceptance of the curve $y = ab^x$ as a general pattern for life survival percentages, there remained two essential points to be determined: (1) Could a universal value of the constant $a$ be assumed that would satisfy all types of tubes? (2) If the value of the constant $b$ were calculated from observed 500-hour results, how closely would the predicted percentages approximate actual life test operation? The answer to the former question at first seemed evident. Since only good tubes are subjected to life test, it was assumed that the $y$ intercept of the curve would be 100 per cent, and therefore the equation would be $y = 100b^x$. Accordingly, the equation was checked with observed data, but it was noted that actual life test results beyond 1,500 or 2,000 hours were in all cases better than predicted percentages. Further analysis of data revealed that the rate of failure during the first 500-hour period of operation was higher than the rate of failure for any succeeding 500-hour period. The data seemed to indicate, in fact, that the rate of failure beyond 500 hours would be fairly constant, and would be approximately half that of the first 500-hour period. To compensate for this phenomenon, it was decided to use the value 99 for the constant $a$. In order to check the validity of predicted percentages, the same groups of data used previously were checked with percentages calculated from the equation $y = 99b^x$, the value of $b$ being determined in each case by the observed 500-hour results. The correlation indices for the three groups were 0.975, 0.996 and 0.948, respectively. Curves for all three groups are plotted in Fig. 2. As an additional check on the general fit of the curve $y = 99b^x$, several types of 5,000-hour tubes were analyzed for correlation between observed data and the straight line based on the 500-hour percentage for each type. The index of correlation with the straight line was 0.986 for triode oscillators, 0.968 for radio-frequency pentodes and 0.976 for audio and video power amplifiers. Observed and calculated curves for each type are shown in Fig. 3.

![Fig. 2](image2.png)

![Fig. 3](image3.png)

Fig. 2—Life survival curves: 5,000-hour tubes. Curves showing correlation of observed and calculated percentages for three heterogeneous groups of tubes.

Fig. 3—Life survival curves: 5,000-hour tubes. Curves showing the correlation of observed and calculated percentages for several types of Premium Subminiature Tubes. Life-test conditions for types indicated were as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>500</th>
<th>150</th>
<th>100</th>
<th>500K</th>
<th>117Vrms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ef</td>
<td>6.3</td>
<td>110</td>
<td>270</td>
<td>110</td>
<td>500K</td>
</tr>
<tr>
<td>Rk</td>
<td></td>
<td>150</td>
<td>100</td>
<td>100</td>
<td>500K</td>
</tr>
<tr>
<td>Ec2</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>1 meg</td>
</tr>
<tr>
<td>Rg</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>117V</td>
</tr>
<tr>
<td>Ehh</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>117V</td>
</tr>
<tr>
<td>audio beam power tube</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>117V</td>
</tr>
<tr>
<td>video amplifier</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>117V</td>
</tr>
<tr>
<td>sharp cutoff pentode</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>117V</td>
</tr>
<tr>
<td>semi-remote cutoff pentode</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>117V</td>
</tr>
<tr>
<td>high mu triode</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>117V</td>
</tr>
<tr>
<td>low mu triode</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>117V</td>
</tr>
</tbody>
</table>

The correlation between predicted percentages and actual results was in all cases so high that the equation $y = 99b^x$ was accepted as the basis for all future statistical controls to be applied to life tests. This pattern of failure was a definite departure from the normal curve expected, and posed additional problems in the development of statistical controls. Earlier experience with incandescent and fluorescent lamps, and with tungsten filament-type vacuum tubes, indicated a certain wear-out point around which regular sigma limits could be plotted, as on a normal Gaussian type curve. A recent

![Fig. 4](image4.png)

Fig. 4—Life failure curve for fluorescent lamps. Fluorescent lamp life data plotted as a normal Gaussian type curve.
advertising bulletin for improved fluorescent lamps showed this type of curve plotted for failure percentages, with the average life marked at 7,500 hours, and standard deviations of 1,000 hours counted off on either side, as in Fig. 4. With such data, engineers can plan on a minimum life for each lamp, or an optimum replacement point for any group of lamps. Manufacturer's advertisements recommend the replacement of panels of lamps after 5,500 hours, a point at which a maximum of 2.5 per cent of the lamps will have failed. The 20 per cent, or 50 per cent, or 90 per cent failure points could be located just as easily.

Unfortunately, failure data for subminiature vacuum tubes do not follow a normal distribution, and conventional measures of central tendency and dispersion are not applicable to the problem of determining proper control limits. Therefore, it became necessary to devise a system of controls which might be applied to the exponential curve \( y = 99b^x \).

The first step in the process of setting up controls was to determine, from the 80 per cent—5,000 hour specification and the calculated \( y = 99b^x \) curve, a minimum limit to be applied at 500 hours. This 500-hour percentage was found to be 96.9 per cent. Then from accumulated data on subminiature tubes, 133 sample life tests of five tubes each were chosen which passed this 96.9 per cent—500-hour limit. Of these tests, not one failed to meet an 80 per cent—5,000-hour limit at the conclusion of the specified life test. These results led naturally to the conclusion that the minimum limit calculated was well chosen, and that the modified 500-hour test would serve as an adequate control on 5,000-hour quality.

Although the choice of a 500-hour limit was the solution to the original problem, it raised a new question of equal importance to manufacturer and customer. This new topic was the probability of release of a lot of tubes which would fail to meet the 5,000-hour life specification. In order to calculate the range of probability of such an occurrence, the five-tube sample life tests mentioned above were used to plot a frequency distribution of 5,000-hour percentages, as shown in Fig. 5. The average 5,000-hour percentage was found to be 89.4 per cent, with 2-sigma limits of 80.3 per cent and 98.5 per cent. These limits on the sample distribution were changed to limits on the universe or parent population by use of the formula

\[
\sigma_{\text{sample}} = \left( \frac{N - 1}{N} \right)^{1/2} \sigma_{\text{universe}}
\]

resulting in new 2-sigma limits of the universe of 80.1 per cent and 98.7 per cent. Statistically speaking, 95 per cent of all released lots of tubes will fall within these limits. Conversely, 2.5 per cent of all released lots may fall on either side of these limits. To use a phrase common to all fields in which quality control is applied, it seems safe to assume an acceptable quality level (AQL) of 2.5 per cent at 5,000 hours.

It would not be reasonable to assume that this life test plan will work equally well for all types of vacuum tubes, made by various manufacturers, until sufficient data to 5,000 hours has been collected and analyzed. The data included in this paper represent only subminiature indirectly heated cathode-type vacuum tubes made at the Kew Gardens Development Laboratory of Sylvania Electric Products Inc. Whether other tube types, or even the same types manufactured elsewhere, would produce equivalent results is a question which only the comparison of actual data will answer. Experience shows that the plan may be applied only to tubes which are designed for long-life operation, are conservatively rated, and are carefully controlled during production. To the writer's knowledge, there has been only one other published indication of an exponential curve of life percentages versus time, a life curve on repeater tubes published by the Bell Telephone Laboratories. It is to be hoped that long-life data may be collected throughout the industry, and that universal life test specifications may be agreed upon by manufacturers and customers. The 500-hour test specification included in this paper was developed with the co-operation of the Bureau of Ships, the chief customer for the tube types represented, and was accepted by them for these particular types as manufactured in Kew Gardens, L. I., N. Y.

There remains one important point not yet mentioned: what kind of guarantee can be given to the customer? What will the manufacturer do if a group of tubes fails to meet the specified life rating in actual operation? Unfortunately, there is no satisfactory answer as yet. For subminiature long-life tubes, there are certain applications, such as hermetically sealed assemblies, where replacement of tubes is impossible. In many other applications for which subminiature tubes have been specially designed, replacement is difficult and expensive. In some cases, the failure of a tube may

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cause the destruction of the entire unit. What the customer requires, therefore, is not a replacement guarantee for tubes which prove unsatisfactory, but a certain degree of assurance of reliability of operation. The plan proposed is an illustration of the application of statistical analysis to this difficult quality control problem. Although this plan may not be the perfect answer to the customers' requirements, it is a step in the right direction. It is at least a foundation for future improvements.

**BIBLIOGRAPHY**


### Magnetic Recording with AC Bias*

R. E. ZENNER†, SENIOR MEMBER, IRE

**Summary**—The function of alternating-current (ac) bias in magnetic recording is analyzed in a manner similar to that used to explain amplitude modulation. Certain simplifying assumptions are made to facilitate manipulation of mathematical expressions. The analytical results are compared with experimental observations of harmonic distortion, amplitude of fundamental, spurious recorded frequencies, frequency response, difficulty of erasure, and the like.

**INTRODUCTION**

In a modulator for amplitude modulation (AM) radio transmission, an audio frequency and a much higher "carrier" frequency are combined in a nonlinear impedance. The output contains the two original frequencies, their sum, their difference, certain harmonics of each depending upon the character of the nonlinear impedance, and sums and differences of harmonics and fundamentals. A value of carrier amplitude must be selected for the particular nonlinear element to provide linearity and sufficient output in the desired band, which includes the carrier frequency and the carrier-audio sum and difference frequencies. A bandpass filter (tank circuit) is provided to attenuate undesired frequencies. The need for selecting a particular carrier amplitude is most obvious in the case of grid modulation.

In like manner, the action of alternating current (ac) bias in magnetic recording may be explained. The desired audio frequency and a much higher "bias" frequency are simultaneously fed into a nonlinear recording system. The recording contains the audio frequency, the bias frequency, and in addition to these, certain harmonics of each, and sums and differences of harmonics and fundamentals. A value of bias amplitude must be selected for the particular nonlinear recording characteristic to provide linearity and sufficient output in the desired audio band. Self-demagnetization in the recording medium and limited playback head resolution provide a low-pass filter which attenuates undesired (higher than audio) frequencies.

With the shapes of nonlinear recording characteristics in general use, this "bias" technique provides greatly reduced harmonic distortion of the audio, as compared to direct current (dc) bias or no bias.

This technique is capable of improving linearity of response for desired frequencies in a variety of nonlinear systems, whether for transmission or recording.

**SCHEME FOR ANALYSIS**

The transfer characteristics for a magnetic recording material is the $B_{II}$ curve, (see Fig. 1). Such a curve may be plotted from data taken by single dc exposures or from data taken in the symmetrically cyclically magnetized condition (SCMC). Curves plotted in these two ways are very similar, though not identical. A convenient set of measuring equipment for the SCMC case has been described by Wiegand and Hansen.*

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In a practical magnetic recorder, each element of length of the recording medium is subjected to substantially a single value of audio field and to several decaying cycles of bias field. The similarity of single exposure and SCMCI $B_r-H$ curves permits us to assume that each element of length of the recording medium is subjected to a single instantaneous value of both audio and bias. We shall later discuss phenomena inconsistent with this assumption.

It would be desirable to find an expression $B_r = F_i(H)$ which closely fits the $B_r-H$ curve, assume constant velocity of the recording medium, set in $H = F_0(t)$, and manipulate the resulting equation into forms which can be physically interpreted.

An expression which provides a good fit is

\[ B_r = \frac{2B_{r0}}{\pi} \left( \tan^{-1} K_1H - K_1He^{-K_2H} \right). \]

However, this expression is quite resistant to a desired kind of manipulation, so we resort to a series,

\[ B_r = -K_1H + K_2H^3 - K_3H^5. \]  

(1)

Fits provided by two and three terms are illustrated in Figs. 2 and 3. Use of more terms should improve the fit, but the difficulties of manipulation then become severe. In the following, the general expressions are now and then reduced to numerical values for the particular curves shown in order to insure that conclusions drawn are limited to the regions of reasonably good curve fits.

**Case I. Ac Bias**

Assuming a sine wave of audio, $A \sin at$, and a sine wave of bias,

\[ B \sin bt \]

we let $H = A \sin at + B \sin bt$  

(2)

and substitute this in (1).

\[ B_r = -K_1[A \sin at + B \sin bt] + K_2[A \sin at + B \sin bt]^3 - K_3[A \sin at + B \sin bt]^5. \]  

(3)

To simplify notation let $X = A \sin at$ and $Y = B \sin bt$, then

\[ B_r = -K_1[X + Y] + K_2[X^3 + 3XY + 3Y^2 + Y^3] - K_3[X^5 + 5X^4Y + 10X^3Y^2 + 10X^2Y^3 + 5XY^4 + Y^5]. \]  

(4)

The following identities are useful:

\[ A^3 \sin^3 at = \frac{3 \sin at - \sin 3at}{4}; \]

(5)

\[ B^3 \sin^3 bt = \frac{3 \sin bt - \sin 3bt}{4}; \]

(6)

\[ A^5 \sin^5 at = \frac{\sin 5at - 5 \sin 3at + 10 \sin at}{16}; \]

(7)

\[ B^5 \sin^5 bt = \frac{\sin 5bt - 5 \sin 3bt + 10 \sin bt}{16}; \]

(8)

\[ A^2B \sin^2 at \sin bt \]

= \[ \frac{\sin bt}{2} - \frac{1}{4} \left[ \sin (2a + b)t - \sin (2a - b)t \right]. \]

(9)
Zepper: Magnetic Recording with AC Bias

Although it is not desirable, a recorder might be designed for an upper audio limit of 15,000 cps (a = 2π × 15,000) while using a bias frequency of 40,000 cps (b = 2π × 40,000). Visualizing such values, we may now inspect the above identities to see what terms occur in the audio region. Self-demagnetization and limited playback resolution will attenuate short wave lengths (high frequencies) and permit us to drop such terms, provided we have chosen an appropriate recording medium speed.

We can see that angular frequencies a, 3a, 5a, (b−2a), and (b−4a) fall in the audio range. If we had chosen a higher bias frequency, say 80,000 cps, the last two difference frequencies would be outside the audio band and therefore negligible. Practical design experience has also shown that a bias frequency at least 5 times the highest audio frequency admitted to the recording head is desirable to avoid distortion from audible beat frequencies. Slightly lower bias frequency may be satisfactory if the recording current amplitude is very small at the upper audio frequencies, as is often true in sound recording.

Let us now decide to use a bias frequency sufficiently high to make these beat notes negligible. Then our expansion of B, contains terms in a, 3a, and 5a.

\[ P_r = - \frac{1}{16} \left\{ \frac{5.1^2K_3}{4} + \frac{5.1^3B^2K_3}{4} - \frac{5.1^4K_3}{4} \right\} \sin 3at \]

which indicates that the amount of bias for zero third harmonic varies with audio amplitude, decreasing as the audio increases.

\[ C_{na} = 0 \]

\[ 5.1^2K_3 + \frac{5.1^3B^2K_3}{4} - \frac{A^2K_3}{4} = 0 \]

\[ 20K_3B^2 = 4K_2 - 5A^2K_3 \]

\[ B^2 = \frac{K_2}{K_3} - \frac{A^2}{4} \]

\[ A \rightarrow 0, B^2 \rightarrow \frac{K_2}{5K_3} \text{ or } 0.2 \frac{K_2}{K_3} \]

\[ B = 200 \text{ oersteds for the material shown in Fig. 3, which is in the region of a reasonable curve fit.} \]

It is also of interest to note that the sign of \( C_{na} \) reverses as B increases from near zero to above the value for \( C_{na} = 0 \).

Let us now investigate \( C_a \), seeking a maximum value.

\[ C_a = - 1.4K_1 + \frac{3.1^2K_3}{4} + \frac{3.1^3B^2K_3}{4} - \frac{5.1^4K_3}{8} \]

\[ \frac{dC_a}{dB} = 3ABK_3 - \frac{15}{2} \frac{A^2B^2K_3}{2} - \frac{15}{2} \frac{A^3B^3K_3}{2} \]

when \( d(C_a)/dB = 0 \) (disregarding root at \( B = 0 \))

\[ 15B^2K_3 = 6K_2 - 15A^2K_3 \]

\[ B^2 = 0.4 \frac{K_2}{K_3} - \frac{A^2}{K_3} \]

which indicates that the amount of bias for maximum \( C_a \) decreases when A increases. When \( A \rightarrow 0 \),

\[ B^2 \rightarrow 0.4 \frac{K_2}{K_3} \]

\[ B = \sqrt{0.4 \frac{K_2}{K_3}} \]

which is \( \sqrt{2} \) the value of B for \( C_{na} = 0 \).

\( B \approx 284 \text{ oersteds for the material of Fig. 3.} \)

If we had chosen to drop the fifth order term from (1), we would have

\[ B_r = - K_1H + K_3H^3 \]

\[ \frac{dB_r}{dH} = - K_1 + 3K_2H^2 \]

\[ \frac{d^2B_r}{dH^2} = 6K_2H^2 \]

The only inflection point is at \( H = 0 \), and the saturation phenomenon is not represented. Applying the sub-
stitution $H = A \sin at + B \sin bt$, we get an expression for $B_r$ involving fewer angular frequencies than in the fifth-order case. Assuming a high bias frequency and low pass filtering, we get
\[
B_r = \left[ -A K_1 + \frac{3}{4} A^2 K_2 + \frac{3}{2} A B^2 K_2 \right] \sin at
- \frac{A^3 K_2}{4} \sin 3at.
\]

(21)

If we seek a value for zero third harmonic, we find it only at $A = 0$, which is a trivial result. When we seek the value of $B$ for maximum fundamental, we find it at $B = \pm \infty$, which is due to failure to include the saturation phenomenon.

It is, therefore, apparent that at least 3 terms of (1) must be taken into account to get physically significant results.

Case II. No Bias Compared to Ac Bias

If the signal is only audio, $H = A \sin at$, we have from (1)
\[
B_r = -K_1 a \sin at + K_3 A^3 \sin^3 at - K_3 A^3 \sin^3 at
\]
(22)
or
\[
B_r = -K_1 a \sin at + K_3 A^3 \frac{3 \sin at - \sin 3at}{4}
- \frac{K_3 A^3}{16} \sin 5at - 5 \sin 3at + \sin at
\]

(23)

Comparing this with (15), we find all terms common except those involving $B$ in (15). Using ac bias as against no bias, $C_a$ is increased in the case of ac bias by the addition of the quantity
\[
\left( \frac{3}{2} A B^2 K_2 - \frac{15}{4} A^2 B^2 K_3 - \frac{15}{8} A B^4 K_3 \right)
\]

and $C_{a3}$ is increased by the addition of $(5/4) A_3 B^3 K_3$. In order for any benefit to result from the use of ac bias, an improvement in linearity must result, that is, $C_a$ must be more nearly proportional to $A$. This will occur if the value of terms in $C_a$ which involve $A^3$ or $A^3$ are reduced by the use of bias.

Let us test
\[
\frac{3}{4} K_2 A^3 = \frac{15}{4} B^3 K_3 A^3
\]

(24)

This value of $B$ will eliminate the $A^3$ term from $C_a$, and it is the value of bias for zero third harmonic when $A = 0$, deduced in (17). Assuming this value of bias, we have
\[
C_a = -A K_1 + \frac{3}{4} A^2 K_2 + \frac{3}{10} A K_2^2 - \frac{5}{8} A^3 K_3
\]

\[
- \frac{3}{4} A^3 K_2 - \frac{3}{40} A K_3^2
\]

(25)

It appears that good linearity and high sensitivity with ac bias will result if $K_3$ is very small compared to $K_2$, and if $K_1$ is small compared to $K_3^2 / K_3$. However, as $K_3$ decreases, the bias required increases.

It seems probable that a seventh-order equation would provide a term involving $BA^3$ which would reduce the $A^3$ term in $C_a$.

Case III. Dc Bias on a Neutral Medium

If the signal is audio plus a dc bias, $H = D + A \sin at$, and
\[
B_r = -K_1[D + A \sin at]
+ K_3[D + A \sin at]^3
- K_3[D + A \sin at]^3
\]

(26)

or
\[
B_r = -K_1[D^3 + 3AD^2 \sin at + 3A^3 \sin^2 at + A^3 \sin^3 at]
- K_3[D^3 + 3AD^2 \sin at + 10A^3 \sin^2 at
+ 10D^3 \sin^3 at + 5DA^3 \sin^4 at + A^4 \sin^5 at].
\]

(27)

The following additional identities are now useful:
\[
\sin^2 at = \frac{1 - \cos 2at}{2},
\]

(28)

\[
\sin^4 at = \frac{1}{8} (3 - 4 \cos 2at + \cos 4at).
\]

(29)

Substituting in (26),
\[
B_r = -K_1[D - K_2 D^2 + \frac{3}{2} K_3 D^2 A^2 - K_3 D^3]
- 5K_3 D^3 \sin^3 at - \frac{15}{8} K_3 DA^4
\]

\[
+ \left[ -K_1 + 3K_2 D^2 A + \frac{3}{4} A^3 K_2 - 5K_3 D^4 A
- \frac{15}{2} K_3 D^2 A^3 - \frac{5}{8} K_3 A^5 \right] \sin at
\]

\[
+ \left[ -\frac{3}{2} K_2 D^2 \sin at + 5K_3 D^3 A^2 + \frac{5}{2} K_3 DA^4 \right] \cos 2at
\]

\[
+ \left[ -\frac{A^5 K_2}{4} + \frac{5}{2} K_3 D^2 A^3 + \frac{5}{16} K_3 A^5 \right] \sin 3at
\]
The condition for \( C_{2a} = 0 \) is
\[ \frac{3}{2} K_3 D^2 + \frac{5}{2} K_4 A^2 = \frac{K_1}{4}, \tag{31} \]
\[ D^3 = \frac{3K_2 - 5K_4 A^2}{10K_4}, \tag{32} \]
which indicates that the value of dc bias for zero second harmonic varies with audio amplitude.
\[ \text{As } A \to 0, \quad D^3 \to \frac{3K_2}{10K_4}. \tag{33} \]
This is the inflection point of (1), or \( D = 245 \) oersteds, for the material shown in Fig. 3.

The condition for \( C_{3a} = 0 \) is
\[ \frac{5}{2} K_3 D^2 + \frac{5}{2} K_4 A^2 = \frac{K_1}{4}, \tag{34} \]
\[ D^3 = \frac{4K_1 - 5K_4 A^2}{40K_4} \quad (D \text{ for zero third varies with } A) \tag{35} \]
as \( A \to 0 \), \( D^3 \to (-K_2/10K_4) \) so that \( D \) differs by a factor of \( \sqrt{3} \) from the value of \( D \) for \( C_{3a} = 0 \), indicating that no one value of dc bias minimizes even and odd harmonics. However, no spurious beat frequencies are encountered as in ac bias.

This analysis does not apply directly to the use of dc bias on previously saturated recording medium. Equation (1) does not apply to this situation.

**Phenomena Consistent with the Analysis**

Fig. 4 shows some experimental data on amplitude and phase of third harmonic and fundamental as a function of bias amplitude, using a small constant value of audio current. The recording wire used in these experiments is the same as was used for the \( B_{\text{con}}-H \) curve shown in Fig. 1. The following points of agreement between the data of Fig. 4 and the analysis are found:

1. The change in sign of the third harmonic as ac bias is increased, and the existence of a value of ac bias which provides zero third harmonic.
2. The existence of a maximum value for the coefficient of the fundamental at an ac bias amplitude higher than that required for zero third harmonic.

Other experimental work, the following additional points of agreement with the analysis have been found:

3. The existence of beat notes between the ac bias frequency or its harmonics and harmonics of high audio frequencies. The frequencies \( (b-2a) \), \( (b-4a) \), and \( (2b-5a) \) have been identified. The last of these would appear in the analysis if a seventh-order series were used for (1).

4. The change with audio amplitude of the value of ac bias required for maximum amplitude of fundamental.
5. The change with audio amplitude of the value of ac bias required for zero third harmonic.
6. The occurrence of even-order harmonics in the presence of dc bias, dc bias may be a result of direct current in the recording head, or residual magnetization in the recording head or residual magnetization in the medium as it reaches the recording head.
7. The improvement in linearity with appropriate amplitude of ac bias.

**Some Phenomena Inconsistent with the Assumptions or Outside the Scope of the Analysis**

1. **Frequency Response**

   The analysis offered does not show that relative high-frequency response falls off more rapidly in the case of ac bias than with dc bias on neutral medium. This does occur, however, and it is ascribed to an erasing or aging action in the case of ac bias. An element of length of the medium is exposed to several decaying ac cycles. This is more effective in reducing the amplitude of short wavelengths than in reducing the amplitude of long wavelengths. Short magnets are more easily demagnetized than long magnets. This aging action is desirable in that the recording is more stable if ac bias is used.

   **2. Difficulty of Erase**

   Nothing in the analysis ascribes a different quality to a \( B \), achieved with small audio and large ac bias than to
the same value of \( B \), achieved with larger audio and less ac bias. Herr, Murphy, and Wetzel\(^1\) have shown that the signal resulting from small audio and large bias is the more difficult to erase. In the charging of permanent magnets for meters and transducers, it is found that more stable (more difficult to demagnetize) magnets result from initially saturating the magnet with dc, and then \("\)aging\) it down to the desired \( B \), with ac fields, than by only exposing it to sufficient dc to bring it up to the desired \( B \), from the demagnetized condition. This is analogous to the results described by Herr, Murphy, and Wetzel.

3. Even Harmonics Resulting from Asymmetry of Bias Wave Form

The analysis does not account for even harmonics resulting from asymmetry of the bias wave form. Textbooks on magnetic phenomena describe the fact that the residual induction in a piece of iron which has been exposed to a varying unidirectional field is determined by the peak value of the field, independent of the time variations of the field.

Thus, so far as the recording process is concerned, asymmetrical bias wave form has a dc effect, even when there is no dc component in the bias field itself. The field has zero dc component if the area bounded by the curve on each side of zero is equal. The recorded effect is quite independent of this area, and sensitive to peak values. Quantitative evaluation of this phenomenon is complicated by the fact that ac bias swings past zero, into the opposite polarity.

4. Variation of Bias with Wavelength

From the analysis presented it would appear that for small audio amplitudes, maximum fundamental amplitude and zero third harmonic appear at particular values of bias, independent of audio frequency or wavelength. This is not true, actually, for at very short wavelengths no appreciable third harmonic is apparent at any level of bias, because of low pass filtering effects (self-demagnetization, playback gap effect, eddy current effects, and electrical circuit filtering effects). At frequencies well below the frequency of maximum response, the third harmonic is accentuated in playback due to rising frequency response. Playback voltage is proportional to the rate of change of \( B \), rather than proportional to \( B \) itself, thus producing rising frequency response in the range of wavelengths which suffer little, or constant, self-demagnetization.

Erasing or aging effectiveness of the bias is also greater at short wavelengths.


5. Decrease of Distortion at Large Bias Amplitudes

The analysis presented does not account for the decrease in distortion at bias amplitudes larger than that at point \( F \) in Fig. 4. High bias values are outside the region of good fit of even the fifth-order series. It is believed that, if many more terms were used, this decrease in third harmonic would appear.

Optimum Bias Frequency

For thin recording wires and tapes, it is desirable that the bias frequency be as high as practical considerations will permit. In designing a recorder, one usually wishes to use the same oscillator for erase and bias. Eddy current losses in the erase head cause the designer to consider the use of low erase-bias frequencies. The designer usually decides upon an erase-bias frequency slightly lower than five times the upper audio limit of his system as the best compromise.

Optimum AC Bias Amplitude

It has been shown that the bias amplitudes for maximum fundamental output and zero third harmonic are not the same, and further that the bias amplitudes for maximum fundamental and zero third harmonic vary with audio amplitude. Also, the bias amplitude for any of these conditions varies with the magnetic materials and geometries of heads, tapes, and wires. Thus it is not surprising that there should be a variety of schemes favored by various people for setting the bias amplitude. For low-cost, low tape-speed equipment, designers often set the bias amplitude for maximum sensitivity at short wavelengths, tolerating the accompanying distortion of long waves on the tape. In such equipment the harmonic distortion in the recording process is often negligible compared to the distortions present in the amplifier.

In high-cost, high-quality equipment, a larger bias amplitude is usually favored. This is much greater than the bias for zero third harmonic at medium and high audio frequencies, and is in the region of low distortion to the right of point \( F \) in Fig. 4. Operation in this region provides low distortion at all wavelengths and some reduction of relative playback amplitude at short wavelengths. The latter is corrected by the use of a sufficiently high tape speed and suitable equalizer circuits.

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Representations of Speech Sounds and Some of Their Statistical Properties*

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Summary—Spectrographic analysis, autocorrelation, and infinite clipping are considered as methods of transforming and analyzing speech sounds with the object of obtaining simple representations without excessive loss of intelligibility. Although not mathematically equivalent in the exact sense, these methods when properly approximated are shown to provide parameters of statistical nature that are simply related. It is conjectured that the parameters describe some essential elements of speech sounds and are statistically invariant. Some experimental results are included.

THERE HAS ALWAYS BEEN a need of pictorial or other physical representation ever since man began to analyze speech sounds. The objective may be twofold. One is to find an accurate representation so that every detailed characteristic of the original sound, including naturalness and emotional content, is retained. The other is to obtain as simple a representation as possible without excessive loss of intelligibility. This paper is concerned with the second type.

Speech compression and sensory replacement are two examples of the fields in which application can be made of the representations to be considered. There is considerable interest in both of these fields at the present time as evidenced by current literature and development work by the Bell Laboratories and others in the vocoder field; and RCA, Haskins Laboratories, and others in the sensory-replacement field.

A problem common to both fields is that of identifying the essential elements for intelligibility as distinguished from the redundant information contained in the original sound. It is conjectured that these essential elements are statistically invariant because of the structural similarity of vocal mechanisms and the tendency of speakers to conform through the process of learning. Names that have been suggested for these essential elements are "gesture," "articulation" and "modulation." The problem is to identify and extract them from the original speech sound.

It is the purpose of this paper to compare some methods of analyses and representations which are prevalent, and to attempt to derive therefrom some statistical parameters which may retain part of the invariant essential elements. One method would be to obtain the representation directly from the vocal or hearing mechanisms; for example, to take pictures showing the movements of the articulators (vocal chord, lips, tongue, and the like) or pictures, if possible, showing the responses of the tremendous number of auditory nerves. The anatomical and neurological techniques involved are, however, not quite within the reach of a communication engineer. This paper, therefore, will be confined to the acoustic aspects of speech sounds.

A commonly used visual representation of speech sounds is the oscillogram, or the intensity-time graph. The intensity may correspond to the pressure of the original sound or the voltage derived from a microphone. Experience with oscillograms indicates that while simple in appearance, they are very complicated in analysis. Therefore, before invariant elements can be obtained, it is necessary to transform the intensity-time function of the sound to a more suitable form. Since many sounds are periodic, it is natural to introduce the concept of frequency and the use of Fourier analysis, the representation in this case being the spectrogram. Some sounds, however, like fricatives, do not possess a high degree of periodicity; yet, they are not entirely random noise. Spectrographic representations of these sounds are not very satisfactory. Since speech sounds, including fricatives, possess a certain degree of continuity, the correlation between intensities of successive intervals is not insignificant. This type of


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correlation can be expressed by a plot of the autocorrelation function $\phi(\tau)$ versus $\tau$.$^{13,16}$ For purely random noise, $\phi(\tau)$ drops instantaneously as $\tau$ exceeds zero. For periodic functions, $\phi(\tau)$ varies with the same periodicity. For fricatives with hidden periodicity, $\phi(\tau)$ may fall rather rapidly, followed by small ripples. The spectrogram and the autocorrelationgram are two transforms of the oscillogram and have been considered previously by others.

A representation which heretofore has not received much consideration is clipped speech.$^{17}$ It is reported that high intelligibility is retained by replacing the original speech wave with rectangular waves having the same zero crossings. There are, of course, other types of representations, such as pulse-code sampling,$^{18}$ complex-frequency mapping,$^{19}$ and so forth; however, this paper is concerned with only the four types mentioned above because of the apparent feasibility of experimental attack.

Fig. 1 shows these four representations: the oscillo-

![Fig. 1](image)

gram, the spectrogram, the autocorrelation function, and clipped speech. Mathematically, if we denote the original sound by $f(t)$, the spectrogram is the Fourier transform of $f(t)$, denoted by $F(f)$. It contains information concerning both amplitude and phase. Under usual conditions, this transform is reversible as indicated by an arrow pointed both ways. This transform can be used in the direct sense $(-\rightarrow)$ for analysis, or in the inverse sense $(\leftarrow)$ for synthesis. The autocorrelation function $\phi(\tau)$ as shown is defined as the average of the product of the original function $f(t)$ and the function shifted in time $f(t-\tau)$. This transformation is expressed mathematically as

$$\phi(\tau) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{+T} f(t)f(t-\tau)dt.$$  \hspace{1cm} (1)

This function, having the dimension of power, can be proved$^{18}$ to be the Fourier transform of the power spectrum. Information about phase is not contained in $\phi(\tau)$ and, therefore, the transform is not reversible as indicated by the unidirectional arrow. In the case of clipped speech the transformation is inherently nonlinear, and no mathematical formulation is ventured here, except to assign the symbol $\tilde{f}(t)$ to the process. The two arrows pointed the same way indicate the very obvious unidirectional properties of the clipping transformation.

These four representations, although not mathematically equivalent in the exact sense, provide equivalent parameters after proper approximations have been made. These same approximations are necessary for the practical performance of the transformations. Fig. 2 shows the effects of these approximations. The part

![Fig. 2](image)
In the case of clipped speech, the approximation has already been considered. It consists of replacing the different intensity levels by only two fixed levels.

In summary, the approximations involved in modifying the three transformations are: (1) the lumping of frequencies in the case of the spectrogram; (2) the use of discrete intervals for autocorrelation time \( \tau \); and (3) the use of only two fixed amplitude levels for intensity in the case of clipped speech. Although these approximations involve three different domains—frequency, time, and intensity—it is felt that if they are carried far enough, the results would probably retain about the same amount of information. Licklider and Pollack have shown experimentally that clipped speech retains a high degree of intelligibility. For this reason, and for simplicity, it is appropriate to begin with clipped speech in showing the equivalence of the three transformations.

If the spacing between zeroes is fairly constant in a short interval of time \( \Delta t \) (e.g., of the order of 1/100 second) further simplification is possible. This involves defining a new function \( \rho_0 \) giving the average number of zero crossings in the interval \( \Delta t \) (or the zeroes per second). Licklider and Pollack have also reported that a still higher degree of intelligibility is retained if the original speech is differentiated before clipping. In this case, the points of maxima and minima of the original function are retained rather than the points of zero crossing; and a similar density function \( \rho_m \) can be defined to give the number of maxima and minima per second. This could be carried still further by defining a third function \( \rho_p \) as the density of points of inflection, and so forth. The symbols \( \rho_0 \) and \( \rho_m \) thus indicate in Fig. 2 two indices which retain certain essential elements and represent a step toward simplification of the original speech sound.

In the study of noise, Rice of the Bell Telephone Laboratories has found that a simple relation exists between the expected density of zeroes \( \rho_0 \) and the averages of the original function and its first derivative. The derivation of this relation as outlined in the Appendix leads to

\[
\overline{\rho_\theta} = k_0 \sqrt{\frac{f''(\theta)}{f(\theta)}},
\]

(2)

A similar relation can be derived to show that, subject to the same restrictions,

\[
\overline{\rho_m} = k_m \sqrt{\frac{f''(\theta)}{f(\theta)}},
\]

(3)

In these equations, the proportionality constants \( k_0 \) and \( k_m \) depend upon the statistical characteristics of the function \( f(\theta) \). For a stationary time series, the ensemble and time averages are indistinguishable. Hence, the mean values \( \overline{f(\theta)^2}, \overline{f''(\theta)} \), and \( \overline{f''(\theta)^2} \) are included in Fig. 2 to indicate additional indices leading to simplification of speech sounds.

It can be shown\(^{11}\) that these averages values are equivalent to the values of the autocorrelation function \( \phi(\tau) \) and certain of its first few derivatives with respect to \( \tau \) at \( \tau = 0 \); thus the symbols \( \phi(0), \phi''(0), \phi''''(0) \) appear beside the autocorrelation graph. The relationships between these quantities are given by

\[
k_0 \sqrt{\frac{\overline{f''(\theta)}}{f(\theta)}} = k_0 \sqrt{-\frac{\phi''(0)}{\phi(0)}} = \rho_0
\]

(4) and

\[
k_m \sqrt{\frac{f''''(\theta)^2}{f''(\theta)^2}} = k_m \sqrt{-\frac{\phi''''(0)}{\phi''''(0)}} = \rho_m.
\]

(5)

It will be noted that, for smooth functions, the first and the third derivatives at \( \tau = 0 \) are both zero. With the knowledge of these five initial values, the initial portion of the \( \rho(\tau) \) curve is fairly well defined.

It can also be shown\(^{15,20}\) that these initial characteristics of the autocorrelation function are related to the moments of the power spectrum. For example, the moment of zeroth order \( M_0 \) is the average power and equals \( \phi(0) \). The other two moments \( M_2 \) and \( M_4 \), are related to the derivatives \( \phi''(0) \) and \( \phi''''(0) \) as shown by the following equations:

\[
k_0 \sqrt{-\frac{\phi''(0)}{\phi(0)}} = 2\pi k_0 \sqrt{\frac{M_2}{M_0}} = \rho_0
\]

(6) and

\[
k_m \sqrt{-\frac{\phi''''(0)}{\phi''''(0)}} = 2\pi k_m \sqrt{\frac{M_4}{M_2}} = \rho_m.
\]

(7)

The symbols \( M_0, M_2, \) and \( M_4 \) are therefore included along with the spectrogram in the figure.

For the special cases where \( f(\theta) \) is a sine wave and where it is a random function having a Gaussian distribution, it can be proved that \( k_0 \) and \( k_m \) are equal to \( 1/\pi \). Application of the relations given by (2) through (7) to a speech sound assumes that it can be regarded as a stationary time series to which a definite distribution can be assigned. Since an exact mathematical formulation of the distribution is very difficult, the extent that this requirement is met can only be conjectured at the present time. However, assuming that these relations do apply to speech sounds, it is suggested that the proportionality constants may not be very much different from \( 1/\pi \).

The previous discussion has presented three types of analysis from a theoretical standpoint. Certain experimental results will now be described that support the conclusions reached using this approach. Fig. 3 shows \( \rho_0 \) and \( \rho_m \)-grams, together with the spectrogram,


for the word "pajama." It is to be noted that there is close similarity between the shapes of the \( \rho_S \) and \( \rho_m \)-grams and the first two bars of the spectrogram. The first and second bars of the spectrogram represent the first and second formants, or resonance regions, of the sound. Since the frequency components in the first bar are usually strong enough to cause zero crossings, the \( \rho_S \)-gram is a close approximation of this bar. The frequency components in the second resonance region may not be strong enough to cause extra zero crossings, but they will affect the slope of the wave and may, therefore, contribute extra maxima and minima which are included in \( \rho_m \). Fig. 4 shows the graphs of the sounds "i," "e," "a," and "u" which give additional evidence of this resemblance. Usually vowel and vowel-like sounds such as these, having bars which are clearly distinguishable, will show closer resemblance than other types.

A comparison of the \( \rho_S \)- and \( \rho_m \)-grams of the word "pajama" with the oscillogram of the same word, as shown in Fig. 5, justifies the contention that the former is a considerably simpler representation. Visual inspection of the zero crossings of the oscillogram will show that the general shape of the given \( \rho_S \)-gram is correct. The same is true in the case of the maxima and minima. Some work has been done on the experimental verification of the theoretical relations involving \( \rho_0, \rho_m, \) and the other three sets of statistical parameters as applied to speech wave forms. The relationship between \( \rho_0 \) and \( f(i)^2 \) and \( f'(i)^2 \) has been checked for some sustained vowel and sustained fricative sounds. This involves the computation of the ratio of the root-mean-square value of \( f'(t) \) to that of \( f(t) \), i.e., the value of the former normalized with respect to the latter. It is preferable that the mean-square value of the original \( f(t) \), that is, \( f(i)^2 \), be kept relatively constant so that \( f'(i)^2 \) will be automatically normalized. This is an inherent property of the types of sounds that have been checked.

For transitional sounds, such as those contained in the words "pajama" and "question," experimental verification is at present impossible since \( \sqrt{f'(i)^2} \) is dependent upon both amplitude and frequency varia-

*Fig. 3—Spectrogram and \( P_m \) and \( P_s \) graphs of "pajama."

Fig. 4

Fig. 5—Oscillogram of the word "pajama."

Fig. 6—Graphs for the words "pajama" and "question." (a) Ordinary speech: (A) \( \rho_S \); (B) \( f(i)^2 \); (C) \( f'(i)^2 \). (b) Clipped speech: (D) \( \rho_S \); (E) \( f(i)^2 \); (F) \( f'(i)^2 \).
tions, with the former predominating. Since the $\sqrt{f(t)^2}$ itself is dependent only upon the same amplitude variations, the ratio as determined by computation using independent measurements does not yield significant results. It would be necessary to employ some automatic-amplitude-control method to either minimize the changes in amplitude, or to obtain the ratio of the two quantities directly. This effect is illustrated for ordinary speech by graphs (A), (B), and (C) of Fig. 6. Visual examination of (B) and (C) indicates that the amplitude effect predominates. Since clipped speech is an extreme case of amplitude control, data from graphs (D), (E) and (F) should give a better check of the relation in question. Visual examination will show that this is true.

Experimental verification of the other theoretical relations has not as yet been attempted because the autocorrelator and moment computer, while under construction, have not been completed.

**Conclusions**

It has been shown that, from a mathematical standpoint, the three methods of analysis considered, namely, spectrographic analysis, autocorrelation, and infinite clipping, provide parameters which are equivalent for certain time functions. Since speech sounds are too complex for mathematical treatment of these types, an experimental attempt at verification of the equivalence for speech sounds is justified. Furthermore, an experimental attempt to determine the degree of invariance of these parameters is advisable. It is hoped that a subsequent paper will report progress currently being made along these lines.

**Appendix**

1. **Mathematical derivations**

   **The Expected Density of Zeroes**

   Consider a random curve $f(t)$ for which the following figure is a sample of the ensemble. The expected density of zeroes is given by

   $$ \rho_0 = \int_{-\infty}^{\infty} | \eta | \rho(0, \eta) d\eta. $$

   In this expression $\rho(0, \eta)$ is $\rho(\xi, \eta)$ for $\xi = 0$, where $\rho(\xi, \eta)$ is the probability density function for the two variables

   $$ \xi = f $$

   $$ \eta = \frac{df}{dt} = f' $$

   i.e., the probability that at time $t$ the value of $f$ in the ensemble lies between $\xi$ and $\xi + d\xi$, and the value of $f'$ lies between $\eta$ and $\eta + d\eta$ is $\rho(\xi, \eta)d\xi d\eta$. Equation (8) may be proved as follows:

   Referring to the figure, in the interval between $t$ and $t + \Delta t$ for all the ensemble, if the slope is positive, i.e.,

   $$ 0 < \eta < \infty, $$

   then, in order for the curve to pass through zero in the interval $\Delta t$, the following inequality must be satisfied:

   $$ 0 > \eta \Delta t. $$

   This is evident from the geometry. The amplitude of $\xi$ must be negative so that the curve will cross the axis with a positive slope $\eta$. Its absolute magnitude must be sufficiently small so that the crossing occurs within the interval. The portion of the curve in the interval $\Delta t$ is assumed to be linear.

   Since the intervals of the variables $\xi, \eta$ are defined by (10) and (9), the expected density of zeroes can be obtained.

   $$ \overline{\rho_0} = \lim_{\Delta t \to 0} \frac{\int_0^{\Delta t} \rho(\xi, \eta) d\xi d\eta}{\Delta t} = \int_0^{\infty} \eta \rho(0, \eta) d\eta. $$

   Similarly, for the interval between $t$ and $t + \Delta t$, if the slope is negative or $-\infty < \eta < 0$, then

   $$ \overline{\rho_0} = -\int_{-\infty}^{0} \eta \rho(0, \eta) d\eta. $$

   Combining these two expressions, (8) is obtained.

   **Relation Between $\rho_0$ and $\xi^2, \eta^2$**

   This relation is expressed by

   $$ \overline{\rho_0} = k_0 \sqrt{\eta^2 \xi^2} = k_0 \sqrt{\frac{f(t)^2}{f(t)^2}} $$

   (11)

   where $k_0$ is a constant and the bars indicate the ensemble average. For stationary time series, the time average and ensemble average are not distinguishable.

   To prove (11), let the bivariate probability density function $\rho(\xi, \eta)$ be expressed in normalized form

   $$ \rho(\xi, \eta) = \xi_0^{-1}\eta_0^{-1}f\left(\frac{\xi}{\xi_0}, \frac{\eta}{\eta_0}\right) = \xi_0^{-1}\eta_0^{-1}f(x, y) $$

   where

   $$ x = \frac{\xi}{\xi_0}, y = \frac{\eta}{\eta_0} $$

   and $\xi_0$ and $\eta_0$ are the bases of normalization.

   In so doing, the two variables in the probability density function become dimensionless, and

   $$ \rho(\eta, \eta)d\eta d\eta = f(x, y) dx dy. $$

   The ensemble averages of $\eta^2$ and $\xi^2$ are

   22 This derivation is essentially similar to that of Rice. See footnote reference 20.
The expected density of zeroes is, from (8),
\[
\rho_0 = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \eta |p(0, \eta)| d\eta
\]
\[
= \eta_0 \int_{-\infty}^{\infty} |y| \xi_0^{-1} \eta_0^{-1} f(0, \eta) \eta_0 dy
\]
\[
= \frac{\eta_0}{\xi_0} \int_{-\infty}^{\infty} |y| f(0, y) dy
\]
\[
= c_3 \eta_0 \xi_0^{-1} \frac{\eta_0}{\xi_0}
\]
(14)
where \(c_1, c_2,\) and \(c_3\) are characteristic constants of the original distribution. Combining (12), (13), and (14)
\[
\rho_0 = c_3 \sqrt{\frac{c_2}{c_1} \sqrt{\frac{\eta_0^2}{\xi_0^2}} = k_0 \sqrt{\frac{\eta_0^2}{\xi_0^2} = k_0 \sqrt{\frac{f'(0)}{f(t)}}}}
\]
which is (11).

Thus, it is proved that for a stationary time series whose distribution is definite, as expressed by \(p(\xi, \eta)\), the expected density of zeroes is proportional to the ratio of the root-mean-square value of the first time derivative and the root-mean-square value of the time series itself, provided the integrals contained in \(c_1, c_2,\) and \(c_3\) also exist.

Relation Between \(\rho_0\) and the Autocorrelation Function

The autocorrelation function is defined as
\[
\phi(\tau) = \overline{f(t) \overline{f(t-\tau)}}.
\]
The bar indicates either the time average or the ensemble average. For \(\tau = 0\)
\[
\phi(0) = \overline{f(t)^2} = \xi^2.
\]
(15)
It may be proved that
\[
\frac{d^2 \phi}{d\tau^2} = -\phi''(\tau) = \overline{f'(t)f'(t-\tau)}.
\]
For \(\tau = 0\)
\[
-\phi''(0) = \frac{f'(0)^2}{f(t)^2} = \eta^2.
\]
(16)
Combining (11), (15), and (16), the expected density of zeroes can be expressed alternatively as
\[
\overline{\eta^2} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \eta^2 p(\xi, \eta) d\xi d\eta
\]
\[
= \eta_0 \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} y^2 f(x, y) dx dy
\]
\[
= \xi_0 \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \xi^2 p(\xi, \eta) d\xi d\eta
\]
\[
= \xi_0 \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} x^2 f(x, y) dx dy
\]
\[
= c_3 \xi_0^3.
\]
(12)

It is proportional to the square root of the ratio of the negative second derivative of the autocorrelation function to the autocorrelation function itself both evaluated at \(\tau = 0\).

Relation Between \(\rho_0\) and the Moments of the Power Spectrum

The power spectral density, \(\Phi(\omega)\), is related to the autocorrelation function by the Fourier transform
\[
\phi(\tau) = \int_{-\infty}^{\infty} \Phi(\omega) \cos 2\pi f \omega d\omega.
\]
For \(\tau = 0\),
\[
\phi(0) = \int_{-\infty}^{\infty} \Phi(\omega) d\omega = M_0.
\]
(18)
Similarly, it may be proved that
\[
-\phi''(0) = 4\pi^2 \int_{-\infty}^{\infty} \Phi(\omega) d\omega = 4\pi^2 M_2.
\]
(19)
Where \(M_0\) and \(M_2\) are used to designate the zero- and second-order moments of the power spectrum, \(\Phi(\omega)\) versus \(f\).

Combining (17), (18), and (19)
\[
\rho_0 = k_0 \sqrt{\frac{f''(0)}{f(t)^2}} = k_0 \sqrt{\frac{-\phi''(0)}{\phi(0)}} = 2\pi k_0 \sqrt{\frac{M_2}{M_0}}
\]
(20)
Equation (20) gives another interpretation to \(\rho_0\). It indicates that the expected density of zeroes is proportional to the square root of the ratio of the second moment of the zeroth moment of the power spectrum.

The Proportionality Constant \(k_0\) for Random Noise

The above derivations are specially applicable to the case when \(f(t)\) represents random noise for which \(p(\xi, \eta)\) is "Gaussian." To show this, consider the Fourier series representation of random noise
\[
f(t) = \sum_{n=1}^{N} c_n \cos (\omega_n t - \phi_n).
\]
(21)
Where \(\phi_1, \phi_2, \ldots, \phi_N\) are angles distributed at random over the range \((0, 2\pi)\)
\[
c_n = [2\Phi(f_n) \Delta f]^{1/2}
\]
\[
\omega_n = 2\pi f_n
\]
\[
f_n = n \Delta f
\]
Under certain conditions the "central-limit theorem" of probability can be applied and the distribution approaches the "normal" or "Gaussian" form. These
conditions may be stated qualitatively along with (21) as follows: 28
(a) \( f(t) \) has a large number of Fourier series components, i.e., \( N \to \infty \).
(b) The ratio of the quadratic constant (i.e., the average power) of any one component in comparison with the total is vanishingly small, i.e., \( c_n \to 0 \).
(c) The phases of the components are distributed at random, i.e., \( \phi_n \) a random variable.
(d) There is no direct-current component, i.e., \( c_0 = 0 \).
These conditions are usually satisfied by random noise. The probability density function \( p(\xi, \eta) \) can be written in the form
\[
p(\xi, \eta) = \frac{\xi^{\alpha-1/2}}{2\pi} \exp \left( -\frac{\xi^2}{2\xi^2} - \frac{\eta^2}{2\eta^2} \right).
\]

Instead of going through the steps to derive (11) which is for the more general case, it is simpler here to substitute (22) directly into (8) whence
\[
\rho_0 = \int_{-\infty}^{\infty} \frac{\xi^{\alpha-1/2}}{2\pi} \exp \left( -\frac{\eta^2}{2\eta^2} \right) d\eta = \frac{1}{\pi} \sqrt{\frac{\eta^2}{\xi^2}}.
\]

\[\text{Comparing (23) with (11), it is found that for a Gaussian distribution, the proportionality constant}
\]
\[k_0 = \frac{1}{\pi}.
\]

For other distributions, \( k_0 \) would be different. It is interesting to note at this point that for a single sine wave of frequency \( f \)
\[
f(t) = A \sin 2\pi ft.
\]
If \( \rho_0 \) is taken as \( \rho_f \), the proportionality constant between \( \rho_0 \) and \( \sqrt{f(t)^2}/f(f)^2 \) is also \( 1/\pi \). This perhaps suggests that for distributions other than Gaussian, as long as (5) applies, the proportionality constant \( k_0 \) may not be very much different from \( 1/\pi \).

The Expected Number of Maxima and Minima

By a similar process, 29 the expected number of maxima in a random function may be expressed as
\[
\mu = k_m \sqrt{\frac{f''(t)^2}{f(t)^2}} = \frac{k_m}{\pi} \sqrt{\frac{\phi''(0)}{\phi'(0)^2}} = 2\pi k_m \sqrt{\frac{M_4}{M_2}}
\]
where \( k_m \) is a constant dependent upon the distribution, \( \phi''(0) \) is the fourth derivative of the autocorrelation curve, \( \phi'(\tau) \) versus \( \tau \), and \( M_4 \) is the fourth moment of the power spectrum of \( f(t) \).

Periodic-Waveguide Traveling-Wave
Amplifier for Medium Powers  
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Summary—A theoretical and experimental study of singly corrugated coaxial transmission lines is given here. The properties of the structure as a transmission line are calculated and the effect of the electron beam is taken into account by a field method. Theoretical values of gain and bandwidth are obtained. The results of the experimental study are compared with the theory. An amplifier giving 50-watts output with 20-db gain and 100-Mc bandwidth at a wavelength of 6.5 cm has been obtained. The best power output and efficiency which have been obtained are 125 watts and 7 per cent, respectively.

INTRODUCTION

THEORETICAL ANALYSES and experimental studies of helix-type traveling-wave tubes have been carried out by Kompfler 3 and Pierce. 2 Other workers have contributed to the theoretical problem, notably Chu 4 who obtained a boundary value solution to the problem using Pierce's ideal helical current-sheet boundary and including the effect of Pierce's electron beam by the method of Hahn and Ramo. Field 4 has investigated other types of waveguide structures.

This paper is concerned with a traveling-wave tube using a corrugated inner-conductor coaxial transmission line with an annular electron beam between the inner and outer conductors. The first part deals with the theoretical analysis of the structure following the method of Goldstein 5 for a field solution in the absence of the electron beam and includes the electronic parameters by the method Chu used for the helix traveling-wave tube. The second part deals with an experimental

---


study and the comparison of the results with the theory.

The choice of the corrugated coaxial structure from the plethora of possible slow waveguide structures was made after a wide investigation. The type of amplifier described by Field and the iris-loaded waveguide structure proved to have very limited bandwidth; the singly corrugated coaxial line represented a compromise between gain, power output, and bandwidth.

**PART I**

**A. Calculation of the Cold Phase Velocity**

The structure we are considering, which is assumed to be lossless, is shown in Fig. 1. It belongs to a large class of periodic waveguides along with the linear magnetron and the iris-loaded waveguide used in linear-accelerator work. The properties of such structures are dealt with extensively by Brillouin,6 Slater,7 and Goldstein,8 the latter treats in detail, but with certain approximations, the properties of our structure.

The method of solution is to obtain in the annular or "hole" region \( r_1 > r > r_2 \) solutions satisfying Maxwell's equation and meeting the boundary conditions at \( r = r_1 \), and to obtain standing-wave solutions for the fields in the slots \( r_2 > r > r_3 \), including higher-order cutoff modes. The field expansions are Fourier series, and by equating coefficients, an equation may be obtained with the required degree of approximation depending on the number of terms used.

The wave functions for circularly symmetric TM waves in this geometry are Bessel functions of order zero of the first and second kinds. The wave equation is easily separated and the following functions are obtained, taking into account that \( E_z = 0 \) at \( r = r_1 \) and at \( r = r_2 \). For \( r_1 > r > r_2 \)

\[
E_z = \sum_{n=0}^{\infty} \frac{A_n}{\gamma_n} Z_0(\gamma_n, r, r_1) e^{in} n \tag{1}
\]

\[
H_\theta = \sum_{n=0}^{\infty} \frac{ik^2 A_n}{\mu \omega \gamma_n} Z_0'(\gamma_n, r, r_1) e^{in} n
\]

where

\[
k^2 = \gamma_n^2 + h_n^2 \quad \text{and} \quad h_n = H_\theta + \frac{2\pi n}{D}
\]

\[
Z_0(\gamma_n, r, r_1) = J_0(\gamma_n r) Y_0(\gamma_n r_1) = J_0(\gamma_n r_1) Y_0(\gamma_n r)
\]

where the derivatives are taken with respect to the argument, and \( k \) is the free-space wave number.

For \( r_2 \leq r \leq r_3 \) in the 6th slot the fields can be written

\[
E_z = \sum_{n=0}^{\infty} e^{in} D \left( \frac{a_n}{k_p} Z_0(\gamma_n, r, r_1) \cos \frac{2\pi p \eta}{d} + b_n Z_0(K_p, r, r_1) \sin \frac{(2\pi + 1) \eta}{d} \right)
\]

\[
H_\theta = \sum_{n=0}^{\infty} e^{in} D k_p \left( \frac{a_n}{k_p} Z_0'(\gamma_n, r, r_3) \cos \frac{2\pi p \eta}{d} + b_n Z_0'(K_p, r, r_3) \sin \frac{(2\pi + 1) \eta}{d} \right)
\]

where

\[
k_p = \sqrt{k^2 - \left(\frac{2\pi p \eta}{d}\right)^2}
\]

and

\[
K_p = \sqrt{k^2 - \left(\frac{(2\pi + 1) \eta}{d}\right)^2}
\]

For one period of the structure at \( r = r_3 \) the longitudinal electric field must be zero for

\[
\frac{D}{2} \geq Z \geq \frac{d}{2}
\]

and for \(|Z| \leq d/2\), continuity of the fields is required. By the usual manipulation of the Fourier coefficients, (3) is obtained.

\[
A_n Z_0(\gamma_n, r_3, r_1) D = \sum_p \sum_q \frac{A_q}{\gamma_q} Z_0'(\gamma_q, r_2, r_3) \left( \frac{2}{d} R_{pq} \right)
\]

---


where

\[ \varepsilon = 1 \quad p \neq 0 \]
\[ \varepsilon_p = 2 \quad p = 0. \]

Equation (3) is a set of \( n \) homogeneous equations in \( n \) unknowns; it is the usual type of equation obtained in these problems and can be solved in principle. Provided the guide wavelength is large compared to \( D \), the amplitudes of the space harmonics are small and one can consider the case where \( n = p = q = 0 \). This amounts to taking the principal mode in the hole and the first even and odd modes in the slot. For values of \( \chi \sim (\pi/D) \), the space harmonics must be included and Slater\(^6\) has given a more general method of solution to this type of problem.

We are concerned only with geometries where \( D < r_3 \) and \( |H_0D/2\pi| < 1 \). Under these conditions, letting \( \gamma' = i\gamma_0 \), and going to the modified Bessel functions, (3) becomes

\[
R_{yn} = \frac{k_p}{Z_0(k_p, r_2, r_3)} \frac{1}{Z_0'(k_p, r_2, r_3)} \frac{1}{\varepsilon_p}
\]

\[
= -K_p \left[ \left( \frac{2p + 1}{d} \right)^2 - h_0^2 \right] \left[ \left( \frac{2p + 1}{d} \right)^2 - h_0^2 \right]
\]

right by equating at \( r = r_3 \) the values of \( E_d/H_s \) averaged over a period of the structure for the fields of the two regions. This latter method does not allow one to calculate the effect of the odd slot mode, which gives an important correction to the phase velocity obtained from the simple method. A qualitative picture of the electric field is shown in Fig. 2.

For very low frequencies the asymptotic values of the Bessel functions for small arguments may be used in (4), except in the second term on the right, which is, for most traveling-wave tube geometries, very nearly unity. The resulting asymptotic phase velocity for low frequencies is

\[
V = \frac{C}{1 + \frac{8d^2}{D^2} \frac{d}{\pi^2Dr_2} \log \frac{r_3}{r_1} - \frac{8d^2}{D^2} \log \frac{r_1}{r_2} + \frac{2\pi^2d^2}{D^2} \left[ \frac{\sin \frac{\pi d}{2}}{\pi^2d} \right]^2 H_2d 
\]

\[
+ \frac{8(\pi d)^2}{D^2} \left[ \cos \frac{\pi d}{2} \right]^2 H_2d \]

\[
= \frac{1}{1 + \frac{8d^2}{\pi^2D^2} \log \frac{r_3}{r_1} - \frac{8d^2}{\pi^2D^2} \log \frac{r_1}{r_2} + \frac{2\pi^2d^2}{\pi^2D^2} \left[ \frac{\sin \frac{\pi d}{2}}{\pi^2d} \right]^2 H_2d 
\]

\[
+ \frac{8(\pi d)^2}{\pi^2D^2} \left[ \cos \frac{\pi d}{2} \right]^2 H_2d 
\]

(4)

It is convenient to regard (4) as an impedance equation. It can be obtained without the second term on the
which is independent of the frequency and always less than the velocity of light. Fig. 3 shows the results of an approximate phase-velocity calculation for a typical structure. Fig. 4 shows a comparison between measured results and the data computed from (3). The mean error is about four per cent and cannot be much reduced without including the effect of several space harmonics.

\[
P(\gamma, r_2, r_3) = \frac{\gamma}{1 - \frac{\alpha}{(\beta - H)^2}} = \frac{d}{D} \frac{Z_0(k_0, r_2, r_3)}{Z_0'(k_0, r_2, r_3)} \left( \frac{\sin H d/2}{H d/2} \right)^2 + \left( \cos^2 \frac{H d}{2} \right) \left( \frac{8(H d)^2}{D \pi^2} \right)
\]

where

\[
P = I_0(\gamma r_2)K_0(\gamma r_1) - I_0(\gamma r_1)K_0(\gamma r_2)
\]

and

\[
\gamma^2 = (H^2 - k_o^2) \left( 1 - \frac{\alpha}{(\beta - H)^2} \right)
\]

and

\[
\alpha = \frac{4\pi(e/m)\rho_0}{\nu_0^2} = 9.5 \times 10^4 \frac{J_0}{V_0^{3/2}} \text{ Volts}
\]

Equation (6) can be solved exactly numerically, but it is far easier to obtain a solution by considering the hot propagation constant as a perturbation on the cold case. This method is in contradistinction to the method of Pierce who considers the hot modes to be perturbations of the Hahn-Ramo waves traveling on the electron stream.

The propagation constant \(H\), with the electron beam, differs from the cold constant \(H_0\) by a small quantity \(\delta\) which may be complex. One may modify (6) by expanding \(P\) in a Taylor series about \(\gamma = \gamma_0\) to the first order in \(\alpha\) and \(\delta\). Setting \(H = H_0\) in the terms on the right (since the term is a correction, the error so introduced is negligible), the equation can be reduced to the following form:

\[
\delta(u - \delta)^2 + A = 0
\]

where

\[
u = \beta - H_0
\]

and

\[
A = \frac{\alpha}{2} \left( \frac{H_0 d}{d} \right)^2 \left( \frac{\sin \frac{H_0 d}{2}}{\frac{H_0 d}{2}} \right)^2 + \left( \cos^2 \frac{H_0 d}{2} \right) \left( \frac{8(H_0 d)^2}{D \pi^2} \right)
\]

With this relation the analysis of Section IA may be carried out and an equation analogous to (3) obtained. Equation (7) is a form of the usual cubic equation obtained in traveling-wave tube theory.
The imaginary part of the complex pair of roots is the gain in nepers per cm. Reduced values of the imaginary part of the complex pair of roots are shown in Fig. 5 and for the real part in Fig. 6. For calculating the frequency dependence of the gain, one must calculate $\phi$ as a function of the frequency from the cold theory and then one readily gets the gain and hot phase velocity from Figs. 5 and 6 and (7).

For small values of $\alpha$, i.e., low beam current, the frequency dependence of the gain is mainly determined by the rate of change of $\phi$ with frequency, i.e., the cold dispersion of the structure. For large values of $\alpha$ the frequency dependence of $\phi$ becomes important.

Actual calculation of the performance of a given length of this structure depends on the initial boundary conditions and corrections for the presence of loss. The method in which these calculations are carried out is similar to that used for helix-type traveling-wave tubes for which extensive analyses are available in the literature. 3, 4, 8, 9

II. EXPERIMENTAL STUDY

A. Description of the Experimental Tube

A number of different structures based on the previous calculation have been made and tested. A drawing of a typical structure is shown in Fig. 7.

The corrugated inner conductor is made by assembling punched metallic disks with small metal spacers on a refractory metal mandrel and clamping the ends. The dimensions of the active part of the tube are, in the notation of Fig. 1,

- $r_1 = 1.35$ cm
- $d = 0.10$ cm
- $r_2 = 1.20$ cm
- $D = 0.125$ cm
- $r_3 = 0.20$ cm
- length $= l = 14.2$ cm.

The input and output of the corrugated coaxial structure are matched to 5/8-inch outside-diameter 50-ohm coaxial transmission line. The outer conductor has three longitudinal slots cut through it; the slots have been found to prevent propagation of an asymmetrical mode, which otherwise propagates freely and causes the amplifier to oscillate.

The annular electron beam is obtained from a pure tantalum ring emitter operated temperature limited for control of the beam current. The electrostatic and magneto-
netic fields are so controlled that the electron orbits are very nearly rectilinear and space charge forces, in the range of currents used, are generally small. The annular beam enters the coaxial structure through an annulus with four transverse spokes which serve to connect the outer conductors for radio-frequency currents. The beam leaves through a similar structure and is collected on a separate collector. The ratio of collected current to cathode current has varied between 0.6 and 0.8. The maximum possible beam efficiency is about 0.8 due to the part of the area of the annulus subtended by the radial spokes.

B. Experimental Results and Comparison with Theory

The operation of a dispersive traveling-wave tube of this type is characterized by a resonant dependence of the electronic gain and power output on frequency. The terminal impedance match is sufficiently broad-band so that the electronic properties alone determine the frequency response of the amplifier.

Fig. 8 shows the resonance voltage as a function of frequency taken with very small beam currents. This curve gives a relation between beam voltage and frequency which allows one to plot the various parameters as a function of this beam voltage. Operation in a region of power saturation causes an upward shift in the resonance beam voltage, but the shift has never exceeded 10 per cent.

Fig. 9 shows the small-signal gain of the tube, with finite cold attenuation, as a function of beam current for various values of the beam voltage, which corresponds to the values of frequency given in parenthesis.

The gain of the amplifier as a function of power level exhibits the usual marked saturation effect seen in traveling-wave tubes. As the power input increases, a point is finally reached where an increase in the input power results in a decrease in the output power. The power output is then the maximum power output of the tube.

Fig. 10 shows the saturation power output as a function of beam current. In the curves in Fig. 10 a slight shift towards higher voltage has taken place due to saturation.

---

10 The ratio of d/D for the theoretical curve is larger than that for the experimental curve which explains the higher experimental voltages in contrast to Fig. 4.
In comparing these results with the theory, it is necessary to take into account the excitation of the three forward waves at the input and the effect of the insertion loss. Excitation of the three forward waves results in a loss calculated\(^{11}\) to be 9 db in the growing wave at synchronism. The value of this excitation loss can be shown by (7) to depend in a complicated fashion on the cold attenuation and the separation of the beam velocity from that for synchronism. The nature of this dependence is not sensitive and the value of excitation loss varies from 6 to 12 db for practical ranges of operation. The correction obtained for attenuation \(L\), uniform along the structure, has been calculated by numerous authors\(^2,8\) and it can be shown that (7) leads to the same conclusion, that one must subtract one third the attenuation from the gross electronic gain for small values of attenuation. The behavior for values of attenuation comparable to the gain can be shown by (7) to require subtracting about one half the total loss. Subject to the use of approximate values, the formula relating the net gain \(G_{\text{net}}\), to the gain per unit length \(G\) which was calculated in Part I is

\[
G_{\text{net}} = lG - 9 - \frac{2L}{5} \text{ db.} \tag{8}
\]

The values \(G\) in db per cm obtained from the experimental results by (8) are compared to the theoretical values in Fig. 11.

The frequency dependence of the gain for fixed beam voltage is readily calculated from (7), and Fig. 12 shows the experimental gain as a function of frequency compared to the theoretical value, again by means of (8). The tube was operating partly saturated when this curve was taken, which has resulted in a shift of the center frequency of the experimental curve towards the theoretical value.

### C. Power Output

The power output of a traveling-wave tube cannot be calculated from the foregoing analysis due to the failure of the small signal approximation. In general, numerical techniques are required. However, experimental studies of helix tubes and qualitative theoretical arguments indicate that the power output is in general given by

\[
P_{\text{out}} = \frac{KG\lambda_0}{8.68\pi\sqrt{3}}I_0V_0 \tag{9}
\]

where \(G\) is the electronic gain in db per cm and \(K\) is a constant which depends on a variety of factors; \(K\) is most sensitive to the uniformity and losslessness of the output section of the tube. For helix tubes, values of \(K\) as high as three have occasionally been obtained. We have been largely unable to control the magnitude of the attenuation in the output section of our tube. The values of \(K\) corresponding to the measured powers shown in Fig. 10 range between 0.9 and 1.2. The best values of efficiency and power output that have been obtained are about 7 per cent and 125 watts at about 4.5 kv and 380 ma beam current with a gain of about 17 db. In view of the work with the helix tubes and of certain theoretical arguments, it is likely that efficiencies the order of 15 to 25 per cent and power outputs in the vicinity of 500 watts are possible in this frequency range with tubes of this general type.
Gain of Electromagnetic Horns*

W. C. JAKES, JR.†, ASSOCIATE, IRE

Summary—An experimental investigation of the gain of pyramidal electromagnetic horns is described. For the horns tested it was found that (1) the "edge effects" are less than 0.2 db so that the gain of the horns may be computed to that accuracy from their physical dimensions and Schelkunoff’s curves; and (2) for the transmission of power between two horns the ordinary transmission formula is valid, provided that the separation distance between the horns is measured between the proper reference points on the horns, rather than between their apertures.

I. INTRODUCTION

The customary method of measuring the gain of large microwave antennas is by comparison with a small standard pyramidal horn. The gain of the standard horn is usually determined by calculation from the physical dimensions of the horn and use of curves given by Schelkunoff. Since these curves are based on the assumption that the aperture field of the horn is the same as though the sides were continued indefinitely, it is apparent that the computed gain of the horn may be somewhat in error because of the doubtful validity of this assumption.

An experimental determination of the amount of error in the theoretically calculated gain due to this "edge effect" could be made by measuring the power transmitted between two identical horns at a separation distance \( r \), measured between apertures, great enough so that the familiar transmission formula holds:

\[
P_R = \left( \frac{G_\lambda}{4\pi r} \right)^2 P_T
\]

where

- \( P_R \) = received power
- \( P_T \) = transmitted power
- \( G \) = gain of each individual horn
- \( \lambda \) = free-space wavelength.

Any measurable difference between the gain computed from the horn dimensions and that given by (1) may be ascribed to edge effects.

Several considerations complicate the simple experiment described above. Ordinarily it is not practicable to make transmission measurements at extremely large values of \( r \) where it is reasonably certain that (1) holds. One condition, at least, that must be fulfilled is that the variation in phase of the transmitted wave over the aperture of the receiving horn should not exceed \( \lambda/16 \).

If the transmitter were a point source, this would fix the minimum separation distance \( r_{\min} \) between the two antennas as

\[
r_{\min} = \frac{b^2}{\lambda} , \tag{2}
\]

where \( b \) is the larger dimension of the horn aperture. Since the transmitting antenna is not a point source, there is some uncertainty about the point from which to measure \( r_{\min} \); however, if one measures from the aperture plane of the transmitter horn, it seems reasonable that the phase error will not exceed \( \lambda/16 \) at an \( r_{\min} \) given by (2). It is not necessarily true, however, that if \( r \) is the distance between aperture planes the transmission formula (1) will be obeyed for the entire range of \( r_{\min} < r < \infty \).

II. EXPERIMENTS

The experimental part of this study was carried out at a wavelength of 1.25 cm, as the distances and physical dimensions of the horns involved become small and easily managed in this range. The variation of \( P_R \) with \( r \) (between apertures) for \( 40 \lambda \leq r \leq 200 \lambda \) was measured for a number of pyramidal horns of various dimensions. Fig. 1 shows the physical setup employed. To reduce the effect of reflections, no objects were allowed to come closer than 70 \( \lambda \) to the center line of the horn.

![Fig. 1—Physical setup for measuring the variation with distance of the power transmission between two horn antennas.](image)

Before listing the experimental results it will be helpful to give the horn nomenclature, as shown in Fig. 2. Note that in general the \( E \)-plane and \( H \)-plane slant lengths, \( l_E \) and \( l_H \), are not necessarily equal. The "axial height" of the horn will be designated by \( h \); if the horn

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is optimum² the axial height will be designated by \( h_0 \). In all, four pairs of horns were constructed and tested. They were made from sheet brass of 1/16 inch thickness; their physical dimensions are given in Table I. Note that horns 1 and 4 were optimum horns.

![Diagram](image)

**Fig. 2—Nomenclature for horn flared in both planes.**

<table>
<thead>
<tr>
<th>Horn</th>
<th>( a_E )</th>
<th>( a_H )</th>
<th>( h )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.72( \lambda )</td>
<td>6.03( \lambda )</td>
<td>10( \lambda (=h_0) )</td>
</tr>
<tr>
<td>2</td>
<td>4.72( \lambda )</td>
<td>6.03( \lambda )</td>
<td>20( \lambda (&gt;h_0) )</td>
</tr>
<tr>
<td>3</td>
<td>4.72( \lambda )</td>
<td>6.03( \lambda )</td>
<td>5( \lambda (&lt;h_0) )</td>
</tr>
<tr>
<td>4</td>
<td>6.73( \lambda )</td>
<td>8.49( \lambda )</td>
<td>20( \lambda (=h_0) )</td>
</tr>
</tbody>
</table>

**Table I**

Curve \( A \) of Fig. 3 shows the experimental results for a pair of optimum horns (No. 1 in Table I); this is typical of the results obtained in general. It is to be noted that \( P_R \) does not vary as \( 1/r^2 \), the departure being greater as \( r \) decreases. A distance \( d \) was found which, when added to the \( r \) co-ordinates of curve \( A \), caused these points to lie on a straight line (curve \( B \)) whose slope corresponds to an inverse square variation of received power with distance. This indicates that if the separation distance is measured between the proper reference points on the horns, the inverse square relationship of (1) will be obeyed. The distance from the horn aperture back to this reference point will be called \( D \).

Since the transmitting and receiving horns were identical in the above experiments, it follows that \( D = d/2 \). For the optimum horns (with \( h = h_0 \)) \( D \) was found to be equal to the axial height. However, for the other horns the following was observed: if \( h > h_0 \), (horn 2) \( D < h \); if \( h < h_0 \), (horn 3) \( D > h \).

Since it has been experimentally demonstrated that (1) is valid for \( r_{min} < r < \infty \) provided \( r \) is measured between the proper horn reference points, this equation may now be used with the proper \( r \) to compute the actual horn gain. Curve \( B \) of Fig. 4 shows the results of this computation for horn 1. For comparison, curve \( A \) of Fig. 4 was computed using for \( r \) in (1) the separation distance between horn apertures. Curve \( C \) is the gain calculated from the physical dimensions of the horn

² An optimum horn is one for which the flare angles in both planes are so chosen that, for a given length of horn, the gain is a maximum. This follows if:

\[ a = 24\lambda; a_H = 32\lambda. \]
and Schelkunoff's curves. These three curves are representative of the results for the four pairs of horns; in general, the difference between curves B and C did not exceed 0.2 db, and for the optimum horns it was less than 0.1 db.

III. Conclusions

When computing the gain of pyramidal electromagnetic horns it is permissible to use their actual physical dimensions and Schelkunoff's curves. The error due to edge effects is less than 0.1 db for optimum horns, with aperture dimensions greater than 4λ.

If it is desired to compute the transmitted power between two identical horns, (1) is valid even in the transition zone between the Fraunhofer and Fresnel regions provided \( r > r_0 + 2D \). Here, \( r_0 \) is the separation between apertures and \( D \) is described above.

\( D \) for an optimum horn is equal to the axial height but for horns shorter or longer than optimum, \( D \) is greater or less than the axial height and must be determined by experiment.

**Evaluation of Coaxial Slotted-Line Impedance Measurements**

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Summary—Most ultra-high-frequency impedance measurements are made by detecting the voltage-standing-wave ratio and nodal position in a slotted section of coaxial transmission line. Sources of error in these measurements are discussed and methods of eliminating or evaluating them are presented. It is shown that the maximum error due to structural defects in determining the relative voltage can be predicted experimentally for most standing-wave machines and that the resulting maximum error in the voltage-standing-wave ratio is twice the maximum error in determining the relative voltage. The resulting maximum error in the nodal position and, also, the fractional errors in the load resistance and reactance due to the errors in the voltage-standing-wave ratio and nodal position are calculated and presented in graphical form.

I. Introduction

As a part of a program to establish standards of measurement of electrical quantities at ultra-high frequencies, the accuracy of impedance measurements using current techniques has been evaluated. The accuracy of measurement of most other uhf electrical quantities is related to the accuracy of impedance measurements. The slotted section of transmission line with a traveling probe is the most widely used measuring instrument in this frequency range. This instrument utilizes what can be regarded as a comparison method, in which the impedance to be measured is compared with the characteristic impedance of the slotted section. Since the characteristic impedance can be determined accurately from the physical dimensions and the electrical properties of the slotted section, the instrument can be considered an "impedance meter" with an inherent reference standard.

In most uhf impedance measurements, the comparison of the unknown impedance with the characteristic impedance of the slotted section is made by determining the voltage-standing-wave ratio (VSWR) and a nodal position by either direct or indirect methods. Obviously, the accuracy of such impedance measurements is a function of the accuracy of the determination of VSWR and nodal position. The purpose of this paper is to present: (1) a brief survey of the literature on sources of error in measurements of VSWR and nodal position together with references to methods of eliminating or evaluating the errors; (2) a study of the maximum errors in determining VSWR and nodal position which result from errors in measuring relative-voltage distribution along the slotted section; and (3) curves for evaluating the errors in impedance measurements resulting from these errors in VSWR and nodal position.

II. Sources of Error in VSWR and Nodal Position Measurements

The principal errors in the determination of VSWR and nodal position originate in the voltage generator, detector, and slotted section. These errors are discussed in the following paragraphs, together with references which describe techniques for reducing the errors to a negligible amount or evaluating the magnitude of the errors.

1. Impure and Unstable UHF Voltage Input

The harmonic content of most unfiltered uhf power sources is of sufficient magnitude to cause serious errors in the measurement of both VSWR and nodal position,
specially if an untuned probe is used. The probe is usually part of a high-Q circuit which is tuned to the fundamental frequency and discriminates against even harmonics. Low-pass filters with low insertion loss can be inserted between the generator and the slotted section to limit harmonic content to a negligible percentage of the fundamental.1

Instability and unwanted frequency modulation of the voltage generator output during an impedance measurement are other sources of error.2 Variations in the amplitude of the uhf voltage generator output also cause errors in the measured values of VSWR. Fortunately, the amplitude and frequency stability of most uhf generators is sufficient for impedance measurements if the generators are operated from highly stabilized power supplies, and proper care is taken to reduce unwanted frequency modulation.

2. Undetermined Response Law of Detector System

The voltage standing-wave existing in a slotted section is determined by sampling the electric field along the length of the slotted section and taking the ratio of the maximum to the minimum field. The response law of the detector system (consisting of detector element, amplifier unit, and indicator) can be determined by terminating the slotted section in a short circuit and plotting the indicated output as a function of probe position.3 If the necessary equipment is available, it is preferable to determine the law of the detector system with a calibrated attenuator. The response of detector elements, such as Litelluses, Wollaston wires, and barretters can be considered “square law” for low-power levels or for small values of VSWR. Of course, the accuracy of indication of any detector is limited by the accuracy of associated dc and af measuring instruments.

3. Alteration of Standing-Wave Pattern by the Probe

The error in measurement of VSWR and nodal position caused by the loading of the slotted section of transmission line by the probe is negligible if the probe is loosely coupled to the line. If the probe penetration does cause distortion in the observed standing-wave pattern, this distortion can be determined by noting the interaction between two identical probes in the same slotted section. If the motion of either probe causes a change in the indicated output of the other probe, which is kept stationary at various selected positions, then the probe penetration is considered excessive. If it is necessary to tightly couple the probe to the slotted section of transmission line in order to perform standing-wave measurements, the magnitude of the errors introduced in the measurement of VSWR and nodal position can be determined as a function of the effective admittance of the probe shunting the slotted section.4 5 6

4. Attenuation

Attenuation in a slotted section is caused by dielectric, conductor, and radiation losses. These losses are usually of such small magnitude that they seldom affect VSWR measurements. However, errors in impedance calculated from VSWR and nodal position measurements can occur if the attenuation between the load terminals and the position at which the VSWR is measured is large. This error can be corrected if the attenuation constant is known.7

5. Effect of Slot

A narrow longitudinal slot cut in the outer conductor of a section of coaxial transmission line decreases the capacitance per unit length of line4 and permits radiation losses. The radiation losses are negligible for most types of measurements, and the capacitance decrease causes a slight increase in the characteristic impedance of the transmission line. The ends of the slot cause impedance discontinuities at the junction of the slotted and unslotted sections. The approximate residual VSWR introduced by these discontinuities can be easily calculated.4 A commercially available 1-inch standing-wave machine was found to have a calculated residual VSWR of less than 1.004 due to the slot. If the effect of discontinuities at the end of the slot and in connectors is appreciable, equivalent impedances can be determined experimentally.8 9 10 11

6. Structural Defects of Slotted Section and Probe Carriage

It may be concluded that the errors in the measurement of VSWR and nodal position discussed above can

be evaluated or reduced to a negligible magnitude by the use of appropriate experimental techniques. It is, however, difficult if not impossible to evaluate or completely correct for the errors in VSWR and nodal-position measurements caused by structural defects or mechanical irregularities of the slotted section and probe carriage. The sag of the center conductor between supports, the mechanical irregularities in probe carriage ways which result in vertical or lateral motion of the probe, and the nonuniformity of cross section of the coaxial slotted section are examples of structural defects. Mechanical irregularities in the probe carriage ways (slotted section mounted horizontally) which result in vertical or lateral displacement of the probe relative to the center conductor as the probe traverses the length of the slotted section are usually found to be the chief sources of error. Because of the large number of parameters involved, it is difficult to predict theoretically the errors in the measurement of VSWR for a given slotted section, but these errors can be predicted from experimental data. One method which can be used to predict the performance of a standing-wave machine involves approximately matching the load end of the slotted section in order that the irregularities in detector response may be measured as a function of probe position along the line. Experimental data for predicting the performance of a selected standing-wave machine are shown in Fig. 1. For this particular standing-wave machine there is a maximum deviation of the measured relative-voltage distribution of about ±2 per cent from the estimated, true relative-voltage distribution. The magnitude of this deviation was found to be constant for frequencies in the range of 300 to 600 Mc. It can, therefore, be assumed that there is a maximum error of 2 per cent in the determination of relative-voltage distribution in this standing-wave machine when measurements are made in the indicated frequency range.

Methods using either audio-frequency voltages or precise mechanical measurements for calibrating or determining the performance of a given slotted section are desired. However, though experimental studies on some slotted sections show correlation, on others no correlation is observed between af, mechanical, and uhf measurements. It is, therefore, concluded that the performance of a slotted-section type of standing-wave machine can be best determined by experiments performed at uhf. The important property to be determined is the fractional error in measuring the relative-voltage distribution. From this, the maximum fractional error in measuring VSWR and nodal position can be determined, and from these, in turn, can be obtained the resulting errors in impedance measurements.

II. Accuracy of Measurement of VSWR and Nodal Position

Theoretically, all errors in the measurements of VSWR and nodal position can be eliminated or evaluated except those errors caused by structural defects in the standing-wave machine. It has been shown that the fractional error (b) in the determination of relative voltage due to these structural defects can be obtained experimentally. The maximum error in the measured value of VSWR \( \rho_b \) resulting from this fractional error (b) can then be predicted. Since

\[
\rho = \frac{V_{\text{max}}}{V_{\text{min}}} ,
\]

where \( V_{\text{max}} \) and \( V_{\text{min}} \) are, respectively, the true values of VSWR, voltage maximum, and voltage minimum, the limiting values of the measured VSWR \( (\rho_b) \) are

\[
\frac{V_{\text{max}}(1 - b)}{V_{\text{min}}(1 + b)} \leq \rho_b \leq \frac{V_{\text{max}}(1 + b)}{V_{\text{min}}(1 - b)} .
\]

For small values of \( b \), (2) reduces to

\[
\rho(1 - 2b) \leq \rho_b \leq \rho(1 + 2b) .
\]

Therefore, the maximum fractional error in measured VSWR will not be more than twice the maximum fractional error in relative-voltage measurement. The maximum error in measurement of VSWR with the standing-wave machine for which sample experimental curves are shown in Fig. 1 would thus be less than 4 per cent.

The error in the determination of the nodal position can also be related to the error in relative-voltage measurement. The nodal position is usually obtained by finding the midpoint between two positions of equal detector response on each side of the minimum. A method of determining the error in measured nodal position resulting from errors in relative-voltage measurements is best described with the aid of Fig. 2. The solid line represents the true voltage distribution \( (V) \) and the dashed lines represent the limits of the measured values of relative voltage, \( (1 \pm b)V \). The measured values, therefore, lie within the area bounded by the dashed lines. There is seen to be a maximum error of \( \pm 2b \) in the location of a given voltage because of possible errors in relative-voltage measurements. An error in the location of the nodal position results from this error, \( \delta \theta \), in location of the equal-response voltages.

\[\text{The analysis in Sections III and IV applies to waveguides as well as to coaxial transmission lines.}\]
It is shown in Appendix B that $\delta \Psi$ is a minimum if equal-response voltages are selected having a magnitude

$$V = \sqrt{\frac{2\rho^2(1 + b^2)}{\rho^2 + 1}} V_{\min}. \quad (5)$$

Since $b^2$ is very small compared to unity, it may be neglected. $V$ rapidly approaches $\sqrt{2}V_{\min}$ as $\rho$ increases as shown in Fig. 3. From equations (4) and (5), the minimum value, $\delta \Psi_m$, of the maximum error in nodal position is found to be

$$\delta \Psi_m = \frac{1}{4 \arccos \left[ 1 - \frac{32\rho^2b^2}{(\rho^2 - 1)(1 - b)^2} \right]} \quad (6)$$

Curves for (6) are shown in Fig. 4.

It is shown in Appendix A that, if it is assumed that the slotted section is lossless and that the probe does not distort the standing-wave pattern, the maximum error ($\delta \Psi$) in the location of the nodal position is given by the equation

$$\delta \Psi = -\frac{1}{4} \arccos \left[ \frac{\rho^2 + 1}{\rho^2 - 1} \frac{1 + (\rho^2 - 1) \sin^2 (\theta - \Psi)}{(1 - b)^2} \right]$$

where $(\theta - \Psi)$ is the magnitude of the distance in electrical degrees from the nodal position to the true equal-response position.

$\delta \Psi$ is seen to be a function of $\rho$, $b$, and $(\theta - \Psi)$. For a given impedance measurement, $\rho$ is the measured VSWR and $b$ is a constant for the slotted section used, whereas $(\theta - \Psi)$ is a function of the equal-response voltages.

![Fig. 2](image)

**Fig. 2**—The determination of the maximum error in nodal position from the fractional error $b$ in relative-voltage measurement.

![Fig. 3](image)

**Fig. 3**—Curve of optimum equal-response voltage for minimum error in determination of nodal position.

**III. Evaluation of Errors in Impedance Measurements as a Function of the Error in VSWR and Nodal Position**

The terminating impedance of a lossless uniform transmission line can be expressed as a function of the
VSWR \( (\rho) \) and the distance \( (\Psi) \) from the nodal position to the load terminals by the following equation:

\[
Z = \frac{\cos \Psi - j\rho \sin \Psi}{\rho \cos \Psi - j \sin \Psi}, \tag{8}
\]

where \( Z \) is the normalized impedance at the load terminals. The assumption, in (8), that the slotted section is lossless introduces only a negligible error in most measurements. However, if the section of transmission line between the load and the measured nodal position has excessive loss, (8) must be modified as described in the literature.\(^7\)

The normalized resistive and reactive components of the complex impedance \( Z \) are given respectively by the following equations:

\[
r = \frac{\rho}{\rho^2 \cos^2 \Psi + \sin^2 \Psi}, \quad x = \frac{(1 - \rho^2) \sin \Psi \cos \Psi}{\rho^2 \cos^2 \Psi + \sin^2 \Psi}. \tag{10}
\]

From the differentials of these equations with respect to \( \rho \) and \( \Psi \), it is possible to obtain the fractional errors in normalized resistance and reactance that result from the errors in the determination of VSWR and nodal position. The fractional errors in resistance and reactance due to small incremental errors \( \delta \rho \) and \( \delta \Psi \) can be expressed as follows:

\[
\frac{\delta r}{r} = -\frac{1 - (\rho^2 + 1)/2 (1 - \cos 2\Psi)}{1 + (\rho^2 - 1)/2 (1 + \cos 2\Psi)} \cdot \frac{\delta \rho}{\rho}, \tag{11}
\]

\[
\frac{\delta x}{x} = \frac{(\rho^2 - 1) \sin 2\Psi}{1 + (\rho^2 - 1)/2 (1 + \cos 2\Psi)} \cdot \frac{\delta \rho}{\rho}, \tag{12}
\]

\[
\frac{\delta x}{x} = \frac{-2\left[1 - (\rho^2 + 1)/2 (1 + \cos 2\Psi)\right]}{(\sin 2\Psi)\left[1 + (\rho^2 - 1)/2 (1 + \cos 2\Psi)\right]} \cdot \delta \Psi. \tag{14}
\]

These equations are plotted in Figs. 5, 6, 7, 8(a), and 8(b). The graphs present the absolute values of the factors by which any fractional errors in the determination of VSWR, and any errors in nodal position, should be multiplied in order to obtain the resulting fractional errors in the load resistance and reactance. The abscissas \( \Psi \) of the curves are distances in electrical degrees from the load terminals to the nearest voltage minimum. If \( \Psi \) is between 90° and 180°, the errors are the same as for an electrical distance of 180° - \( \Psi \) since the curves are symmetrical about \( \Psi = 90° \).

A Smith Chart\(^8\) is useful in understanding the shape of the curves of Figs. 5, 6, 7, 8(a), and 8(b). For example, in Fig. 5 the error in resistance is found to be zero for certain combinations of values of VSWR and nodal

position. An inspection of the portion of the Smith Chart which includes these values of VSWR and nodal position shows that the resistance is practically constant for small changes in VSWR. Similarly, in Figs. 8(a) and 8(b), the error in reactance is seen to be zero for certain values of VSWR and nodal position. For these values, the Smith Chart shows the reactance to be practically constant for small changes in nodal position. Fig. 8(b) is a supplement to Fig. 8(a) and presents the ratio $\delta x/\delta \psi$ for values of $\psi$ near $0^\circ$ and $90^\circ$. Fig. 8(b) is desirable since the ratio $(\delta x/\alpha)/\delta \psi$ in Fig. (8a) becomes too large for graphical representation with the selected scale as $\psi$ approaches $0^\circ$ or $90^\circ$.

![Fig. 8(a)—Curves for determining errors in reactance caused by small errors in measurement of VSWR.](image)

**Fig. 7**—Curves for determining errors in reactance caused by small errors in measurement of VSWR.

**CONCLUSION**

A study of the accuracy of impedance measurements made by determining the voltage-standing-wave ratio and nodal position in a slotted transmission line indicates that all errors except those introduced by structural imperfections can be corrected or evaluated by known techniques. It is possible to obtain the maximum magnitude of this last type of error by experimentally determining the maximum error in relative-voltage measurement for each standing-wave machine and frequency band. The maximum fractional error in the voltage-standing-wave ratio is twice this constant, and the maximum error in nodal position can then be obtained from a graph, provided the proper equal-response voltages are used.

The effect of these and any other errors in VSWR and nodal position on the accuracy of the calculated terminal resistance and reactance can also be obtained from graphs. Therefore, although the errors in impedance caused by imperfections in the standing-wave machine cannot be easily corrected, their maximum values can be obtained from an experimentally determined constant and a few equations or graphs.
Appendix

A. Maximum Error in Locating Nodal Position

In Fig. 2, $\Psi$ and $\theta$ are respectively the distances in electrical degrees from the load terminals to the nodal and probe positions. $\theta_1$ and $\theta_2$ are the probe locations of two equal response voltages. The maximum error $\delta\Psi$ in determining the nodal position is half the sum of the maximum errors, $\delta\theta_1$ and $\delta\theta_2$, in the location of the equal response voltages. The limits of the measured nodal position may be expressed as follows:

$$\Psi \pm \delta\Psi = \frac{(\theta_1 \pm \delta\theta_1) + (\theta_2 \pm \delta\theta_2)}{2} \tag{18}$$

or

$$\Psi \pm \delta\Psi = \frac{\theta_1 + \theta_2 \pm \delta\theta_1 + \delta\theta_2}{2}. \tag{16}$$

The maximum error in the location of the nodal position is, therefore:

$$\delta\Psi = \pm \frac{\delta\theta_1 + \delta\theta_2}{2}. \tag{17}$$

Expressions for $\delta\theta_1$ and $\delta\theta_2$ can be obtained from the equation for a voltage standing-wave on a lossless transmission line,

$$V = V_{\text{min}}[1 + (\rho^2 - 1) \sin^2(\theta - \Psi)]^{1/2} \tag{18}$$

where $(\theta - \Psi)$ is the distance in electrical degrees from the probe position to the position of a voltage minimum. The maximum error in the location of a selected response voltage is obtained by calculating the distance between positions at which the expressions for $V$ and either $(1 + b)V$ or $(1 - b)V$ are equal. Because of the symmetry of the voltage distribution curve, the distances $\delta_x\theta_1$ and $\delta_x\theta_2$ of Fig. 2 are equal. Therefore, by substituting $\delta_x\theta_2$ for $\delta_x\theta_1$, $\delta\Psi$ becomes equal to one-half the sum of the absolute values of $\delta_x\theta_1$ and $\delta_x\theta_2$. By equating the expressions for $V$ and $(1 - b)V$ at $\theta_2$,

$$(1 - b)[1 - (\rho^2 - 1) \sin^2(\theta_2 - \Psi + \delta_x\theta_2)]^{1/2} V_{\text{min}} = [1 + (\rho^2 - 1) \sin^2(\theta_2 - \Psi)]^{1/2} V_{\text{min}}. \tag{19}$$

Similarly, by equating the expressions for $V$ and $(1 + b)V$ at $\theta_2$,

$$(1 + b)[1 + (\rho^2 - 1) \sin^2(\theta_2 - \Psi - \delta_x\theta_2)]^{1/2} V_{\text{min}} = [1 + (\rho^2 - 1) \sin^2(\theta_2 - \Psi)]^{1/2} V_{\text{min}}. \tag{20}$$

From (19),

$$\delta_x\theta_2 = \frac{1}{2} \cos^{-1} \left[ \frac{\rho^2 + 1}{\rho^2 - 1} - \frac{1 + (\rho^2 - 1) \sin^2(\theta_2 - \Psi)}{\frac{\rho^2 - 1}{2}(1 - b)^2} \right] - (\theta_2 - \Psi). \tag{21}$$

From (20), and the equality of the absolute values of $\delta_x\theta_1$ and $\delta_x\theta_2$,

$$\delta_x\theta_1 = \delta_x\theta_2 = (\theta_2 - \Psi) - \frac{1}{2} \cos^{-1} \left[ \frac{\rho^2 + 1}{\rho^2 - 1} - \frac{1 + (\rho^2 - 1) \sin^2(\theta_2 - \Psi)}{\frac{\rho^2 - 1}{2}(1 - b)^2} \right]. \tag{22}$$

The maximum error, $\delta\Psi$, in the nodal position determined from two equal-response voltages at a distance $(\theta - \Psi)$ electrical degrees from the voltage minimum is equal to half the sum of (21) and (22), or

$$\delta\Psi = \frac{\delta_x\theta_1 + \delta_x\theta_2}{2} = \frac{1}{4} \cos^{-1} \left[ \frac{(\rho^2 + 1)(1 - b)^2}{(\rho^2 - 1)(1 - b)^2} - \frac{1}{2} \right]. \tag{23}$$

Since $1 + (\rho^2 - 1) \sin^2(\theta - \Psi) = (V/V_{\text{min}})^2$ from (18), $\delta\Psi$ may be expressed as a function of the equal-response voltages used, or

$$\delta\Psi = \frac{1}{4} \cos^{-1} \left[ \frac{(\rho^2 + 1)(1 - b)^2}{(\rho^2 - 1)(1 - b)^2} - \frac{1}{2} \right]. \tag{24.1}$$

B. The Minimum Value of $\delta\Psi$

The value of $V$ for which $\delta\Psi$ is a minimum is obtained by equating to zero the derivative of (24) with respect to $V$. The value of this equal-response voltage $V$ for which $\delta\Psi$ is a minimum is found to be

$$V = \sqrt{\frac{2\rho^2(1 + b^2)}{\rho^2 + 1}} V_{\text{min}}. \tag{25}$$

Since $b^2$ is very small compared to unity, the expression for $V$ reduces to

$$V = \sqrt{\frac{2\rho^2}{\rho^2 + 1}} V_{\text{min}}. \tag{26}$$

The voltage is of this magnitude at values of $(\theta - \Psi)$ such that

$$\sin(\theta - \Psi) = \sqrt{\frac{\rho^2(1 + 2b^2) - 1}{\rho^2 - 1}}. \tag{27}$$

If the expression for $V$ in (25) is substituted in (24), the minimum value $\delta\Psi_m$ of the maximum error in determining nodal position is given by

$$\delta\Psi_m = \frac{1}{4} \cos^{-1} \left[ 1 - \frac{32\rho^2 b^2}{(\rho^2 - 1)(1 - b^2)^2} \right]. \tag{28}$$
Alternate Ways in the Analysis of a Feedback Oscillator and its Application*

E. J. Post† and H. F. Pit†

Summary—It is a well-known fact that negative feedback has a favorable influence on the phase stability of an amplifier. However, if the negative feedback is applied between the input and output terminals of an amplifier, which is the active part of an oscillating loop, it turns out that the negative feedback may be interpreted either in terms of phase stability of the amplifying section or in terms of phase discriminating properties of the passive frequency determining section of the loop.

The consequences of this alternate point of view for the design of oscillator networks are discussed.

I. Introduction

An analysis of an oscillator circuit, obtained by writing down the complete set of circuit equations, in principle may give all information available about the behavior of a particular circuit.

Because of the algebraic complexity of the problem, the consequences of changes in circuit elements or the influence of additional elements are not always easily understood.

However, Llewellyn's1 principles, which make oscillator frequency substantially independent of plate- and filament voltage, may serve as a brilliant example that a complete analysis of the circuit is extremely useful.

From a designer's point of view, some principles allowing a more synthetic approach of the problem may be of use.

Most oscillators may be regarded as a closed loop of an active and a passive four-terminal. In general, the passive four-terminal has a frequency determining function, whereas the active four-terminal is necessary to compensate losses in the frequency determining part.

The problem of generating constant frequencies may be summarized in the conditions which have to be imposed on the active and passive part of the closed loop.

A necessary and sufficient condition for a single closed loop to cause oscillation is given by a Nyquist plot surrounding the appropriate critical point. This criterion, however, gives little information about the frequency which is to be generated.

To study frequency behavior the following necessary, although not sufficient conditions can be used:

1. The net phase-shift ϕ around the oscillating loop must be zero or an integral number of times 2π.

\[ \phi = n \times 2\pi, \quad n = 0, 1, 2, \ldots \]  

2. The net gain g around the closed loop must be one or greater than one:

\[ g \geq 1. \]  

In the following text it will be supposed that, moreover, the Nyquist criterion is always satisfied.2

Before proceeding to formulate the conditions which have to be imposed on the amplifying and frequency determining part of the closed loop, in order to obtain constant frequencies, we want to call the attention to the fact that the splitting up of a closed loop into an active and passive part is not necessarily unique.

A very instructive example may be illustrated in the following section by means of the network of Meacham's well-known crystal oscillator.3

II. A Topological Peculiarity of Meacham's Oscillator4

The network shown in Fig. 1(a) is the conventional concept of the Meacham oscillator. In the neighborhood of the generated frequency the tuned transformers will be regarded as ideal. The frequency determining section with in- and output transformer of the amplifier is drawn once more in Fig. 1(b). The dotted line in Fig. 1(b) is of no consequence, in case the connection to the primary of the transformer is suitably chosen no current will flow in it. According to this, the circuit of the Meacham oscillator (Fig. 1(a)) can be rearranged as shown in (Fig. 1(c)). An inspection of Figs. 1(b) and 1(c) shows that the dotted line of 1(b) is a full drawn line in 1(c), connecting a tap of the input transformer to one side of the secondary of the output transformer of the amplifier. Moreover, the resistive branch of the bridge circuit of Fig. 1(a) is included in the amplifier section of Fig. 1(c).

Apparently oscillator networks Figs. 1(a) and 1(c) are equivalent from a point of view of loop transmission.

The only difference between the networks Figs. 1(a) and 1(c) is the sectioning of the loop into amplifying and frequency determining part.

Once the equivalence of networks 1(a) and 1(c) has been established an interesting conclusion may be drawn.

According to Meacham, the frequency stability of oscillator network 1(a) is explained by the extraordinary

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1 Decimal classification: R139.I X R133. Original manuscript received by the Institute, December 12, 1949; revised manuscript received, July 21, 1950.

2 Radio Laboratory of the Netherlands' Postal and Telecommunication Services, 's-Gravenhage, Netherlands.


4 In case of a multiple loop transmission this applies to the intentionally positive feedback loop.


6 The point of view developed in this section has been suggested by the comments of G. H. Baast and W. H. van Zoest.
phase discriminating features of the bridge circuit in the frequency determining four-terminal, however, obtained at the expense of additional attenuation.

The frequency determining four-terminal of network 1(c) has a comparatively moderate attenuation, and exhibits no extraordinary phase-discriminating qualities. The amplifier part, on the other hand, has a considerable amount of negative feedback, reducing its excess of gain and resulting in an improved phase stability of the active part of the loop circuit.

With regard to general relations between phase and attenuation, the following rule is suggested:

An additional attenuation associated with a corresponding improvement in the phase discriminating properties of the frequency determining four-terminal may as well be interpreted as an inversed feedback between the output and input terminals of the amplifier.

Fig. 1—Network equivalence for Meacham oscillator circuit.

The rule enunciated above allows one to approach the problem in more than one way, and can be used as a suitable tool in oscillator network synthesis.

In the same way as the bridge circuit can be interpreted in terms of voltage feedback, the bridge-T circuit may be interpreted in terms of current feedback. As discussed by Shepherd and Wise, the phase discriminating properties of the Hartley (or Colpitts) oscillator can be improved by the use of a bridged-T section. Figs. 2(a) and 2(b) show that a frequency determining section of a Hartley oscillator connected to an amplifier with current feedback is equivalent to a bridged-T section combined with an amplifier of which the current feedback has been removed.

III. Phase Properties of Active and Passive Sections

Having made a definite separation between active and passive section of the closed loop, the attention may be directed to a more detailed study of the phase-frequency characteristics of amplifier $\phi_1(\omega)$ and frequency determining four-terminal $\phi_2(\omega)$ (see Fig. 3). In the neighborhood of the frequency to be generated, $\phi_1$ and $\phi_2$ may be developed around their points of zero phase $\omega_1$ and $\omega_2$.

Hence

$$\omega = \omega_1 \frac{1}{1 + S} + \omega_2 \frac{1}{1 + \frac{1}{S}}$$

$$S = \frac{\partial \phi_2(\omega_2)}{\partial \omega} \omega_2$$

The natural condition to make the influence of the frequency determining part predominating is:

$$S \gg 1.$$  

The magnitude of $S$, defined in (4), has to be regarded as a criterion to what extent the frequency generated in the loop can be made independent of the amplifier section. However, an excessive high figure for $S$ only is by no means a guarantee for frequency constancy.

It is worth while to point out that the definition of $S$ satisfies the principle of equivalence enunciated in section II. A moderate slope $\partial \phi_2(\omega_2)/\partial \omega$ combined with a very small $\partial \phi_1(\omega_1)/\partial \omega$ of the active section yields a same figure for $S$ as a very large slope $\partial \phi_2(\omega_2)/\partial \omega$ combined with a moderate slope of $\partial \phi_1(\omega_1)/\partial \omega$.

The relations (3) and (5) may serve as a starting point to formulate the prevailing properties which have to be satisfied by the active and passive four-terminal sections of the loop for generation of constant frequencies.

AMPLIFIER A

1. The slope of phase versus frequency must be small and constant in the neighborhood of the generated frequency $\omega$.
2. The frequency of zero phase $\omega_1$ is fixed near $\omega$.

The importance of negative feedback is obvious as a means to diminish the slope of phase versus frequency.

It is believed that, in the long run, the phase stability of capacity resistance coupled amplifiers compare favorably to tuned amplifiers.

FREQUENCY DETERMINING CIRCUIT B

1. The point of zero phase $\omega_1$ must be fixed.
2. The slope of phase versus frequency must be large and constant.

Fluctuating stray capacities across input and output terminals of the frequency determining circuit must have little influence on $\omega_1$. In many cases low impedance filter sections are favorable.

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Requirement \( B_2 \) involves the use of nearly purely reactive elements, hence high \( Q \). In case of electromechanical elements like crystals, the accessory reactive elements of the four terminals must be chosen with care so that the favorable properties with regard to requirement \( B_1 \) are not impaired. For crystal oscillators this is an argument to use series resonance, using the electromechanical branch of the crystal only.

It must be kept in mind that condition \( B_1 \) has a priority over condition \( B_2 \). An extremely high \( Q \) is useless, unless condition \( B_1 \) is satisfied. From a designer's point of view it is very instructive to study existing oscillator circuits by splitting up in passive and active sections and analyzing the subsequent parts in order to learn to what extent the conditions mentioned above are satisfied.

IV. Oscillator Circuits

Any properly matched combination of amplifier stages and frequency determining four terminals, possibly on low impedance basis, allowing a net phase shift of zero or \( n \times 2\pi \) radians and a loop gain adjustable to unity, may give a suitable, linearly operating, oscillator.

An amplifier section operating in a linear part of its characteristic is an essential condition to guarantee phase stability, hence frequency stability of the complete loop.\(^7\)

An adjustment of the loop gain of a purely linear oscillator to unity exactly is well beyond the aims which can be realized physically, unless an automatically regulating device is included.

The oscillator circuit shown in Fig. 4 may serve as an example for the principles of design developed in the foregoing sections.\(^8\) A low impedance output stage of the amplifier has been used to supply the input voltage of the bridge. The positive feedback loop is connected to the cathode, the negative feedback loop to the grid of the differential input stage of the amplifier. The two tubes are coupled by a conventional capacity resistance network to close the loop.

The amplitude controlling device is usually included in the negative feedback loop by means of a thermal resistance. The properties of this system of amplitude control are not identical to those of the conventional Meacham bridge, because of the fact that one of the bridge elements is a dynamic impedance. The influence of this impedance is such that a completely compensating control of the amplitude can be obtained in spite of a very moderate gain of the amplifier.

Moreover, the bridge is not seriously affected if crystals with considerable difference in loss resistance are inserted, in view of the fact that the dynamic cathode impedance of the differential input stage automatically readjusts the bridge equilibrium.

An analysis of the amplitude controlling device is somewhat lengthy, but straightforward (see Appendix).

V. Conclusion

The alternate points of view discussed in Sections II and III of this paper have been illustrated by methods of "network geometry."\(^1\)

The principal aim of its application has been to emphasize the prevailing points which make oscillator frequency substantially independent of ambient influences on the amplifying section, e.g., variations in power supply, and aging of tubes and circuit elements.

A searching investigation may be necessary to scan the practical boundaries. The difficulties arising from very high figures of \( S \) (see (4) and (5)) being used, are analogous and partly identical to the problems encountered in feedback amplifier design and must be attacked accordingly.\(^2\)

APPENDIX

Analysis of the Amplitude Control

In case one of the bridge elements is the cathode-resistance of an amplifier tube, one has to deal with the effective impedance of the cathode circuit.

For an amplifier stage with a differential input, the input impedance on the cathode is a function of the voltage ratio \( e_e/e_h \), \( e_h = \) grid voltage, \( e_e = \) cathode voltage. (Fig. 5.) The input impedance \( Z_i \) on the cathode is defined as

\[
Z_i = \frac{e_h}{I_1}.
\]

The circuit equations are

\[
e_e = I_zZ_k - I_zZ_a.
\]

\[
\mu(e_e - e_h) = I_z(R_1 + Z_k + Z_a) - I_zZ_t.
\]

1 As shown by one of the reviewers of the original manuscript, the equivalence is obvious from an analytical point of view as well.

in which all the elements are supposed to be purely resistive and \( R_4 \) is written for \( Z_a \), being the fourth element of the bridge. Fig. 6 gives a plot for a television pentode of \( R_4 \) as a function of the voltage ratio \( \alpha = e_o/e_k \); \( e_o \) and \( e_k \) having the same phase.

The bridge circuit connecting the cathode of the grounded plate stage to the cathode and grid of the differential input stage of oscillator circuit Fig. 4 is shown separately in Fig. 7.

The voltage ratio \( \alpha \) may be expressed in the bridge elements \( R_1, \ldots; R_4 \) being the selective series-resistance of the crystal. The resulting expression for \( (1-\alpha) \) is (Fig. 7)

\[
1 - \alpha = \frac{e_o - e_k}{e_k} = \frac{R_1R_4 - R_2R_3}{R_1R_4 + R_2R_4}.
\] (11)

Inserting (11) in (10a) gives a linear equation for \( R_4 \). Solving for \( R_4 \) yields a formula expressing \( R_4 \) as a function of the remaining bridge elements \( R_1, \ldots; R_3 \) and the parameters of the differential amplifying stage:

\[
R_4 = \frac{R_1R_2R_3}{R_1 + R_2} \text{ if } R_k \ll (R_1 + R_a).
\]

Writing \( S_r \) for the effective transconductance \( SR \), \( 1/R_1 + R_a \), we have the expression:

\[
R_4 = \frac{R_1 + R_2 + S_rR_2R_3}{R_1 + R_2 + S_rR_2R_k}. \quad \text{(12)}
\]

An inspection of equation (12) shows that \( R_4 \) approximates

\[
\frac{R_2R_3}{R_1} \text{ if } S_r \gg \frac{R_1 + R_2}{R_1R_k}.
\]

or, in other words, the effective resistance \( R_4 \) tends to approximate bridge equilibrium.
The practical consequence of this peculiarity is that, within certain limits, crystals with arbitrary differences in loss resistance may be inserted without seriously disturbing the adjustment of the bridge.

It must be emphasized, however, that the phenomenon, being strictly linear, must be looked upon as a device of automatic bridge-readjustment. It has no amplitude controlling features of its own.

A control of the amplitude can be obtained with a nonlinear element only. Let us suppose the bridge element $R_1$ to be a thermal resistance with negative characteristic. Its nonlinear properties will be explained by the formula

$$R_1 = R_0(1 - \gamma \Delta I_1)$$

now

$$I_1 = \frac{E}{R_1 + R_2} \quad \text{(see Fig. 7)}$$

and

$$dR_1 = \frac{dR_2}{dE} dE = -\frac{\gamma R_0}{R_1 + R_2} dE. \quad (13)$$

If the loop is in a steady state of oscillation, the net gain is exactly unity. Therefore the attenuation of the bridge is reciprocal to the gain $g$ of the amplifier. Hence the bridge circuit (Fig. 7) gives an expression for the gain:

$$e_e - e_a = \frac{1}{E} = g = \frac{R_4}{R_3 + R_4} + \frac{R_2}{R_1 + R_2}. \quad (14)$$

Differentiation to the variable elements $g$, $R_1$ and $R_2$ gives

$$-\frac{dg}{g^2} = \frac{R_3}{(R_3 + R_2)^2} dR_4 + \frac{R_2}{(R_1 + R_2)^2} dR_4. \quad (15)$$

According to formula (12) the differential $dR_4$ can be expressed in the differentials of $R_1$ and the differential of the gain of the amplifier, because $g$ is proportional to $S_e$.

$$dR_4 = \frac{\partial R_4}{\partial g} dg + \frac{\partial R_4}{\partial R_1} dR_1. \quad (16)$$

Inserting (16) and (13) in (15) and solving for $dE$,

$$dE = -\frac{1}{g^2 + \frac{\partial R_4}{\partial g} (R_3 + R_4)^2} dR_1 \left[ \frac{R_3}{\partial R_1} + \frac{R_2}{R_1 + R_2} \right] (R_3 + R_4)^2 \quad (17)$$

This expression relates a change in gain to a corresponding change in $E$, the input voltage of the bridge. A compensated control of the amplitude is possible if

$$\frac{\partial R_4}{\partial g} = \frac{(R_3 + R_4)^2}{g R_3}. \quad (17)$$

An inspection of formula (17) shows that $\partial R_4/\partial g < 0$ if $R_4R_1 > R_3R_2$. The last inequality being a necessary condition to assure an excess of positive feedback.

For the computation of the differential quotient $\partial R_4/\partial g$ it has to be remembered that the gain of the amplifier depends on $S_e$. There are other factors affecting the gain; the influence, however, of the second (cathode follower) tube is comparatively small because of its individual reversed feedback.

A similar conclusion is obtained if $R_2$ is taken as a thermal resistance with positive characteristics.

Hence, the combined efforts of pseudo-linear element and dynamic impedance as elements in the bridge create the possibility of a compensated control of the amplitude for a finite and very moderate gain of the amplifier.

In general, the source supplying the input voltage of the bridge has a finite internal impedance. Therefore, the use of a thermistor (negative characteristic) being a constant voltage device on its own, assists the stabilizing properties of the control action.

**Correction**

D. D. King, author of the paper, "Two standard field-strength meters for very-high frequencies," which appeared on pages 1048-1051 of the September, 1950 issue of the Proceedings of the I.R.E., has brought the following error to the attention of the editors.

In the caption for Fig. 7 on page 1051, "1 volt per wavelength ($E\lambda = 1$)," should read "1 volt per resonant wavelength ($E\lambda = 1$)."
Spectrum Analysis of Transient Response Curves*

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Summary—The paper describes a method of computation of amplitude and phase response of a network from its measured transient response. Tables and nomographs have been included to facilitate the numerical evaluation.

Introduction

Since transient tests are rapidly becoming standard engineering tools, the importance of spectrum analysis of measured response curves is steadily increasing.

It is well known that such an analysis can be made in cases where the mathematical expression of the respective curve is given by evaluating the Fourier integral.

In cases where only the graph of the response curve is known, this leads to a lengthy and laborious graphical integration and is hardly practical.

Another method will be briefly described here which was presented by Bedford and Fredendall.† The principle of this method, called by its authors "square-wave analysis," is as follows:

The given curve is approximated by the sum of several step-functions which are regularly spaced in time (Fig. 1). The complex Fourier spectrum of each step function is computed. The sum of the individual spectra is the spectrum of the sum of step functions. Since this sum is assumed to be a good approximation of the given curve, it is reasonable to assume that its spectrum is a good approximation of the spectrum of the original curve. The corresponding mathematical operations are given below: If \( F(t) \) is the given curve, \( f(t) \) a unit step function and \( \tau \) the spacing between adjacent steps:

\[
F(t) \approx \sum_{n=0}^{\infty} B_n f(t - n\tau)
\]

where \( B_n \) are the amplitudes of the individual step functions.

The Fourier spectrum of a single step function is:

\[
\phi(\omega) = \int_{-\infty}^{\infty} B_n f(t - n\tau)e^{-j\omega t} dt = B_n \frac{e^{-jn\omega \tau}}{j\omega}
\]

and the spectrum of the function \( F(t) \):

\[
\Phi \approx \frac{1}{j\omega} \sum_{n=0}^{\infty} B_n e^{-jn\omega \tau}.
\]

The equation for the (complex) transfer function \( H(\omega) \), if we assume an ideal unit function at the input terminals, is, therefore:

\[
H(\omega) \approx \sum_{n=0}^{\infty} B_n e^{-jn\omega \tau}.
\]

Method Using \((\sin x/x)\)-Functions

This method which has proved very useful in a great number of cases is based on the following fact: Almost all transient response curves have one property in common; namely, their spectrum does not contain components above a certain limit, say \( f_s \), to any appreciable amount. This is due to the inherent properties of the system under test and of the test equipment itself. In cases where an oscilloscope is used, the scope amplifier might be the limiting item; in other cases, different parts of the test setup might cause the frequency limitation. A function of this type, namely, a function the frequency spectrum of which has an upper limit \( f_s \), can be synthesized exactly by a sum of functions of the type \( \sin x/x \). This was proved by Shannon in a recent pub-

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† General Electric Company, Electronics Park, Syracuse, N. Y.
The conditions for the synthesis will be explained with the help of Fig. 2: The measured curve is “sampled” at regular intervals (τ) which must be smaller than or equal to (1/2f₀). At each sample point, a curve of the described type is placed with an amplitude equal to the amplitude of the corresponding sample point. In Fig. 2 the sin x/x curves are only partly drawn in order to improve the clarity of the figure. The next step is to find the complex Fourier spectrum of each individual sin x/x function. Then, the sum of these spectra is the Fourier spectrum of the measured curve. Provided that the above assumption holds, that is, that no frequency components above fₑ are present, this would be the correct answer, not an approximation. The validity of this assumption will be discussed later.

The mathematical derivations for the method described above, follow: Let the given time function be again F(t) and τ the time spacing between adjacent sampling points, then:

\[ F(t) = \sum_{n=0}^{\infty} A_n \frac{\sin f_c(t - n\tau)2\pi}{f_c(t - n\tau)2\pi} \; ; \; \tau \leq \frac{1}{2f_c} \]  

(5)

where \( A_n \) are the amplitudes of the sampling points, and \( f_c \) is the highest component in the frequency spectrum of \( F(t) \). It can be shown that the spectrum of the \( n \)th term of the sum of (5) is

\[ \phi(\omega) = \int_{-\infty}^{+\infty} A_n \frac{\sin 2\pi f_c(t - n\tau)}{2\pi f_c(t - n\tau)} e^{-j\omega t} \; dt \]

\[ = A_n \frac{e^{-j\omega \tau}}{2f_c} \]  

(6)

Hence, the Fourier spectrum of the given curve \( F(t) \) is:

\[ \Phi(\omega) = \sum_{n=0}^{\infty} A_n \frac{e^{-j\omega \tau}}{2f_c} \; ; \; \tau = \frac{1}{2f_c} \]  

(7)

This equation relates the spectrum to the measured points \( A_0, A_1, A_2, \ldots \) of the transient response curve and is, therefore, the answer to our problem. In many cases, however, it is of advantage to express the spectra not by the sample amplitudes \( A_n \), but by the first differences or increments of \( A \). If we define \( B_n = A_{n+1} - A_n \), and neglect constant time delay, then (7) becomes (8), as derived in the mathematical Appendix.

\[ \Phi(\omega) = \frac{1}{j4f_c} \sum_{n=0}^{\infty} B_n e^{-j\frac{\pi}{2}/f_c} \]  

In a case where the measured curve is the response to an ideal step function the complex transfer function of the system under test will be described by (9). The transfer function is, of course, the complex notation of amplitude and phase response of a network.

\[ \Phi(\omega) = \frac{\pi/2}{\sin (\pi/2/f_c)} \sum_{n=0}^{\infty} B_n e^{-j\pi f_c/n} \]  

(9)

Our assumption, on which the derived formulas (8) and (9) are based, was that the spectrum of the response curve does not contain frequencies above a certain limit \( f_c \). Since this assumption will never be fulfilled with full mathematical rigor for a practical network, the practical value of the method might be questioned. It can, however, be shown that the amount of the error, which will be largest near the nominal cutoff frequency \( f_c \), will be in general smaller than the amplitude response at \( f_c \), provided that the response does not rise again above its value at \( f_c \) for frequencies \( f/f_c > 1 \). An example, in which the condition for a frequency cutoff has been fulfilled only approximately, follows here.

A certain transient response curve (Fig. 3) was assumed of which the accurate mathematical expression is given by (10)

\[ F(t) = 1 - e^{-2\pi f_c t} - \frac{2}{\sqrt{3}} e^{-\frac{\pi}{f_c} t} \sin \left( \sqrt{3} \pi f_c t \right) \]  

(10)

and analyzed by three different methods: First, by the evaluation of the Fourier-integral which, of course, provides the exact answer; second, by the method just described and, third, by the “square-wave method” mentioned earlier. The time spacing for the sampling was chosen to be \( 1/5f_c \). The results are shown in Fig. 4. The solid curve shows the correct solution, the crosses the results of the proposed method and the circles the results of the “square-wave method.” The time delay-response is omitted for reasons of space.

In spite of the fact that our assumption was not completely fulfilled (we have at \( f_c \) only 24 db instead

\[ H(\omega) = \frac{1}{(\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c)} \]

The solution is:

\[ H(\omega) = \frac{1}{(\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c)} \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})(1 + jf/f_c) \]  

\[ - (\pi f_0 - e^{j\pi f_c})(\pi f_0 + e^{j\pi f_c})
of an infinitely large attenuation), the results obtained are of considerable accuracy. This can also be seen from Fig. 5, which shows the relative error of the amplitude responses.

where

\[ H(\omega) = \text{complex transfer function} \]
\[ \Phi(\omega) = \text{complex Fourier spectrum} \]
\[ E/j\omega = \text{complex spectrum of an ideal input step function of amplitude } E \]

it is not necessary to discuss the numerical evaluation of \( \Phi(\omega) \) as well.

For a certain frequency \( f_0 \) for which the calculation of phase and amplitude of a network is desired, the expression for \( H(\omega) \) takes the form:

\[
H(\omega) = \frac{\pi/2 \cdot f_0}{f \sin \frac{\pi}{2} f_0/f_c} \cdot \sum_{n=0}^{\infty} B_n e^{-i\pi n f_0/f_c} \tag{12}
\]

On the right side, all values are known; the \( B \)'s are the differences of the sample amplitudes, \( f_0 \) is the frequency for which the evaluation is being performed, and \( f_c \) is the cutoff frequency. The main part of the evaluation is to form the complex sum \( \sum B_n e^{-i\pi n f_0/f_c} \). This can be done graphically (as for a similar case proposed by Bedford and Fredendall). Another method is used here; we write:

\[
\sum_{n=0}^{\infty} B_n e^{-i\pi n f_0/f_c} = \sum_{n=0}^{\infty} B_n \cos (n\pi f_0/f_c) - j \sum_{n=0}^{\infty} B_n \sin (n\pi f_0/f_c) \tag{13}
\]

\[
\sum B_n e^{-i\pi n f_0/f_c} = \sum \alpha_{\cos} - j \sum \alpha_{\sin}. \tag{14}
\]

Tables are computed for different values of \( n, B_n \) and \( f_0/f_c \) which allow one to find \( \alpha_{\sin} \) and \( \alpha_{\cos} \). If the sums \( \sum \alpha_{\sin} \) and \( \sum \alpha_{\cos} \) are found and called \( \alpha_{\sin} \) and \( \alpha_{\cos} \) the nomographs I or II allow one to find the amplitude response of the network being analyzed (|\( H(\omega) | \)) for \( f_0 \). Nomograph III gives the phase for \( f_0 \).

It should be mentioned that the phase angle thus obtained is the so-called "principal value," i.e., it might be necessary to add a multiple of \( \pi \) to it.

The constant time delay cannot be computed by this method, since terms pertaining to it were neglected in the course of the derivation.

**Instructions for the Use of Tables and Nomographs**

**General**

The tables are computed for a sampling point spacing of 0.05 \( \mu s \); they are valid for any other sampling point spacing \( \tau^* \) if the frequency values printed on tables and nomographs are multiplied by 0.05/\( \tau^* \)).

**The Sampling**

(a) Use a spacing \( \tau \) smaller than 1/2 \( f_c \), where \( f_c \) is the cutoff frequency, defined in the first part of this paper.
NOTE: TO ESTABLISH THE LINE PERPENDICULAR TO SCALE 3 AND ANY VALUE, CONNECT THIS VALUE ON SCALE 3 WITH THE SAME VALUE ON SCALE 12.

Nomograph I

NOTE: TO ESTABLISH THE LINE PERPENDICULAR TO SCALE 3 AT ANY VALUE, CONNECT THIS VALUE ON SCALE 3 WITH THE SAME VALUE ON SCALE 12.'
(b) Place the sampling points so that the first point (subscript $n = 0$) is not farther to the right than one interval $\tau$ past the start of the variation of the curve (see Fig. 6). Sampling points must continue to the point where the curve ceases varying.

(c) Tabulate the amplitudes at the sampling points. Let these be called $A_0, A_1, A_2, A_3, \ldots, A_n, \ldots$.

(d) Form the differences $A_0 - 0, A_1 - A_0, A_2 - A_1, \ldots$, and let these be called $B_0, B_1, B_2, \ldots, B_n, \ldots$. (Some values of $B$ might be negative.) If necessary, the values of $B$ should be multiplied by an arbitrary scale factor so that the largest value of $B$ lies between 70 and 99; this assures higher accuracy in the results.4

(e) Round off the values of $B$ thus found to the nearest whole number.

The Computation of the Auxiliary Values $C_{\text{sin}}$ and $C_{\text{cos}}$

Select the table (Tables I–XII) for the frequency for which amplitude and phase is to be computed. For calculation of $C_{\text{sin}}$ use the heading marked "for $C_{\text{sin}}". Enter the argument column (under the heading $B_n$) with the $B_n$ value; proceed horizontally to that column for which the heading contains the corresponding subscript number $N$ and tabulate the value thus obtained. (Note: The value $c_{\text{sin}}$ which has been found, normally has the same sign as $B_n$ unless the subscript in the heading is preceded by an asterisk, in which case they have opposite sign.) This must be done for all $B_n$’s of which the subscripts are listed in the heading.

It is advisable to perform this conversion not in the sequence of the points (i.e., $B_0, B_1, B_2, \ldots$) but rather in the sequence of the groups indicated by the headings (e.g., for 0.625 Mc and $C_{\text{sin}}$: first for the points with the subscripts 1, 15, 17, 31 then for the next group 2, 14, 18, 30, etc.).

Add all values $c_{\text{sin}}$ thus found, retaining proper signs. The sum is the auxiliary value $C_{\text{sin}}$.

4 The scale factor will only appear in the final result for the amplitude; it can be eliminated by dividing the result by the scale factor. This, however, is not necessary if only relative values are of interest.
### TABLE I

<table>
<thead>
<tr>
<th></th>
<th>$C_{\sin}$</th>
<th>$C_{\cos}$</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>0.00</td>
<td>0.10</td>
</tr>
<tr>
<td>3</td>
<td>0.10</td>
<td>0.20</td>
</tr>
<tr>
<td>4</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
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<td>0.40</td>
</tr>
<tr>
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<td>0.40</td>
<td>0.50</td>
</tr>
<tr>
<td>7</td>
<td>0.50</td>
<td>0.60</td>
</tr>
<tr>
<td>8</td>
<td>0.60</td>
<td>0.70</td>
</tr>
<tr>
<td>9</td>
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<td>0.90</td>
</tr>
<tr>
<td>11</td>
<td>0.90</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Note:** The table continues with similar entries for $C_{\sin}$ and $C_{\cos}$.
| TABLE II |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 10 | 20 | 30 | 40 | 50 | 60 |
| 20 | 40 | 60 | 80 | 100 | 120 |
| 30 | 60 | 90 | 120 | 150 | 180 |
| 40 | 80 | 120 | 160 | 200 | 240 |
| 50 | 100 | 150 | 200 | 250 | 300 |
| 60 | 120 | 180 | 240 | 300 | 360 |

| TABLE III |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 10 | 20 | 30 | 40 | 50 | 60 |
| 20 | 40 | 60 | 80 | 100 | 120 |
| 30 | 60 | 90 | 120 | 150 | 180 |
| 40 | 80 | 120 | 160 | 200 | 240 |
| 50 | 100 | 150 | 200 | 250 | 300 |
| 60 | 120 | 180 | 240 | 300 | 360 |
### Table IV

<table>
<thead>
<tr>
<th>B&lt;sub&gt;n&lt;/sub&gt;</th>
<th>C&lt;sub&gt;sin&lt;/sub&gt;</th>
<th>C&lt;sub&gt;cos&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.200</td>
<td>0.979</td>
</tr>
<tr>
<td>2</td>
<td>0.210</td>
<td>0.977</td>
</tr>
<tr>
<td>3</td>
<td>0.220</td>
<td>0.975</td>
</tr>
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<td>4</td>
<td>0.230</td>
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<td>7</td>
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<td>0.967</td>
</tr>
<tr>
<td>8</td>
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<td>0.965</td>
</tr>
<tr>
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<tr>
<td>10</td>
<td>0.290</td>
<td>0.961</td>
</tr>
</tbody>
</table>

### Table V

<table>
<thead>
<tr>
<th>B&lt;sub&gt;n&lt;/sub&gt;</th>
<th>C&lt;sub&gt;sin&lt;/sub&gt;</th>
<th>C&lt;sub&gt;cos&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.200</td>
<td>0.979</td>
</tr>
<tr>
<td>2</td>
<td>0.210</td>
<td>0.977</td>
</tr>
<tr>
<td>3</td>
<td>0.220</td>
<td>0.975</td>
</tr>
<tr>
<td>4</td>
<td>0.230</td>
<td>0.973</td>
</tr>
<tr>
<td>5</td>
<td>0.240</td>
<td>0.971</td>
</tr>
<tr>
<td>6</td>
<td>0.250</td>
<td>0.969</td>
</tr>
<tr>
<td>7</td>
<td>0.260</td>
<td>0.967</td>
</tr>
<tr>
<td>8</td>
<td>0.270</td>
<td>0.965</td>
</tr>
<tr>
<td>9</td>
<td>0.280</td>
<td>0.963</td>
</tr>
<tr>
<td>10</td>
<td>0.290</td>
<td>0.961</td>
</tr>
</tbody>
</table>
### TABLE VI

<table>
<thead>
<tr>
<th>Bₙ</th>
<th>( \text{For } C_{\sin} )</th>
<th>( \text{For } C_{\cos} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>2</td>
<td>0.29</td>
<td>0.39</td>
</tr>
<tr>
<td>3</td>
<td>0.26</td>
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<tr>
<td>4</td>
<td>0.22</td>
<td>0.32</td>
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<td>5</td>
<td>0.19</td>
<td>0.29</td>
</tr>
<tr>
<td>6</td>
<td>0.17</td>
<td>0.27</td>
</tr>
<tr>
<td>7</td>
<td>0.15</td>
<td>0.24</td>
</tr>
<tr>
<td>8</td>
<td>0.13</td>
<td>0.21</td>
</tr>
<tr>
<td>9</td>
<td>0.11</td>
<td>0.19</td>
</tr>
<tr>
<td>10</td>
<td>0.09</td>
<td>0.17</td>
</tr>
<tr>
<td>11</td>
<td>0.07</td>
<td>0.15</td>
</tr>
<tr>
<td>12</td>
<td>0.05</td>
<td>0.13</td>
</tr>
<tr>
<td>13</td>
<td>0.03</td>
<td>0.11</td>
</tr>
<tr>
<td>14</td>
<td>0.01</td>
<td>0.09</td>
</tr>
</tbody>
</table>

### TABLE VII

<table>
<thead>
<tr>
<th>Bₙ</th>
<th>( \text{For } C_{\sin} )</th>
<th>( \text{For } C_{\cos} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.18</td>
<td>0.28</td>
</tr>
<tr>
<td>2</td>
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<td>0.12</td>
<td>0.22</td>
</tr>
<tr>
<td>5</td>
<td>0.10</td>
<td>0.20</td>
</tr>
<tr>
<td>6</td>
<td>0.08</td>
<td>0.18</td>
</tr>
<tr>
<td>7</td>
<td>0.06</td>
<td>0.16</td>
</tr>
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<td>0.04</td>
<td>0.14</td>
</tr>
<tr>
<td>9</td>
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<td>0.12</td>
</tr>
<tr>
<td>10</td>
<td>0.00</td>
<td>0.10</td>
</tr>
</tbody>
</table>
TABLE VIII

\[ F = 5 Mc \]

For \( C_{\text{sin}} \)
Add the values of \( B_n \) for the following subscripts (retaining proper signs)
\[
\begin{align*}
1 & \quad 5 \\
9 & \quad 13 \\
17 & \quad 21 \\
25 & \quad 29 \\
\end{align*}
\]
and add the values for the following subscripts (reversing their signs)
\[
\begin{align*}
3 & \quad 7 \\
11 & \quad 15 \\
19 & \quad 23 \\
27 & \quad 31 \\
\end{align*}
\]

For \( C_{\text{cos}} \)
Add the values of \( B_n \) for the following subscripts (retaining proper signs)
\[
\begin{align*}
0 & \quad 4 \\
8 & \quad 12 \\
16 & \quad 20 \\
24 & \quad 28 \\
\end{align*}
\]
and add the values for the following subscripts (reversing their signs)
\[
\begin{align*}
2 & \quad 6 \\
10 & \quad 14 \\
18 & \quad 22 \\
26 & \quad 30 \\
\end{align*}
\]

For the calculation of the auxiliary value \( C_{\text{cos}} \) proceed in exactly the same way, using the heading for \( C_{\text{cos}} \).
The tables are prepared for a maximum of 32 points. It is, however, easy to use these tables for any number of points if the following is kept in mind:

For all frequencies except the lowest (0.3125 Mc) the column which applies to \( B_n \) applies as well to \( B_{n+32} \). The same is true for the lowest frequency (0.3125 Mc) but, in addition, the sign of \( B_{n+32} \) must be reversed.

Computation of Amplitude

Use nomograph II unless the first digit of the larger one of the auxiliary values \( C_{\text{sin}} \) and \( C_{\text{cos}} \) lies between 2 and 8, in which case nomograph I should be used for higher accuracy. Connect, with the aid of a straight edge, the \( C_{\text{sin}} \) value on scale 1 with the \( C_{\text{cos}} \) value of scale 2. The value at the intersection of scale 3 with the straight edge is the desired value in cases where the frequency is equal to or smaller than 1.675 Mc. For higher frequencies, proceed perpendicularly from the value found on scale 3 to the scale marked with the proper frequency.

Computation of Phase

Use nomograph III. Connect the values \( C_{\text{sin}} \) on scale 1 with the value of \( C_{\text{cos}} \) on scale 2 with a straight edge and find the phase angle \( \alpha \) on scale 3 at the intersection with the straight edge. If \( C_{\text{sin}} \) and \( C_{\text{cos}} \) have the same sign, take the angle as positive; if they have opposite signs, take it as negative.

Example:

Subscript \( n \) of sample

<table>
<thead>
<tr>
<th>Points</th>
<th>Subscript</th>
<th>Scale Factor (=7)</th>
<th>Evaluation for ( f_s = 0.625 ) Mc</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0.08</td>
<td>0.0614</td>
</tr>
<tr>
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<td>2</td>
<td>0.00</td>
<td>0.0002</td>
</tr>
<tr>
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<td>3</td>
<td>0.01</td>
<td>0.0056</td>
</tr>
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</tr>
<tr>
<td>7</td>
<td>8</td>
<td>0.06</td>
<td>0.0336</td>
</tr>
</tbody>
</table>

\[ F = 6.25 \text{MC} \]

For \( C_{\text{sin}} \)

\[ \begin{align*} C_{\text{sin}} &= 0.12 + 0.12 + 0.17 + 0.22 + 0.95 - 0.33 + 0.7 - 3.92 = 0.393 \end{align*} \]

For \( C_{\text{cos}} \)

\[ \begin{align*} C_{\text{cos}} &= -0.78 + 1.53 - 2.22 + 4.93 - 25.78 + 82.23 + 55.91 + 0.97 + 12.84 = 122.84 \end{align*} \]

Nomograph II gives \( |F(0.625 \text{Mc})| = 126.0 \)
Nomograph III gives \( \alpha = 13.5^\circ \)
### TABLE X

<table>
<thead>
<tr>
<th>B</th>
<th>N</th>
<th>C&lt;sub&gt;SIN&lt;/sub&gt;</th>
<th>C&lt;sub&gt;COS&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>0.045</td>
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<td>1</td>
</tr>
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<td>1</td>
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<td>1</td>
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### TABLE XI

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**F=7.5 MC**

**F=8.75 MC**
Vertical Incidence Ionosphere Absorption at 150 Kc*

A. H. BENNER†, MEMBER, IRE

Summary—The results of a year’s experimental observations of the ionospheric absorption at vertical incidence at 150 kc are presented. In particular, the diurnal and seasonal variations of the absorption are examined. The existence of relationship between the variation of the absorption and the sun’s zenith angle and vertical incidence critical frequency is established.

INTRODUCTION

The absorption of radio waves in the ionosphere has been investigated by a number of workers, primarily at frequencies above the standard broadcast band. At the low end of the spectrum, scientists in England have explored the very long waves from 16 to 30 kc. That portion of the spectrum between 30 and 500 kc has, until recently, suffered a considerable lack of attention. This region is now becoming a center of active interest, partially because of its possible use for long-range navigational aids.

A rather cursory estimation of the daytime reflection

<table>
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<th>TABLE XII</th>
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<tr>
<td>$F = 10$ Mc</td>
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<tr>
<td>$C_{\sin} = 0$</td>
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<td>For $C_{\cos}$</td>
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<td>Add the values of $B_n$ for the following subscripts (retaining proper signs)</td>
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<td>and add the values for the following subscripts (reversing their signs)</td>
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<td>1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31</td>
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</table>

* Decimal classification: R113.22. Original manuscript received by the Institute, May 25, 1950.

Since

$$\sum_{0}^{\infty} e^{-n\tau} = \frac{1}{1 - e^{-\tau}} \quad \text{for} \quad \tau > 0$$

the series

$$\sum_{0}^{\infty} e^{-n\tau}$$

can be considered to be a geometrical progression, which is known to be convergent for $e^{-\tau}<1$, i.e., the series convergent for any positive, finite values of $\delta$.

Using the formula for the sum of an infinite geometric progression, we obtain:

$$\sum_{0}^{\infty} e^{-n\tau} = \frac{1}{1 - e^{-\tau}} = \frac{1}{1 - e^{-j\omega r}}$$

or after a transformation:

$$\sum_{0}^{\infty} e^{-n\tau} = \frac{e^{j\omega r/2}}{2j \sin \omega r/2}$$

Finally, we obtain (neglecting the constant time delay $e^{j\omega r/2}$):

$$\Phi(\omega) = \frac{\pi}{\omega_c} \frac{1}{2j \sin \omega r/2} \sum_{0}^{\infty} B_n e^{-j\omega r}$$

With $\tau = 1/2f_c = \pi/\omega_c$ we obtain (8).
coefficient as a function of frequency in this portion of the spectrum has indicated that this coefficient is near unity at the very low frequencies near 16 kc drops to a low minimum near 100 kc, and rises slowly again near 500 kc. The Radio Propagation Laboratory has been conducting measurements of virtual height and absorption at vertical incidence at 150 kc since February, 1949. It is the purpose of this paper to present a résumé of the experimental results obtained from the absorption measurements.

**Equipment**

Measurements were conducted on transmissions from a high-power pulse transmitter at a carrier frequency of 150 kc, a pulse rate of 1.5625 pps, and a Gaussian pulse shape 150 microseconds in width. The transmitter consists of a self-excited oscillator using ten 304TH triodes, pulsed by a hydrogen thyratron modulator through a pulse-forming network. The transmitting antenna is a folded dipole 3,000 feet long and 96 feet high. The receiving site is separated approximately 4 km from the transmitter, and an automatic record of the virtual height, the amplitude of the echo, and the amplitude of the ground pulse is made.

Investigations of the polarization of the echo indicated that under normal conditions it was elliptical, left-handed, and rather constant in orientation and configuration with variation of time; at least during night hours. This alleviated the necessity for attempting to devise a discriminator for use with the receiver in separating the two, non-split, magneto-ionic components. The receivers are superheterodyne type especially designed for this application. The height is recorded continuously and simultaneously from an oscillographic presentation by two cameras, one on a 150-km range and one on a 300-km range. The short-range record is scaled every fifteen minutes to an estimated accuracy of ±1 km. The absorption is recorded by a servo on the gain of another receiver.

**Experimental Procedure**

The method of recording the reflection coefficient is the familiar procedure of Appleton. The reflection coefficient $\rho$ is given by:

$$\rho = \frac{2hE'}{kG},$$

where $\rho$ is the reflection coefficient, $2h$ is the total path, $G$ is the amplitude of the ground pulse, $E'$ is the amplitude of the first E-layer echo, and $k_1$ is a constant to be determined. $k_1$ may be determined by observation of the second E-layer reflection, $E''$, since

$$\rho^2 = \frac{E''^4 k_1}{kGk_2},$$

where $k_2$ is the ground reflection coefficient. From Terman, for a dielectric constant of 10 and a conductivity of $6 \times 10^{-14}$ emu at 150 kc $k_2$ for both vertical and horizontally polarized waves at normal incidence is in order of 0.96. Therefore,

$$\rho = \frac{2E'''}{0.96E'} = \frac{2hE'}{kG}.$$  (1)

The constant $k_1$ may thus be determined by plotting $hE'/G$ versus $E''/E'$, and observing the slope of the least-square radial line passing through the experimental points. Such a calibration is performed at least once a week.

The reflection coefficient is related to the absorption coefficient $k$ by $\rho = \exp (-\kappa ds)$ where $ds$ is the differential of the total path traversed by the wave and $\kappa ds$ is the total absorption. Hence, the absolute value of the total absorption in nepers is equal to $|\log \rho|$.

The records are scaled for $G$ and $E'$, and the reflection coefficient is computed from (1). $|\log \rho|$ is then plotted and a smooth mean curve drawn as shown in Fig. 1. The original records are examined for fine detail correlations such as sudden ionospheric disturbances, magnetic storms, and ionospheric storminess reported at short waves. The diurnal curves of $|\log \rho|$ are studied for relationship to the E-layer critical frequencies, the sun's zenith angle, and for seasonal trends.

![Fig. 1 — $|\log \rho|$ versus time for 1/18/50.](image)

**Experimental Results**

Since the virtual height enters into the calculation of the total absorption, some mention must be made of its general behavior. The virtual height of the layer as studied at 150 kc is similar to that reported by Helliwell from measurements at 100 kc. From midnight the
virtual height rises from a median value near 95 km to about 98 km at sunrise. At sunrise it drops rapidly about 10 km, then reaches a minimum near 85 km just after local mean solar noon to rise slowly again toward the midnight value. Splitting of the echo is quite prevalent, and in such cases the first echo is recorded. Tentative polarization measurements have indicated that such splits are not magneto-ionic.

Fig. 2 is a dual plot presenting the seasonal variation of the average nighttime absorption (from 2200 to 0200) and the maximum value of absorption attained each day. As will be shown later, the maximum absorption does not normally fall at local noon. The gap in the maximum absorption during the summer months represents insufficient system gain to close the curve near noon. The gap between October and November is due to equipment modification. Evident from this figure is a minimum in absorption both in day and night near the winter solstice on December 21. During this time some short period nighttime reflection coefficients were greater than unity, which could be due to some phenomenon such as focusing. Although no noon-day records have been obtained near the summer solstice, the maximum absorption can be estimated to be in the order of 7 nepers. This value is obtained by extrapolating the \( \log \rho \) curve from a known value of 0800 or 0900 to 1200 LMST by the relation

\[
\frac{\log \rho_1}{\log \rho_2} = \left( \frac{\cos x_1}{\cos x_2} \right)^n
\]

(2)

where \( x \) is the sun's zenith angle, and \( n \) is an exponent that will be determined below.

Appleton\(^4\) has shown that the total absorption, theoretically, should follow \( \cos x \) to the \( 3/2 \) power for nondeviating absorption such as is experienced by \( F \) layer reflections. It is therefore logical to assume that the total absorption at these low frequencies should also follow some \( \cos x \) law. It may be further assumed that the exponent will be smaller than \( 3/2 \), since in low frequency case we are dealing with deviating absorption in a level in the layer where collision is large. Computation have established that the quasi-longitudinal approximation to the Appleton-Hartree dispersion equation is valid for this application. Using this approximation,\(^5\) a double parabolic fit to the Chapman electron distribution curve,\(^6\) and an exponential collision frequency versus height relation, a proportionality between the total absorption and \( \cos x \) may be established.\(^7\) Such a determination is dependent on the ability to accurately, experimentally fix the location of the height of the maximum ionization, and the value of the collisional frequency at some specified height, for a given value of the sun's zenith angle. These computations have given an exponent on \( \cos x \) to be in the order of \( 0.8 \), but with an absolute value of \( |\log \rho| \) that is too small. The data have been studied to determine this exponent. It is obtained by plotting \( \log |\log \rho| \) versus \( \log \cos x \). If the plot is linear, the exponent on \( \cos x \) is the linear slope of the curve. An example of such a plot is shown in Fig. 3. The results of this study are presented in Table I.

The row entitled "total data" represents all days


\(^7\) This problem will be examined in a later paper.
whose \( \log \rho \) curves did not visually indicate any unusually perturbed condition. The second row and the third row represent the total data less any days in the CRPL-F bulletin with a storm character number of 4 or greater on short-wave ionospheric storminess or geomagnetic storminess, respectively. No significant change is evident from this elimination. The fourth row gives the total data purged of days with evidences of sporadic \( E \). Rather paradoxically, although the mean exponent has remained the same, the coefficient of variance has spread to a value of 54 per cent for the AM data. In the last row, all of the days with storms or sporadic \( E \) were cast out and in addition, only the very smoothest \( \log \rho \) curves were considered. Both the morning and afternoon mean values dropped, and the PM coefficient of variance closed up to 37.6 per cent. The consistently smaller amount of data in the afternoon is a result of a lag in the ionization, which will be discussed later, causing the PM cases to be nonlinear. It should be emphasized that the object of this Table is to find the best value of \( \chi \), and not to demonstrate the control of storms or sporadic \( E \) on these data. These values agree in order of magnitude with the value of the exponent cited above.

An important ionospheric quantity is the ratio of the noon-day values of the total absorption for summer and winter. Using the exponent 0.75 in (2) the ratio for the midday absorption between December 21 and June 21 is 1.8. This, however, does not check with the experimental value. The December 21 noon value is about 2 nepers, but the noon value at June 21 is much greater than 1.8 times this value. Using the estimated value of 7 nepers, the experimental ratio would be greater than 3.5. Such a seasonal anomaly has been reported by observers on nondeviating absorption at short waves. White and Straker\(^8\) reported a value of 2.9 experimentally against 3.73 theoretically. Appleton\(^4\) cites a value of 2.6 experimentally against a value of 6.4 theoretically for southeast England. Best and Ratcliffe\(^11\) found that both the diurnal and seasonal changes obeyed the 1.5 exponent for selected days of \( F \)-layer reflection. It is of some significance that at 150 kc the exponent necessary to explain the seasonal change is considerably larger than that given by the diurnal curves, while the converse is true at short waves.

The 3/2 law on \( \cos \chi \) for nondeviating absorption at short waves has been confirmed for selected days by Best and Ratcliffe.\(^11\) A number of other investigators have measured this exponent and found it to be lower than the theoretical value of 3/2. These lower values have been attributed to the presence of an absorbing region below the normal \( E \) region, referred to as the \( D \) layer. It is hoped that more information can be obtained on this region from a thorough study of these low-frequency results.

Fig. 4 shows the relative coincidence of the point of "inflection" of the \( \log \rho \) curve near sunrise and sunset to the variation of the actual ground sunset as given in the Ephemeris.\(^12\) These curves show that there is a close correlation of the sunrise data, but that there is a noticeable lag in the sunset point of inflection. An explanation for this latter effect will be given below.

An inspection of the complete diurnal curves of \( \log \rho \) reveals that there is a distinct skewness or displacement of these curves past local noon, contrary to the simple Chapman theory. All available complete \( \log \rho \) curves were examined for the point of maximum absorption, and a histogram of the results of this study is presented in Fig. 5. From this figure, it is evident that the maximum absorption occurs in the vicinity of 1300 hours LMST. This displacement or lag of the absorption with the sun's zenith angle corresponds with the lag noted in the sunset point of inflection in Fig. 4. Since we have seen that the AM value of \( \log \rho \) varies as the 3/4 power of \( \cos \chi \), and it has previously been established that the \( E \)-layer critical frequency varies as the 1/4 power of \( \cos \chi \),\(^13\) we then should expect \( \log \rho \) to

\(^8\) Ionospheric Data, CRPL-F, U. S. Dept. of Commerce, National Bureau of Standards, Central Radio Propagation Laboratory, Washington, D. C.


vary as the cube of the E-layer vertical incidence critical frequency $f_e$. Examining the records for such a relationship, we are immediately impressed by a similar skewness of these critical frequencies. Using critical frequencies taken from sweep-frequency records the AM value of exponent for 5 cases is 3.8 and the PM, 3.2. Using CRPL monthly means, the values are 2.85 for AM and 2.46 for PM. No other cases were examined because of the lack of high accuracy, local critical frequencies. For so few cases, these values check reasonably well with the value of 3.0. Because of a lag in the critical frequencies, the morning and afternoon values of these exponents are more nearly equal than are the exponents on cos $x$.

The lag in the diurnal variation of the ionization by observation of critical frequencies has previously been reported by Best, Farmer, and Ratcliffe, and Kirby, Gilliland, and Judson. This phenomenon can be explained in terms of recombination in Chapman's theory. Wilkes has calculated the value of recombination coefficient from the above investigator's experimental results. He has shown that the lag is small where the layer is the densest, but that the lag increases at lower levels, which conforms nicely with the 150-ke results.

**Conclusions**

The analysis of the absorption data has brought out several important facts. First, the vertical incidence absorption at night is in the order of 1 neper, and the maximum absorption in the daytime varies from 2 nepers in midwinter to about 7 nepers in summer. Second, the exponent on cos $x$ that relates it to the total absorption is about 0.7 for the morning and 0.6 for the afternoon. Third, a seasonal anomaly exists on long waves. Finally, a lag in the absorption with the sun's zenith angle is quite predominant.

**Acknowledgment**

The author would like to acknowledge the guidance of A. H. Waynick. This work was supported in part by Contract AF19(122)-44 with the U. S. Air Force, through the sponsorship of the Geophysical Research Directorate, Air Materiel Command.

**Table I**

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<td>$\bar{X}$</td>
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<td>2. Without Ionospheric Storms</td>
<td>39</td>
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<td>3. Without Magnetic Storms</td>
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<td>4. Less Sporadic</td>
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<td>5. Best Data</td>
<td>10</td>
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<td>0.202</td>
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</table>

Legend: $N =$ the number of days

$\bar{X} =$ arithmetic mean of exponent on cos $x$

$\sigma =$ standard deviation

$CV =$ coefficient of variation $= \sigma/\bar{X}$. 

---

Secondary-Emitting Surfaces in the Presence of Oxide-Coated Cathodes

S. NEVIN†, AND H. SALINGER†, FELLOW, IRE

Summary—The experiments described here show that the delterious effect of oxide cathodes on secondary-emitting surfaces of silver magnesium can be overcome by using tantalum instead of nickel as the base metal for the oxide coating.

It is well known that secondary-emitting materials are subjected to contamination from heated cathodes. The deterioration in secondary emission caused by this contamination is so serious that tubes using a hot cathode source and electron multiplication have usually been specially designed so as to make the target ("dynode") less accessible to material coming from the cathode. According to a recent paper by Mueller, this difficulty has been overcome for filamentary cathodes and also, to some extent, for indirectly heated cathodes.

The experiments described here were entirely confined to indirectly heated cathodes, and as they resulted in a novel means to avoid the contamination, a short report on them may be of interest.

I. Experimental Technique

A. Tubes

While an oxide cathode is being formed, its temperature is raised, for a short time, to a value which may be about 200° above its operating temperature. It is thus possible that the target contamination occurs, at least in part, during the forming process. Most of the experiments were therefore performed with tubes as shown in Fig. 1, with a sliding target which did not face the cathode during formation. The arrangement is cylindrical. The straight cathode K (diameter 1/4 inch) occupies the center; it is surrounded by a collector which is shaped as a squirrel cage (24 tantalum wires, three of them 0.015 inch, the others 0.005 inch thick, held together by top and bottom Ta ribbons; outside diameter 1/2 inch). The target is coaxial with the cathode and collector and can slide on three support rods S. On the pump the tube is mounted upside down, so that the target slides by gravity into the position shown in the drawing. In operation, it slides down to surround the collector.

A similar construction, without the movable features, was used on fixed-target tubes, in which the target is permanently exposed to the cathode.

Eight per cent, 4 per cent, and 1.7 per cent Mg-Ag alloy was used as target material, but the final experiments all used the 1.7 per cent alloy.

Fig. 1—Sliding target tube.

B. Forming Schedules

The procedure which worked best was as follows: The tube, after assembly of parts, is given a vacuum bake-out at 460°C, and then the cathode temperature is raised in steps, so as to outgas it. The cathode is then flashed to about 1,150°C (true temperature), and then the collector is brought up to about 200 v, with the emission rising up to 80 ma. Thereafter, the cathode is cooled, oxygen is admitted, and the target is heated for about 1 minute with radio-frequency current. This oxidizes the target, but damages the cathode so that it
has to be re-formed. Then the getter (if a getter was used) is flashed and the target once more outgassed by radio-frequency current after which the tube is sealed off.

Numerous variations of this process (such as a bake in ozone) were used at one time or another.

C. Secondary Emission

The secondary emission was measured under standardized conditions: 100 volts on the target, 200 volts on the collector; the primary current density on the target was 2.6 ma per square centimeter.

The secondary emission coefficient $K$ was defined as

$$K = \frac{I_e}{I_e - I_t} \quad (1)$$

where $I_e$ and $I_t$ are collector and target currents. This formula neglects the fraction $\alpha$ of the primary electrons which are intercepted by the collector without ever reaching the target. If this fraction is taken into account, it is found that the "true" secondary-emission coefficient $K_1$ is connected to $K$ as defined above by the formula

$$K - 1 = (K_1 - 1) (1 - \alpha) \quad (2)$$

Attempts to determine $\alpha$ met only with a limited success; the best estimate is that $\alpha = 20$ per cent in our tubes. This would mean that $K = 3$ really corresponds to a "true" coefficient $K_1 = 3.5$. The data recorded below refer to $K$ rather than $K_1$, because $K$ gives a more direct measure of the practical gain than can be realized in a secondary-emission tube.

The $K$ measurements were performed with direct current, but in order to guard against the possible presence of time delays, as in the Malter effect, it was ascertained that the collector current perfectly reproduces the cathode-emission variations, at least up to 1 Me.

For life tests, it was necessary to keep the primary emission current of the cathode constant. This proved difficult, because any excess emission led to a noticeable increase in collector temperature which, by radiation, caused the cathode temperature to rise, thus increasing the emission still further. For the life tests, therefore, a thyratron circuit was used in the filament supply, controlled by the emission current so as to keep it constant.

II. Results

Early results indicated that the decay in secondary emission depended very much on the cathode temperature. It became increasingly clear that the contamination came from the nickel base rather than from the oxide (barium-strontium carbonate, sprayed to a thickness of 0.002 inch with an amy1 acetate binder, was used throughout). The base was a nickel sleeve (#799 D11 in most cases). By a properly chosen formation schedule, we finally succeeded in achieving a constant secondary-emission ratio over several hundred hours on sliding targets. But even more constant results were obtained, on fixed as well as sliding targets, after the nickel sleeve had been replaced by tantalum. This was done on the assumption that a material which evaporated less easily than Ni should be used.

Fig. 2 shows life data taken on tube #365 (sliding target) and #368 (fixed target), both of which had a Ta sleeve as base for the oxide coating. As a further proof that Ta sleeves, even when run at overtemperature, cause no contamination, the record of tube #358 is offered: This tube was operated at the usual emission current of 10 ma for 240 hours, showing a secondary-emission coefficient of $K = 3.2$. From 240 to 375 hours the emission was raised to 15 ma, giving $K = 3.4$. Thereafter, the emission was raised to 40 ma for 8 hours. During this time, values of $K$ between 2.3 and 2.5 were measured, but it is almost certain that space charge formed between target and collector. When the emission was again lowered to 10 ma, $K$ was 2.9 and stayed at this value. Similar, though less exacting, experiments with Ni always showed a rapid and permanent decay of $K$ to values below 2.

One other experiment may be quoted to support the idea that the nickel sleeve is the source of contamination. In a tube of somewhat different construction it was possible to expose a target to a #799 Ni base without oxide coating. This base was heated to about 900°C. $K$ dropped within 4 hours from its initial value of 3.2 to 1.9.

A similar experiment was performed in which Ba was evaporated. This, too, caused a rapid decay in secondary emission. The decay caused by an oxide cathode has commonly been ascribed to barium, while there are also accounts which seem to minimize the importance of Ba. From our experiments, we are inclined to agree with this latter view.

2. This circuit was designed and built by H. Beach.
III. Discussion

While these experiments prove that the main source of contamination comes from the Ni sleeve, there may be some doubt whether the nickel itself is to blame or some impurity in it. It may however be noted that Ni reaches a vapor pressure of $10^{-4}$ mm Hg at 1,160°C, i.e., slightly above the operating temperature, whereas Ta would have to be heated to 2,400°C in order to reach the same vapor pressure. It is, therefore, quite possible that the contaminating substance is the nickel itself.

Using Ta, or some other metal with a low vapor pressure, instead of Ni, is entirely practical. It has been argued that oxide cathodes on a Ni base have a higher efficiency than those on other base metals. Our experiments have not extended in that direction; however, even if it should be found that the cathode temperature has to be slightly higher on Ta than on Ni, this would be a small price to pay for the resulting increase in tube life.

As good results were obtained in fixed-target tubes, it is seen that no special structure is required to prevent exposure of the target to the cathode during formation. This may be stated somewhat more generally as follows: Any contaminating agent which might come from the cathode during formation will be harmless if it is either not evaporated below the cathode-forming temperature (1,100°C) or else if it does not react with the target and can be re-evaporated below the target outgassing temperature (about 600°C).

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On Poisoning of Oxide Cathodes by Atmospheric Sulfur

H. A. STAHL†

B Y ELECTRON diffraction Huber and Wagener have found that on commercial oxide cathodes occasionally a face-centered space lattice appears. According to the lattice constant (d = 6, 37 Å), this lattice had to be attributed to barium sulfide. The question as to the origin, and effect of that sulfide on the emissivity was followed up during World War II.

This investigation was carried through both on colloidal mixed carbonates, after Bußg and co-workers, and routine pastes precipitated from barium-strontium nitrate, or hydroxids. All the cathodes were either spread cataphoretically, or sprayed upon flat casings. In the latter case, an additional surface glazing by means of an amber roller was necessary. After conversion to oxide in the diffraction camera the cathodes were scrutinized at grazing incidence.

So as to identify the origin of cathodic sulfur, about 120 cathodes were distributed into several groups and stored for several months. They were laid on routine bakelite trays, on fluted cardboards, in Petri dishes, or were hung on nail boards, all exposed to the free access of air. Some control cathodes were sealed into glass bulbs, and evacuated.

These storage experiments showed that the strongest diffraction rings of BaS space lattice appear after a period fluctuating within wide limits from some days to several months, and that on all cathodes, except in sealed ones, nearly simultaneously. If so, the barium sulfide ring intensity gradually increased with storing period. As to the speed of sulfurizing, no reproducible results could be attained, however.

The observations suggested that cathode sulfur originates from atmospheric air, the sulfur content of which varies, especially in cities and industrial districts, by a factor of 10. An average value is approximately 10−6 per cent by volume.

Tests on freshly made cathodes showed strong barium sulfide rings after exposing them for some seconds to hot combustion gases of a city gas-fed Bunsen burner. The same result appeared with cathodes exposed for 15 minutes to air containing 1 per cent sulfur dioxide, hydrogen sulfide, or carbon disulfide.

Emission measurements on sulfurized cathodes yielded a remarkable decrease of emissivity with increasing sulfur content (see Fig. 1). In accordance with Hiroshi Kamagawa’s results on glasses rich in barium oxide, it was concluded that on the cathode surface that was not broken down, a barium sulfite or sulfate was formed by atmospheric sulfur. This was thought to be reduced while converting at 1360° K, because of the carbon content of the collodion paste used. Attempts to confirm the existence of sulfate or sulfate on the spread carbon surface failed, however.

It was felt worth while mentioning that several air-hygienists employ Ost’s “baryta patch method,” the main feature of which is barium carbonate as a detergent for atmospheric sulfur (both SO2 and SO3). The action of barium carbonate in this case is, in several respects, much the same as on the cathode surface. Their manners of spreading differ by irrelevant subordinates only.

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Amplification by Acceleration and Deceleration of a Single-Velocity Stream

A method of amplification at microwave frequencies based upon the growth of space-charge waves in a decelerating stream of electrons has recently come to our notice. This mechanism became evident during a study of the type of waves described by Hahn and Ramo. It was found here that these waves not only change in length as the stream velocity changes, but also change in amplitude.

By a suitable combination of gradual decelerations and sudden accelerations, the amplitude of the space-charge wave may be essentially arbitrarily increased without the necessity for either wave carrying circuits, additional ions, or electron streams with different or distributed velocities, or space-charge-produced differences of velocity in a single stream.

An even simpler mechanism of amplification involving only short accelerating and decelerating gaps and constant potential drift regions exists which is closely related to the one just described. Consider a space-charge wave with ac velocity \( v_1 \) and an ac convection current density \( i_1 \) on a stream of electrons at a dc velocity \( v_0 \), described by

\[
\psi = \psi_0 \cos \left( \frac{\omega z}{v_0} \right) e^{-i \omega t / \omega x} \tag{1}
\]

where \( \omega = qE/v_0 \) and \( i_1 \) is the dc beam-current density. Now if at a position along the stream at which the ac velocity reaches its maximum velocity \( v_0 \), the dc velocity is suddenly changed from \( v_0 \) to a lower value \( u_1 \), the ac velocity will increase from \( v_0 \) to \( v_0 \), such that

\[
v_0 = v_0 \sin \frac{\omega z}{v_0} \tag{2}
\]

provided only that the dc velocity change occurs in a distance which is short compared with a quarter space-charge wavelength at the low velocity. That this is so can be demonstrated by simple kinematics or by application of the Llewellyn-Peterson diode equations.

If the beam is then allowed to drift at the low velocity \( u_1 \) for an odd number of quarter space-charge wavelengths, that is, until the ac velocity has disappeared and the ac convection current which it produces is in phase with this current \( i_1 \) will be

\[
v_1 = v_0 \sin \frac{\omega z}{v_0} \tag{3}
\]

in which \( i_1 \) is the maximum ac convection-current density which would have been produced by the velocity modulation \( v_0 \), if the stream had remained at the velocity \( u_1 \). At this point the stream may be suddenly returned to the dc velocity \( u_1 \). If this is again done in a distance which is short compared with the quarter space-charge wavelength at the lower velocity, the ac convection current is continuous across the gap, and the stream has returned to the original dc velocity with an ac current modulation which has been amplified from its original value by \( (u_1/v_0)^{3/2} \). If the beam is again allowed to drift an odd number of quarter space-charge wavelengths, this current will convert to an ac velocity which is also \( (u_1/v_0)^{3/2} \) times its original maximum value.

The dc velocity may be suddenly dropped by avoiding this process of repeated. Thus each stage consisting of one short low-velocity drift space and one long high-velocity drift space will provide an ac power amplification of \( (V_1/V_2)^{3/2} \), where \( V_1 \) and \( V_2 \) are the dc voltages in the high- and the low-velocity drift spaces, respectively.

Amplification appears to be essentially independent of beam-current density, although the density determines the required lengths of the drift spaces, and the total beam current determines the maximum obtainable ac convection current, and hence the large signal saturation level.

An amplifier based on the above principles has been constructed and has provided a net power gain of 22 db at 3,000 Mc, using a single low-voltage drift region at 51 volts and two helices at 1,900 volts for modulation and demodulation of the stream. With the potential of the center drift region raised to 1,900 volts, the gain changed to zero db. Gain of progressively larger amounts was observed at drift region voltages of 178 volts, 117 volts, 78 volts, and 51 volts corresponding to \( \pi \) quarter space-charge wavelengths in the 5-cm drift space where \( n = 5, 7, 9 \), and 11, respectively. The total beam current was 0.7 ma and the approximate beam diameter, 0.15 cm.

At sufficiently high signal frequencies, the effective plasma frequency in the stream is reduced because of the finite beam size, and consequently the gain is reduced. At very high frequencies, it becomes difficult to excite the first-order plasma waves used in the above discussion, and higher-order space-charge waves will appear. It seems that they can be used to give gain, but require longer drift spaces and will saturate at lower power levels.

Finally, it might be mentioned that space-charge wave frequency may be decreased as well as amplified by using similar principles, and where noise exists on the stream in the form of space-charge waves, the noise content in a limited frequency range may be reduced in this fashion. This has been experimentally verified in some low-noise traveling-wave amplifiers.

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The Traveling-Wave Cathode-Ray Tube

The paper by K. Okawa, S. Terahata, T. Hada, and T. Nakamura on "The Traveling-Wave Cathode-Ray Tube," in the October, 1950, issue of the PROCEEDINGS OF THE I.R.E., reveals significant progress in the field of microwave oscillography. In order to establish the development of this art—for 20 years of the writer's hobby—the following comments may be of some interest.

The prototype of the traveling-wave deflecting system are the multiphase deflecting plates. According to Fig. 1(b) and (c), they consist of subsequent pairs of deflecting plates exhibiting alternate polarity due to their cross-connections. Maximum

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Fig. 1—(1) Single-, (2) two-, and (3) three-phase deflecting field.
sensitivity occurs, of course, if frequency and beam velocity are matched in such a way that the traveling electrons pass the field always whenever they have the same polarity.

The improvement caused by the multiphase deflection, as compared with a single field (Fig. 1(a)) under dc operation, can be expressed by means of the multiphase inversion formulas:

\[ p_i = \frac{\sin \frac{\phi}{2} - 2 \sin \frac{\phi}{6}}{\sin \frac{\phi}{6}} = \frac{1}{2} \phi \sqrt{1 - \cos \frac{\phi}{2}} \]

where \( \phi \) denotes the transit-time angle over the total deflecting system:

\[ \phi = \frac{\omega L_c}{v_B} = \frac{\lambda I}{\sqrt{V_p \text{vol}} \times 10^4} \]

(\( \omega \) = velocity of light; \( v_B \) = beam velocity; \( V_p \) = plate voltage). The function \( P_1 \) is the almost classic inversion factor of a single field, \( \phi \) is the dynamic sensitivity at any vhf referred to the static sensitivity. The functions \( P_1 \) and \( P_3 \) are the two- and three-phase versions. All three functions are diagrammed in Fig. 2. The two-phase system for dc produces no deflection whatsoever because the first partial field compensates the second field. The curve of the three-phase system starts at \( \frac{1}{3} \) because only one partial field remains effective. The loss of static sensitivity, however, is compensated for by the shifting of the dynamic maxima towards higher \( \phi \)-values or higher frequencies, respectively. The first \( P_1 \)-maximum occurs in the vicinity of \( 2\phi \) and \( P_3 \) in the vicinity of \( 3\phi \) which, in terms of present-day language, means accord between phase and beam velocity.

The inversion spectrophotograph \(^1, ^2, ^5\) produces the inversion spectra shown in Fig. 3. The stray fields, \(^3\) not included in the multiphase analysis, assure only a qualitative agreement between formulas and experiment. The fact that the maxima of an \( N \)-phase system remain below one and do not appear accurately at \( N\phi \) is caused by the transit-time effects of the first kind, i.e., by the transit time elapsing in each individual field as well as by the phase-jumps.

The disadvantage of the earlier multiphase systems with equal and adjacent fields can be overcome by various means. The simplest method is to diminish the axial length of the partial fields or that they operate quasi-statically with sufficient interspace in-between; however, this does not eliminate the stray field effects. Another method was applied by Pierce \(^4\) in his multiphase or traveling-wave oscilloscope, wherein the former phase opposition is reduced by means of lumped-constant circuits, each feeding an individual pair of plates. From this device, only a short step leads to the traveling-wave oscilloscope described in Heff's patent \(^5\) and by the Japanese authors.

The ultradynamic Lissajous figures shown in the Japanese paper are the same as the writer's figures taken as far back as ten years ago. \(^5, ^7, ^9, ^11, ^12\) The writer's method of graphical analysis may well be applied to the Japanese figures. This may easily be understood because the traveling-wave system eliminates only the transit-time effect of the first kind but does not affect that of the second kind, namely, the transit time between both perpendicular deflecting fields.

All in all, the analogy between the step from the multiphase fields to the traveling-wave oscilloscope on the one hand and the step from the linear electron decelerator to the traveling-wave tube on the other hand is quite obvious.

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**Correspondence**

**Representation on Circuit Diagrams of Conductors in Contact**

In Fig. 14 of M. A. Schultz's paper \(^1\) on "Linear Amplifiers," the lead to C26 and J4 (discriminator output) is drawn as making contact with the "ground" line. This is an obvious mistake, caused by putting a spot at the intersection of two conductors.

This occurrence prompts me to draw attention to the recommendation which has appeared for the last sixteen years in the British Standard Specification No. 530. \(^3\)

"Of wires meeting at a connecting point, not more than two should be shown colinear."

They should be shown thus:

\[ \begin{array}{c}
\text{Fig. 3—Experimental inversion spectra of the multiphase systems.}
\end{array} \]

\[ \begin{array}{c}
\text{Fig. 2—The dynamic sensitivities of the three systems shown in Fig. 1 versus transit-time angle.}
\end{array} \]

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\(^1\) A. Heff, U. S. Patent No. 2,064,409.


\(^7\) H. E. Hollmann, "Die Braunsche Röhre bei sehr hohen Frequenzen. II. (The cathode-ray tube at vhf), Zeit. für Hochfrequenz, vol. 40, p. 97, 1932.

\(^8\) H. E. Hollmann, "Die Braunsche Röhre bei sehr hohen Frequenzen. III. (The cathode-ray tube at vhf), Zeit. für Hochfrequenz, vol. 40, p. 97, 1932.


\(^12\) H. E. Hollmann, "Die Braunsche Röhre bei sehr hohen Frequenzen. VII. (The cathode-ray tube at vhf), Zeit. für Hochfrequenz, vol. 40, p. 97, 1932.

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**L. H. Bainbridge-Bell**

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\(^1\) Received by the Institute, June 22, 1950.


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From 1946 to 1949 Dr. Benner was a research engineer with the Ordnance Research Laboratory, State College, Pa. From 1949 through 1950 he was associated with the Radio Propagation Laboratory of that College. He is a member of Sigma Xi and Tau Beta Pi.

A. H. BENNER

Robert C. Ellenwood (A’44) was born in Wooster, Ohio, on July 13, 1917. He received the B.S. degree from Ohio University in February, 1942, and after graduation he was employed by the Crosley Radio Corporation as a development engineer. During the war he served as a radio technician in the United States Navy. From 1945 until 1950 he was employed by the National Bureau of Standards as a research engineer to work on ultra-high-frequency standards and associated problems.

At present Mr. Ellenwood is an electronics engineer for the Electronics Shore Division, Bureau of Ships, Navy Department, in Washington, D.C.

GORDON C. DEWEY

Gordon C. Dewey (A’47) was born in New York, N. Y., in 1923. He received the B.A. and the M.A. degrees in physics, both from Harvard University. Mr. Dewey was a wartime member of the staff of the Radiation Laboratory at the Massachusetts Institute of Technology. From February, 1947, to July, 1949, he was associated with the Federal Telecommunication Laboratories, Inc., during which time the work described elsewhere in this issue was carried out.

Since September, 1949, Mr. Dewey has been a member of the Weapons Systems Evaluation Group which was formed in the National Military Establishment during February, 1949, under the sponsorship of the Joint Chiefs of Staff, the Office of the Secretary of Defense, and the Research and Development Board.

Sze-Hou Chang (S’16–A’48) was born on September 23, 1913, in Ningpo, Chekiang, China. He received the B.S. degree in electrical communications by the Chiao Tung University, Shanghai, in 1934. In 1946 he received the M.S. degree in communications engineering and, in 1948, the Ph.D. degree in engineering sciences and applied physics, both from Harvard University.

During the period from 1934 to 1945, Dr. Chang served successively as assistant, lecturer, and professor in Tsing Hua University, Hunan University, and Chiao Tung University, all in China. He was associated with Cambridge Research Laboratories in Cambridge, Mass., as an electronic engineer from 1946 until 1948.

Dr. Chang is now an associate professor of electronic research at Northeastern University, Boston, Mass.

Sze-Hou CHANG

Enoch B. Ferrell (A’25–M’29–SM’43) was born in Sedan, Kan., on June 1, 1898. He received the B.A., B.S. in electrical engineering, and M.A. degrees from the University of Oklahoma in 1920, 1921, and 1924, respectively. Mr. Ferrell taught in the department of mathematics of that university until 1924.

Since 1924 Mr. Ferrell has been a member of the research department of the Bell Telephone Laboratories, where he has been engaged in work on short-wave and ultra-short-wave radio transmitters, and on relays and switching systems for use in the telephone central-office plant.

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Mr. Essigmann holds associate membership in the American Institute of Electrical Engineers and Sigma Xi, and is a member of the American Association for the Advancement of Science, the American Society for Engineering Education, and Tau Beta Pi.

Donald G. Fink

Donald Glen Fink (A’33–SM’45–F’47) was born on November 8, 1911, in Englewood, N. J. He was graduated in 1933 from the Massachusetts Institute of Technology with the B.S. degree in electrical communications. After a year as a research assistant on the staff of the departments of geology and electrical engineering at MIT, Mr. Fink joined the staff of the journal Electronics, as editorial assistant. In 1937 he became managing editor; in 1945, executive editor; and in 1946, editor-in-chief. In 1942 he was awarded the degree of M.Sc. in electrical engineering by Columbia University.

Obtaining a leave of absence from Electronics in 1941, Mr. Fink became a member of the staff of the Radiation Laboratory at MIT, where, in 1943, he headed the loran division. He then transferred to the Office of the Secretary of War as an expert consultant on radio navigation and radar. During his war service Mr. Fink traveled over 80,000 miles from Cairo, Egypt, to Darwin, Australia, sitting loran stations and arranging for the use of the loran system by the allied forces. He participated in the atom bomb tests at Bikini, also.

Mr. Fink is the author of numerous books, including “Engineering Electronics,” “Principles of Television Engineering,” and “Radar Engineering.” As editor of the
Contributors to the Proceedings of the I.R.E.

Theodore S. George was born on October 10, 1911, at Grove City, Pa. He received the B.S. degree in mathematics from Grove City College in 1932, and the M.A. and Ph.D. degrees in mathematics from Duke University in 1936 and 1942, respectively. From 1938 to 1945 he served as instructor and assistant professor of mathematics at the University of Florida. During the period from 1942 to 1945 he was on military leave as a Naval electronics officer, leaving the university with the rank of lieutenant commander. During this time, he served as a radar officer aboard a carrier and later in the Bureau of Aeronautics in charge of development of electronic bombing and fire-control devices.

Since the war Dr. George has been a consulting engineer in the research division of the Philco Corporation doing theoretical work in a variety of electronic problems.

T. S. GEORGE

Scott Nevin was born on September 11, 1924, in Ithaca, N. Y. He received the B.M.E. degree from Cornell University in 1945.

He joined the Capchart-Farnsworth Corporation in Fort Wayne, Ind., in 1946. Since that time, Mr. Nevin has worked on cathode-ray tubes. His recent research has also included the study of secondary-emission devices.

SCOTT NEVIN

Theodore J. Marchese (A’44-SM’50) was born in Carlstadt, N. J., on October 17, 1912. In 1932 he was employed by the Federal Telegraph Company as a technician in their vacuum-tube department and he worked at a number of technical and supervisory jobs until 1941, when he joined the engineering department of Federal Telephone and Radio Corporation as a vacuum-tube engineer on large tubes.

In 1947 he transferred to the Federal Telecommunication Laboratories, Inc., as an engineer on microwave power generators, and is presently employed in the development of negative-grid and traveling-wave amplifier tubes.

He received the B.S. degree in electrical engineering in 1948 from the evening school of Newark College of Engineering.

T. J. MARCHESCE

Eleanor M. McElwee was born in New York, N. Y., in 1924. She received the A.B. degree in English and mathematics from LaFayette College, Highland Falls, N. Y., in 1944, and has done additional work in science at Cooper Union.

Miss McElwee was employed by the Western Electric Tube Shop in New York, N. Y., from 1944 to 1947 as assistant product engineer. She joined the staff of Sylvania Electric Products Inc., in 1947, and was in charge of the statistical analysis program and life-testing of tubes for the Product Development Laboratories at New Garden, L. I., N. Y., until early in 1950. She is at present a member of the editorial and information section at the same Laboratory.

ELEANOR MCELWEE

William C. Jakes, Jr. (S’43-A’49) was born in Milwaukee, Wis., on May 15, 1922. He received the B.S.E.E. degree from Northwestern University in 1944, then entered the Navy and served for two years as airborne electronics officer. He returned to Northwestern University in 1946 for graduate study, receiving the M.S. degree in 1947 and the Ph.D. degree in 1949. During part of this time he was employed by the Microwave Laboratory at Northwestern as a research associate.

Since July, 1949, Dr. Jakes has been a member of the technical staff of the Bell Telephone Laboratories, Inc., engaged in microwave propagation and antenna studies. He is a member of Sigma Xi, Eta Kappa Nu, and Phi Mu Epsilon.

W. C. JAKES, JR.

Eleanor M. McElwee

Philip Parzen was born on June 28, 1916, in Poland. He received the B.S. degree in physics from the College of the City of New York in 1939 and the M.S. degree in physics from New York University in June, 1946. He is at present completing his work for the Ph.D. degree in mathematics at New York University.

During the war he was employed at the Westinghouse Research Laboratories and, since 1947, at the Federal Telecommunication Laboratories, Inc., working on problems in microwave tubes and electromagnetic wave propagation. Mr. Parzen is a member of the American Physical Society.

PHILIP PARZEN

George E. Pihl (A’41) was born on February 22, 1915, at Brockton, Mass. He received the B.S. degree in electrical engineering from Northeastern University in 1937 and the M.S. degree in communications engineering from the Harvard Graduate School of Engineering in 1939.

Since 1938 Mr. Pihl has been a member of the faculty of Northeastern University, where he is at present an associate professor. He is a member of the American Institute of Electrical Engineers and Tau Beta Pi.

GEORGE E. PIHL
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Hugo F. Pit was born in Utrecht, Netherlands, on April 3, 1924. Having attended the Haarlem Gymnasium, he is now studying electrical engineering at the Delft Institute of Technology. The study of oscillator behavior in this issue of the Proceedings was a result of his activities in the Central Laboratory of the Netherlands Postal and Telecommunications Services during the summer of 1949.

Evert J. Post was born in Rotterdam, Netherlands, on October 20, 1914. He received the degree of Physical Engineer from the Delft Institute of Technology.

In 1946 Mr Post joined the Central Laboratory of the Netherlands Postal and Telecommunications Services at The Hague where he has been primarily concerned with the development of quartz crystals and oscillators.

Mr. William E. Ryan (S'43-A'45) was born in Springfield, Mass., on February 6, 1920. He received the B.S. in both electrical engineering and mathematics from Michigan University in 1943. He was enrolled in evening classes at George Washington University Graduate School in Washington, D.C., from 1946 to 1950. From 1943 to 1944 he was employed by the Naval Research Laboratory as a radio engineer assisting in tests of anti-aircraft gun directors.

Since 1944, Mr. Ryan has been employed by the National Bureau of Standards, assisting in the development of field intensity standards. At present he is associated with the Ultra-High Frequency Standards Group of the Microwave Standards Section of CRPL in Washington, D.C. He is a member of Eta Kappa Nu and Sigma Pi Sigma.

Hans Salinger (A'37-SM'46-F'51) was born in Berlin, Germany, on April 1, 1891. In 1915, he received the Ph.D. degree from the University of Berlin. From 1919 to 1929 he was a research associate at the Reichspostcentralamt. From 1929 to 1935, a professor at the Heinrich Hertz Institute, both in Berlin. In 1936, he joined Farnsworth Television, Inc., and is now a research engineer with the Capehart-Farnsworth Corporation in Fort Wayne, Ind. He is also doing part-time teaching at the Purdue University Extension Center in Fort Wayne.

Dr. Salinger has published numerous papers on filters, measuring methods, electron multipliers, and other subjects. He is a member of Sigma Xi, the American Association for Advancement of Science, and the American Physical Society.

H. A. Samulon (A'46) was born in Graudenz, Germany, in 1915. He attended the Swiss Federal Institute of Technology in Zurich, graduating with the degree of dipl. ing. in 1939. After doing postgraduate work at the Institute of High-Frequency Techniques, he was employed from 1945 to 1946 as an instructor and research engineer at the Institute of Communication Techniques and the Acoustical Laboratory of the Swiss Federal Institute of Technology.

In 1947, Mr. Samulon joined the Electronics Department (Electronics Laboratory Division) of the General Electric Company, where at present he is mainly engaged in TV problems, with special regard to transient phenomena as well as system problems in black-and-white and color television.

Howard E. Sowards (A'48) was born in Hewitt, Texas, on August 10, 1918. He received the B.A. degree in mathematics from Baylor University in 1940. After a year as instructor of mathematics and physics in the Sabinal, Texas, Public High School, he joined the technical staff of the National Bureau of Standards. He attended night classes of the George Washington Electrical Engineering School from 1941 to 1945, following which he entered the Graduate School, receiving the M.A. degree in physics in 1948. At present he is enrolled in the University of Maryland Graduate School. From 1941 to 1943 he assisted in various phases of the program for the development of field intensity and voltage standards. During World War II he assisted in several projects of the radar electronic countermeasures program conducted by the National Bureau of Standards for the Bureau of Ships. From 1947 to present he has been in charge of the Ultra-High Frequency Standards Group, Microwave Standards Section, CRPL, Washington D. C.

Mr. Sowards is a student member of AIEE and is an associate member of Sigma Pi Sigma and Sigma Xi. At present he is a member of the AIEE Sub-Committee Radiation Measurements above 300 Mc.

Raymond E. Zenner (M'46-SM'50) was born in Chicago, Ill., on April 16, 1910. He received the B.S. degree in physics from the University of Chicago in 1933, and has pursued graduate studies at the Illinois Institute of Technology. He has been employed in development and research work with the Teletype Corp., the A. B. Dick Co., Eicor, Inc., and the Armour Research Foundation, all of Chicago, on printing telegraph systems and terminal equipment, mimeograph products, magnetic recording research and product design, ordnance development, and tactical situation simulators for training military personnel. He is now supervisor of instrumentation and recording, electrical engineering department, at Armour Research Foundation.

Mr. Zenner is serving on the Sound Recording and Reproducing Committee, the Magnetic Recording Subcommittee, and the Annual Review Committee of the IRE, and also on the RMA Magnetic Recording Subcommittee.
Institute News and Radio Notes

TECHNICAL COMMITTEE NOTES

The Standards Committee, under the
hairmanship of Professor J. G. Brainard,
eld a meeting on December 14. The fol-
lowing Standards have been approved by
this Committee: Proceeding: Standard on Elec-
trical Properties: Definition of Terms, prepared
by the Electrical Properties Committee of IRE;
and Standard Abbreviations of Radio Elec-
tronic Terms, prepared by the Symbols
Committee. . . . On November 28, the Wave
propagation Committee held a meeting, at
which C. R. Burrows presided as Acting
chairman. Reports on the activities of the
various Subcommittees were given by the
chairmen. The Receivers Committee
under the Chairmanship of R. F. Shea held
meeting on November 1. Reports on the
progress of work going on in the Subcommit-
tees were given by the Chairman. This
Committee is working towards the comple-
tion of a Standard on Radio Receivers:
Methods of Measurement of Spurious Radi-
ation, Frequency Modulation and Television
receivers. It is expected that this Standard
will be available in the Fall of 1951 . . . A
meeting of the Video Techniques Committee
was held on November 16, under the Chair-
smanship of J. E. Keister. Subcommittee 23.3,
Video Systems and Components, prepared
two tutorial papers which appeared in the
January issue of the PROCEEDINGS, and work
onwards the preparation of more tutorial
papers is continuing. The Video Techniques
Committee also prepared a Standard on
Television: Methods of Measurement of
Electronically Regulated Power Supplies,
published in the January issue of the
PROCEEDINGS, reprints of which may now be
purchased from Headquarters. . . . Reprints
of Standards on Circuits: Definitions of
Terms in Network Topology, may also be
purchased at Headquarters. . . . The pro-
posed Standards on Electronic Computers:
Definition of Terms, prepared by the Elec-
tronic Computers Committee of the IRE, has
been approved as an IRE Standard and will
be published in the March issue of the
PROCEEDINGS. . . . Axel G. Jensen, Chairman
of the Definitions Co-ordinating Sub-
committee, has distributed to all Technical
Committee Chairmen copies of a Proposed
standard on Definitions of Receiver Terms,
prepared by the Receivers Committee, and
also a proposed definition for the term
transfer characteristics. This is in line with
the new procedure to obtain comments on
the definitions by mail prior to submission
of the Standards Committee for approval.
. . . A Joint IRE/AIEE Conference on Elec-
tron Tubes for Computers was held on
December 11 and 12 at the Haddon Hall
Hotel, Atlantic City, N. J. Members of the
IRE Technical Committee on Electron
Tubes and Solid-State Devices, and the
Committee on Electronic Computers, par-
Tubing in Display at IRE CONVENTION

The devices shown above, which will be on dis-
play at the Armed Services exhibit, are typical of
the wide variety of electronic equipment to be shown
at Grand Central Palace during the IRE Convention.
At top is the console of a Cloud Base and Top
Indicator, capable of measuring the thickness of over-
head cloud decks from 300 to 50,000 feet, through
rain if necessary. Continuous facsimile recordings are
provided.

bottom is a new device for measuring the ex-
tent of exposure of individuals to atomic radiation.
The dosimeter, which is worn around the neck, gives
readings one minute after exposure through a self-
developing photographic process.

Calendar of COMING EVENTS

1951 IRE National Convention, Wal-
dorf-Astoria Hotel and Grand
Central Palace, New York, N. Y.,
March 19-22
URSI Spring Meeting, Washington,
D. C., April 16-18
IRE Southwestern Conference, Dal-
as, Texas, April 20-21
1951 Convention of SMPTE, April
30-May 4, Hotel Statler, N. Y.
1951 Annual Meeting of the Engineer-
ing Institute of Canada, Mount
Royal Hotel, Montreal, May 9-11
1951 IRE Technical Conference on
Airborne Electronics, Biltmore
Hotel, Dayton, Ohio, May 23-25
1951 IRE 7th Regional Conference,
University of Washington, Seat-
tle, Wash., June 20-22
1951 Summer General Meeting of
AIEE, June 25-29, Royal York
Hotel, Toronto, Canada
1951 IRE West Coast Convention,
San Francisco, Calif., August 20-
31

1951 IRE Convention Slated
FOR MARCH 19-22 IN NEW YORK

The 1951 IRE National Convention, to
be held on March 19-22 in New York, N. Y.,
promises to be the largest and most im-
portant convention in Institute history. An
extensive technical program of over 200 pa-
pers will be presented in 43 sessions and sym-
posia at the Waldorf-Easton Hotel, Belmont
Plaza Hotel, and Grand Central Palace. The
Radio Engineering Show, comprising 269
exhibits of electronic and communications
equipment and their applications, will fill
three floors of Grand Central Palace.

The Convention will open with the An-
nual Meeting of the Institute on Monday
morning, March 19, in the Grand Ballroom
of the Waldorf. James W. McCane, director
of transmission development for Bell Tele-
phone Laboratories, will be the principal
speaker. In addition, reports will be heard
from IRE officers concerning the operations
of the Institute during 1950. The program
of technical sessions will commence on Monday
afternoon.

A noteworthy feature of the technical
program is the prominent part played by
IRE Professional Groups in organizing sym-
posia in their respective fields of interest.
Fourteen symposia are scheduled for this
year's program, eleven of which are the re-

result of Professional Group activities. The
sponsoring Groups and the titles of their
symposia are as follows: Audio Group—
"Loudspeakers"; Broadcast Transmission
Systems Group—"Broadcast Transmission
Systems" and "Panel Discussion on the Em-
pire State Story"; Circuit Theory Group—
"New Extensions of Network Theory"; In-
strumentation Group—"Amplification of
DC Signals," "Panel Discussion on Perfor-
mance of DC Amplifiers," and "Industrial
Instrumentation"; Nuclear Science Group—
"Nuclear Reactors"; Quality Control Group—
"Panel Discussion on Tube Reliability";
Radio Telemetry and Remote Control
Group—"Telemetering Systems" and "Sim-
ulation as an Aid To Design of Remote
Control Systems."

Symposia will also be held on the follow-
ing subjects: "Matching Schools and Indus-
try" (sponsored by the IRE Education Com-
mittee), "Color Television," and "Some Sys-
tems Problems of Air Traffic Control."

The complete program, with abstracts
of all papers, will be published in the March
issue of the PROCEEDINGS.

The attention of broadcast engineers is
called to "Broadcast Day" on Tuesday,
March 20, when two Broadcast Group
symposia (as noted above) will be held in
the morning and afternoon, climaxed by the Color
Television symposium on Tuesday night.

Of particular interest to all Professional
Group members will be the President's
Luncheon on Tuesday where tables will be
assigned to each Group, allowing Group
members a unique opportunity to broaden
their contacts within their own fields.
First Call for Papers for West Coast IRE Convention

Authors are invited to submit prospective papers for the 1951 West Coast IRE Convention, particularly in the fields of Antennas, Circuits, Computers, Propagation, and Vacuum Tubes. The Convention will be held in San Francisco on August 29, 30, and 31. The following information should be submitted: (1) Name and address of author, (2) title of paper, and (3) a 100-word abstract and such additional information as may be required in order to properly evaluate the paper for inclusion in the technical program.

Please address all material to J. V. N. Granger, Stanford Research Institute, Stanford, Calif. The deadline for acceptance is May 1, 1951. Your prompt submission will insure full consideration.

Deadline Set for Papers for IRE 7th Regional Conference

Persons or companies are invited to submit prospective papers for the IRE 7th Regional Conference of 1951, to be held at the University of Washington, Seattle, Wash., on June 20, 21, and 22. In addition, manufacturers are invited to display equipment specifically tied in with the papers they may present. The following information should be submitted: (1) Name of paper, (2) author, (3) person or persons who will present it, (4) synopsis and (5) will equipment tie-in with the paper be displayed.

The deadline for acceptance is March 31. Please send all material to J. E. Hogg, Electronics Department, General Electric Co., 1146 Dexter Horton Building, Seattle, Wash.

NAB Conducts Third Annual Survey of TV Employment

Approximately 8,500 persons comprise the staffs of the TV stations and networks now on the air, according to an estimate announced by Richard P. Doherty, director of the National Association of Broadcasters' Employee-Employer Relations Department, in the third NAB annual TV employment survey. The compilation was based on information supplied by 56 TV stations (exclusive of networks) for a typical operative week during the late spring of 1950.

The increasing number of television stations which have become operative during the past year has reduced the "per station" employment average from 60 to 57 persons, according to the findings of the survey. The "per station" employment decline is a statistical consequence of the operational increase within the industry. The 1949 survey revealed the average station (exclusive of networks) employed 66 persons (16 full-time and 20 part-time); the mean in the spring of 1950 was 57 (39 full-time and 18 part-time). The reasons, in part, for this drop are that new stations are on the air less time than the established telecasters; and,
The Expansion of the IRE Professional Group System

The membership of the Institute may be justly proud of the healthy development of the IRE Professional Groups. It was the aim of these Groups to offer every member the opportunity to affiliate with other members interested in the same engineering specialties as himself. Thus the most advanced information in his preferred fields is rapidly made available to him. The Groups are, in fact, essentially technical societies within the IRE framework. They are an extremely important development, and warrant the interest and support of every member. A detailed description of their work follows. Each member should particularly study that part of this description dealing with fields of particular interest to him. It would be well if each member were to join the corresponding Professional Groups, if he has not already done so.

To join a Group, a member need only write to L. G. Cumming, Technical Secretary, The Institute of Radio Engineers, 1 East 79 Street, New York 21, N. Y., asking for details as to the necessary procedure.—The Editor.

In the space of two and one-half years, since the formation of the first IRE Professional Group, the growth of the Group system and the continuing interest in it have proven the worth of the Groups.

Since June 2, 1948, when the Institute approved the petition for the formation of its first IRE Professional Group, nine other groups have been approved, and all have contributed to the Institute’s program. The groups are, namely: Audio; Broadcast Transmission Systems, Antennas and Propagation; Nuclear Science; Vehicular Communications; Circuit Theory; Quality Control; Broadcast and Television Receivers; instrumentation, and Radio, Acoustics, and Remote Control. Approval is now pending on the petition for the formation of the eighth Professional Group on Airborne Electronics. Membership in the Groups is steadily increasing and bringing with it new members of the Institute. By now the total membership of the ten Groups is in excess of 1,500. Applications for Group membership may be obtained by applying to the Technical Secretary of the IRE.

The growth of the Professional Group system is evidenced by the fact that at the 1950 National Conference six new Groups have sponsored symposia. All ten of the Groups are planning to participate at the 1951 National Convention and each has nominated a representative to serve on the Technical Program Committee for this Convention. In addition, plans are underway to set up a procedure for the systematic publication of Transactions of Group symposia, which will be accomplished with the cooperation of the Editorial Department. One of the Groups has recently reviewed papers for possible publication in the Proceedings. IRE Sections are kept constantly informed of the activities of the Groups by copies of “Newsletters,” Conference Notes, Minutes, etc. Moreover, an account of the Group activities is published each month in the Proceedings of the IRE.

A short history of the progress made to date by each of the ten Groups follows:

The IRE Professional Group on Audio was formed with the approval of the Executive Committee on June 2, 1948. A large national meeting of the Group members took place on March 9, 1950, during the IRE National Convention. The Group has three times sponsored symposia of national scope: at the Radio Fall Meeting in Syracuse in October, 1949; at the 1950 National Convention of the IRE; and at the Radio Fall Meeting in Syracuse in November, 1950. The Electroacoustics session at the 1950 National Electronics Conference in Chicago was arranged by the Group. As a service to its members, the Group began the distribution of Newsletters in March of last year. The Group has reviewed two papers for publication in the Proceedings, and on the initiative of the Group and in cooperation with the Group, the Editorial Department at Headquarters is attempting to procure six or eight papers on Audio for forthcoming issues of the Proceedings. In December, 1949, a local Group was formed in Boston which has held technical meetings on a monthly basis since its formation. Active local Groups exist in Milwaukee and Washington, D. C., and in Detroit, the local Audio Group has been holding meetings for the past two years. Dr. Leo Beranek of the Massachusetts Institute of Technology is currently serving as the Group’s Chairman. A total of 1,126 engineers are now enrolled as members of the national Group.

On July 7, 1948, the second Professional Group came into existence with the approval of a petition to form the Professional Group on Broadcast Engineers. The name of this Group was changed in August, 1949, and it is now known as the IRE Professional Group on Broadcast Transmission Systems. The Group is currently conducting a large membership drive aimed at the engineers in all broadcast stations and engineers concerned with the manufacture of broadcast equipment. A substantial mailing has been accomplished for the Group by IRE Headquarters which will undoubtedly result in an increase of IRE membership. The Group in the past two years was not sufficiently organized to sponsor a symposium, but is looking toward the 1951 National Convention with a great deal of interest. A full day’s program is being planned for “Broadcast Day” in March. It is anticipated that several papers presented on Broadcast Day will be submitted for possible publication in the Proceedings. In the summer of 1949 a lively program was inaugurated by the local Boston Group which has resulted in several technical meetings. Mr. Lewis Winn of the Bryan Davis Publishing Company is the Group’s Chairman and 808 members of the national Group are now enrolled.

On January 1, 1949, the third Group, IRE Professional Group on Antennas and Propagation, was formed. The national Group has been very active since the date of its formation and a great deal of time has been given by its officers toward a full and stimulating program. On October 31, November 1 and 2, 1949, in Washington, D. C., the Group, together with URSI, sponsored a highly successful symposium. On April 3 and 4, 1950, another successful symposium was sponsored with URSI, this time in San Diego, Calif. Dr. L. C. Van Atta, last year’s Group Chairman, has prepared an excellent article entitled “The Role of Professional Groups in the IRE,” which was published in the October, 1950, issue of the Proceedings. In accordance with the Institute’s policy, abstracts of the papers presented at the Group’s San Diego symposium were published in the Proceedings in August, 1950, and the Group has sponsored four papers which will be packaged as a single article for publication in a forthcoming issue. The Group’s present Chairman is Mr. Newbern Smith of the National Bureau of Standards. A total of 910 members are presently enrolled in the national Group and, in addition, 300 applications for membership are pending. The Group will undoubtedly be one of the largest in the Institute.

On April 3, 1949, the Institute approved petitions for the formation of three new Groups. One of these was the IRE Professional Group on Nuclear Science. Prior to the formation of the Group, the Technical Committee on Nuclear Studies had sponsored a number of symposiums jointly with AIEEE. The responsibility for this annual project was assumed by the Group and on October 31, November 1 and 2, 1949, the IRE/AIEEE Joint Conference on Electronic Instrumentation in Nuclear and Medicine was held. Over 750 attended the Conference, which included an exhibition staged by the Atomic Energy Commission and a trip to the Brookhaven National Laboratory. The Group sponsored a similar Conference this year.
with the AIEEE on October 23, 24, and 25, again in New York City, and a technical session at the 1950 National Convention. Soon after its formation, the Group initiated a regular Newsletter which has been stimulating and informative. The former Committee on Nuclear Studies had initiated the procurement of a series of papers for the Proceedings. A dozen of these papers were published in 1948 and 1949. Upon the formation of the Group, procurement activities were assumed by the Group and four papers were published in 1950. It is expected that five more will soon be submitted. The Group's present Chairman is Mr. M. M. Hubbard of the Massachusetts Institute of Technology, and its membership totals 518.

Another Group formed on April 5, 1949, was called the Group on Vehicular and Railroad Radio Communications. The name of this Group was changed on July 12, 1950, to IRE Professional Group on Vehicular Communications. On November 3, 1950, in Detroit, the national Group held a full day's technical meeting on Land Mobile Communications at which eight papers were presented. A local Group has been formed in Detroit and steps are being taken toward the formation of local Groups in Chicago, New York, and Portland, Ore. Mr. Austin Bailey of the American Telephone and Telegraph Company is the present Chairman, and the membership totals 413.

The petition to form an IRE Professional Group on Circuit Theory was approved by the Institute's Executive Committee on April 5, 1949. The Group sponsored a technical session at the 1950 National Convention and plans to participate in the 1951 National Convention. Organization of the Group has not been completed. In addition to the 29 petition signers who are at present listed as members of the Group, Headquarters has received applications for membership totaling 994. It is expected that organization of the Group will have been accomplished by the time these notes are published. The acting Chairman for the Group is Professor J. G. Brainard, of the University of Pennsylvania.

On April 9, 1949, the IRE Professional Group on Quality Control was formed by the Executive Committee's approval of its petition. The Group sponsored a technical session at the Radio Fall Meeting in 1949, and a technical session and a symposium at the 1950 National Convention. The Group again sponsored a technical session at the Radio Fall Meeting in 1950. Three papers are being published in the Proceedings on the recommendation of the Group, two of which are an outcome of the Group's symposium. Mr. R. F. Rollman of Allen B. DuMont Laboratories, Inc., is the Group's present Chairman. The membership totals 316.

The petition to form an IRE Professional Group on Broadcast and Television Receivers was approved by the Institute on August 9, 1949. The Group has been active in sponsoring technical meetings, including two sessions at the Radio Fall Meeting in 1949, a symposium at the 1950 National Convention, and two sessions at the Radio Fall Meeting in 1950. An article by Mr. John D. Reid, procured by the Group, was published in the October, 1949, issue of the Proceedings. The Group has an active Canadian section. There are 302 presently enrolled as members of the national Group, and 612 pending applications for membership. The Group's Chairman is Mr. Virgil Graham, of Sylvania Electric Products Inc.

January 31, 1950, saw the inauguration of the IRE Professional Group on Instrumentation. The Group sponsored a symposium on Improved Quality Electronic Components in cooperation with AIEEE and RMA in Washington, D. C., on May 9, 10, 11, 1950. The Group sponsored the High Frequency Measurement Conference in cooperation with the Joint IRE/AIEEE Committee on High Frequency Measurements which was held in Washington, D. C., on January 10, 11 and 12, 1951. The Group's Vice-Chairman, Mr. H. L. Byerlay, has prepared a short article entitled, "Organizing the Professional Group on Instrumentation at the Section Level." Copies of this article may be secured from IRE Headquarters.

There exists the nucleus of a local Group in Detroit, but no action has yet been taken to set up local Groups. The Group's Chairman, Professor Ernst Weber, of the Polytechnic Institute of Brooklyn. Its membership totals 3,362, all local Groups.

The petition for the formation of the IRE Professional Group on Radio Telemetry and Remote Control was approved by the Institute's Executive Committee on July 12, 1950. Members have been appointed to the Administrative Committee and a meeting will soon be called to discuss Council for participation in the 1951 National Convention. The Group has not yet had an opportunity to carry on a membership drive, so at the present its members consists of the twenty-seven petition signers.

PROCEEDINGS OF THE I.R.E.

February

PROFESSIONAL GROUP NOTES

The Committee on Professional Groups has drafted revisions to certain pages of the Manual for Professional Groups in order to outline a tentative plan for the publication of papers resulting from Group-sponsored symposia and technical meetings. The proposed plan will provide the Groups with a systematic, and effective manner of publishing the Transactions of their conferences and will facilitate the publication of several of these papers in the Proceedings of the I.R.E. ... A petition to form an IRE Professional Group on Electronic Devices has been received at Headquarters from Mr. J. J. Rappaport of the Dayton Section. It is hoped that the Institute's Executive Committee will be able to act on the petition at its February meeting. If it is approved, the future Group will sponsor the 1951 National Convention on Electronic Devices in co-operation with the Dayton Section of the IRE. The conference will be held on May 23, 24, and 25, 1951. The success of a similar conference held in 1950 led a group of people to petition for the formation of the Group. The regular joint spring meeting of the U.S.A. National Committee of the International Scientific Radio Union (URSI) and the IRE Professional Group on Antennas and Propagation will be held April 16, 17, and 18, 1951, at the National Bureau of Standards in Washington, D. C. Information regarding the meeting may be secured from Newbern Smith, Chairman of the Group, at the National Bureau of Standards, Washington 25, D. C. ... The IRE Professional Group on Audio has distributed a Newsletter No. 4 to its members. The letter contains a summary of five papers presented by the Group at the Radio Fall Meeting and at the Boston and Milwaukee Sections. A ballot for election of new officers and Administrative Committee members was included with the letter. ... The Administrative Committee of the IRE Professional Group on Broadcast Transmission Systems held a meeting on December 1, 1950, at which plans for Broadcast Day at the 1951 National Convention were discussed. Two hundred applications for membership in the Group have been received as a result of the Group's recent mailing to chief engineers of broadcast stations and manufacturers of broadcast equipment. ... Members of the initial Administrative Committee of the IRE Professional Group on Circuit Theory have been appointed. J. G. Brainard, E. A. Guillen, and W. N. Tuttle will serve on the Committee for a three-year term; W. E. Bradley and J. M. Petri for a two-year term; and L. Dietzold, C. H. Page, and J. R. Ragazzini for a one-year term. Professor Brainard is Acting Chairman of the Group. ... The IRE Professional Group on Quality Control has begun implementation of its plan outlined in these Notes in the January issue of the Proceedings to establish facilities to assist the IRE Sections in preparing local programs and securing outstanding authorities as speakers for meetings. Questionnaires have been sent to all Sections and these will be filled in to indicate the Sections' interest or need for speakers on quality control in the electronics field. The Group's first Newsletter has been mailed to the members. It is planned that a Newsletter will be distributed bi-monthly and will include information relevant to the general subject of quality control, abstracts of papers, and news of Group activities. ... The recently formed IRE Professional Group on Radio Telemetry and Remote Control has held its first Administrative Committee meeting. In order to secure members for the new Group, a card announcing its formation has been mailed to eight of the IRE Sections which will be most interested in the Group. ... During the past few months Headquarters has received word of plans on the part of several IRE sections for new Professional Groups. The fields in which interest has been expressed in recent communications are: basic science, electronic computers, engineering management, industrial electronics, information theory, and piezoelectricity.
compete with commercial TV broadcasting either for audience or for frequencies, but that the public interest required the setting aside of TV channels for educational purposes.

**Credit Regulation Is Amended; Distributors Protest Ruling**

The Federal Reserve Board has announced that it is amending its recently established Regulation "W" which controls consumer credit.

The revised regulation, which increases the required down payment on a TV or radio receiver from 15 per cent to 25 per cent, immediately drew the ire of radio and television distributors and dealers. The revised rules also would reduce the maximum maturity for such purchases from 18 to 15 months and lower the controlled sale from $100 to $50.

**Controls**

The National Production Authority has issued an order which, in effect, sets aside 10 per cent of the zinc produced for military use. The order was issued, NPA said, "to provide for the equitable distribution of priority rated orders among all producers and fabricators of zinc ..." Two orders affecting the use and distribution of copper were issued by the National Production Authority in efforts to "assure copper supplies for the expanding rearmament program." The NPA order (M-12) limiting non-defense use of copper was milder than had been expected by observers. However, NPA copper officials told RTMA that the current copper situation is worse than it was at any time during World War II. This week's orders were described as the initial step. We are "merely getting our feet wet," one NPA official stated. The National Production Authority has issued an order requiring tin inventories to be held at a 60 days' supply. NPA also called for reports on inventories, receipts, consumption, imports, and distribution of tin. Under the new reporting requirements, all persons having 1,000 pounds or more of pig tin in their possession or under control on the first day of the month must file a report. The National Production Authority has issued an order restricting the use of aluminum for nondefense purposes to 65 per cent of the average quarterly use of the metal during the first six months of this year. The NPA directive became effective January 1. In December of this year, NPA said, users of aluminum will be permitted 100 per cent of their average monthly consumption in the first months of 1950.

**FCC TV Network Restrictions Opposed by TV Broadcasters**

About forty petitions were filed in connection with the FCC's proposal to adopt rules that would require TV stations in areas served by less than four stations to use a minimum of program time from each of the four television networks.

Majority of the petitions opposed the FCC proposal to limit one-station areas to the use of only two hours of a single network's programs in the afternoon and nighttime. Most of the petitions also recommended that full-scale hearings be held before the FCC takes any final action.

**FCC AUTHORIZES TESTS OF SUBSCRIBER-VISION SYSTEM**

The FCC has granted the request of the General Teleradio, Inc., licensee of WOR-TV, New York, N. Y., for special temporary authority to test, under which conditions, the "Skatron Subscriber-Vision System" during the nonregular hours of operation of that station.

The "subscriber-vision" system of Skatron Corp. sends a coded "scrambled" TV picture over the air. It can be received only by a receiver equipped with a special decoder. The system employs a coder unit at the camera and another at the receiver. The standard TV synchronizing pulses are fed into a small kinescope tube and projected onto a photocell, the output of which is used to supply the final synchronizing pulse.

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**NEARLY SIX MILLION TV TUBES ARE SOLD IN SIX MONTHS' PERIOD**

Television receiver manufacturers purchased 5,934,391 TV picture tubes in the first 10 months of 1950, according to reports to RTMA. October tube sales to set manufacturers totaled 484,387 units valued at $23,589,590, compared with 764,913 tubes valued at $20,423,353 in September.

The trend to large-type cathode-ray tubes continued in October with tubes 16 inches in size and larger representing 92 percent of the month's sales. Rectangular tubes comprised 58 percent of the October sales to set producers.

Total sales of all types of cathode-ray tubes, including oscillographs, camera pickup tubes, etc., in October amounted to 947,872 units valued at $26,206,183 and brought the ten months' total to 6,378,210 tubes valued at $165,611,700. Television receiver production in eleven months of 1950 aggregated 6,529,615 sets, according to preliminary industry estimates. RTMA's estimates represent production by member and nonmember companies. November radio and television production each dropped eight per cent below the previous month's output. TV sets produced in November numbered 752,005 units and radio receiver production amounted to 1,304,094. Radio receivers, including home sets, auto and portable models, manufactured in the 11-month period, totaled 12,785,917.
IRE People

Rudolph Goldschmidt, eminent radio engineer who originated one of the first high-frequency alternators which was named for the inventor, died in November at the age of 74 in England.

Dr. Goldschmidt, who was born on March 9, 1876, at Mecklenburg, Germany, received his engineering education at the Technical University of Darmstadt. Following his graduation he served as an assistant professor.

The inventor of reflex alternators built for powers up to 100 kilowatts, Dr. Goldschmidt also invented the receiver instrument known as the tone wheel which receives continuous waves on a musical note before heterodyning.

He was president of his own company, The High Frequency Machine Company, at Berlin, during the years 1912 to 1923, and was at one time a member of the IRE.

Later Dr. Goldschmidt became an independent inventor in Berlin, and designed mechanical means for changing rotating into reciprocating motion. He also invented an electromechanical mechanism using these means.

Thomas McLellan Davis (M'28 SM'43), head of the Radio Techniques Branch of Radio Division 11 of the Naval Research Laboratory, Washington, D.C., recently has completed 40 years of military and civilian service in the Navy. A pioneer radio engineer, Mr. Davis was born in Farmington, Maine. His naval career began with his enlistment on October 21, 1910. After a course at the Navy Electrical School, he was assigned as radio operator on the staff of Admiral Ward on the USS Florida, with similar duty subsequently in New York Navy Yard. From 1915 to July, 1919, he was in radio duty on Atlantic Fleet flagship, USS Wyoming, which was attached to the British Grand Fleet in the latter part of World War I.

He transferred from the Wyoming at Scapa Flow to U.S. Fleet flagship Pennsylvania, from which he conducted a school in British radio procedure for the radio personnel of ships stationed at New York Navy Yard. After similar duty at Norfolk, he became assistant to the Radio Officer of Washington Navy Yard's Radio Test Shop in October, 1919. A year later he conducted a school in civilian status at the Yard, becoming the ranking civilian in charge of the engineering and test phases of Radio Test Shop activities (except transmitters) a year prior to his transfer to NRL.

In September, 1923, Mr. Davis joined the radio staff at the Laboratory. As Head of the Radio Receiver Section, he became responsible for research, development, and design of nearly all military types of radio receiving equipment, including in addition radio direction-finder research in the period 1933 to 1940. Since 1947, he has been head of the Radio Techniques Branch, which was formed by merger of the former Receiver Section with the Radio Measurements and Components Section, encompassing a broad field of research and development in electronics.

The Navy's radio receiving equipment for the past three decades has been outstanding in reliability and performance. A major factor in this has been Mr. Davis' keen appreciation of naval radio problems and his ability to provide highly successful engineering solutions thereto.

Mr. Davis is a member of the American Physical Society and was Chairman of the Washington Section of the IRE in 1934. He served as representative to the D. C. Council of Engineering and Architectural Societies from 1935 to 1948.

Carl L. Frederick (M'45) of Chevy Chase, Md., was recently awarded the degree of Doctor of Science by Nebraska Wesleyan University, Lincoln, Neb. The degree was recommended by J. C. Jensen, professor of physics, and was presented by Carl C. Bracy on the occasion of his installation as Chancellor.

The citation reads as follows: "Carl LeRoy Frederick—Scholar and leader in scientific research, a physicist of high repute devoting time and skill to research in and for the development of means of defense from those who would destroy our democratic way of life, an alumnus of whom your alma mater is justly proud—upon recommendation of the faculty and by vote of the Board of Trustees, I am highly honored to confer upon you the Degree of Doctor of Science with all the rights, honors, and privileges of this degree." Dr. Frederick delivered an address before a joint meeting of Sigma Pi Sigma and Phi Kappa Phi, honorary fraternities, on the subject, "Training for a Scientific Career."

Thomas G. Banks, Jr. (A'39) has been appointed to the newly created position of Director of Research and Development at Gates Radio Co., Quincy, Ill. Prior to accepting the new position, Mr. Banks served as a Gates sales engineer for the Oklahoma-Kansas territory.

Previously he owned and managed his own broadcast station. Mr. Banks is a recognized broadcast consultant before the FCC.

Robert Charles Woodhead (A'37-M'46) died suddenly on November 8 at the age of 36. Born at Edmonton, Alberta, Canada, Wing Commander Woodhead received his engineering education at McGill University, Montreal, from which he was graduated with the degrees of B.Sc. and B.Eng.

From 1935 until World War II, he was employed in an engineering capacity by the Bell Telephone Company of Canada. Joining the Royal Canadian Air Force shortly after the outbreak of war, he was employed for a period as a navigator, and then in the Telecommunication Branch.

Retiring from the service at the cessation of hostilities to resume employment with the Bell Telephone Company, he rejoined the service in 1946 and was appointed to permanent commission in the Telecommunication Branch of the Royal Canadian Air Force. At the time of his death, he held the appointment of Director of Telecommunication Engineering, RCAF, Headquarters, Ottawa, Canada.

Wing Commander Woodhead was largely responsible for the basic engineering work connected with the domestic and overseas radio telegraph circuits activated by the Royal Canadian Air Force.

He also led, for a period, a joint service group which engineered an automatic tape relay which formed the backbone of the National Defense Communication System in Canada and into which RCAF major radio teleprinter circuits were integrated.

More recently, he was responsible for the engineering decisions leading to the selection of all telecommunication equipment adopted by the RCAF, and for the general technical policy governing its use.

Marvin Hobbs (A'35-M'41-SM'43) was recently appointed Chief of the Electronics Division of the Munitions Board and Government Chairman of the Electronics Equipment Industry Advisory Committee. He has served with the Munitions Board, which is a part of the Office of the Secretary of Defense, since May, 1940, when he was appointed Deputy Director of the Secretariat of the Joint Electronics Committee.

Norman Snyder (M'43 SM'43) of the International Standard Electric Corp., a subsidiary of the International Telephone and Telegraph Corp., is at present engaged in company activities in Saudi Arabia.
Hector R. Skifter (A’31–M’36–SM’43–51), president of Airborne Instruments Laboratory, Mineola, L. I., N. Y., has announced that a group of executives and employees of Airborne Instruments Laboratory in association with Laurence S. Rockefeller and certain of his associates, and with the American Research and Development Corporation, Boston, Mass., have purchased the entire stock of the Laboratory from Aeronautical Radio, Inc.

The transaction provides for the three groups to share nearly equal ownership of the research and development laboratory organized in 1945 as an outgrowth of three World War II laboratories associated with Columbia University, Harvard, and the Massachusetts Institute of Technology.

Management of AIL will remain in the hands of Mr. Skifter, as general manager and resident; D. M. Miller, vice-president; and May, secretary-treasurer.

The new board of Directors is comprised of Stuart N. Cott, Joseph Powell, Jr., Georges Doriot, Randolph B. Marston, Harper Woodward, John N. Dyer, Mr. Miller, and Mr. Skifter.

J. Gilman Reid, Jr., (A’50–M’50–SM’50) has been appointed Chief of the Electronics Division of the National Bureau of Standards. He has been Chief of the Engineering Electronics Section since January 3, 1939.

For the present he will continue to act in his capacity, in addition to assuming duties as Division Chief.

In 1937 Mr. Reid joined the staff of the National Bureau of Standards as a member of the Heat and Power Division. In 1941 he became a project engineer for the uranium project at the Bureau, working on the design and development of electrical and electronic control equipment for special process control in isotope separation. From 1943 to 1944 he worked on power supply systems for radio proximity fuses, and from 1944 to 1946 carried a major fuzo project through final development and production phases. From 1946 until his appointment as Chief of the Engineering Electronics Section, he was chief engineer for the Electronic Instrumentation Laboratory, working on special instrument systems for the Navy’s Bureau of Ships and Bureau of Aeronautics, the Treasury Department, and other laboratories within the NBS.

Mr. Reid attended the University of Mississippi, where he received the B.A. degree in physics in 1931 and the M.A. degree, also in physics, in 1933. From 1933 to 1936 he was a member of the staff of the Museum of Science and Industry in Chicago, and from 1936 to 1937 was on the teaching staff of the RCA Institute, instructing in physics, electronics, and mathematics.

He is a member of the American Physical Society and of the American Institute of Electrical Engineers. He has represented the Bureau on a number of society committees concerned with various phases of electronics and instrumentation.

M. A. Acheson (A’36–M’37–F’41), has been transferred to the staff of E. Finley Carter, as vice-president in charge of engineering of Sylvania Electric Products Inc., in New York, N. Y.

Mr. Acheson joined the engineering staff of Sylvania Electric in 1934. From 1935 to 1942 he supervised development engineering for radio receiving tubes, including portable types. During the war he directed Sylvania’s development of proximity-fuse tubes for the Navy Bureau of Ordnance and received an award for exceptional service from the Bureau.

Appointed as manager of research and development in 1942, he served as manager of the Advanced Product Development Department of Sylvania’s Central Engineering Laboratories, until he was named chief engineer for the radio tube division in 1948.

Previously, Mr. Acheson had been a member of the research staff of the General Electric Company, where he specialized in the design and development of high-power radio transmitting tubes and broadcast transmitters.

He holds approximately thirty patents on radio transmitter circuits, water-cooled power tubes, and tubes for television transmission.

B. Richard Teare, Jr. (A’41–SM’45–F’51) has been appointed Dean of Graduate Studies in the Carnegie Institute of Technology College of Engineering and Science. He is also head of Carnegie’s electrical engineering department and Buhl professor of electrical engineering. He will remain in these posts.

He joined the Carnegie faculty in 1939, and was named Buhl Professor in 1943. He worked toward the establishment and organization of a graduate program in the electrical engineering department, and became head of the department in 1914.

Dr. Teare has been secretary and chairman of the committee on graduate degrees for the College of Engineering and Science. As Dean of Graduate Studies he will now be chairman of this committee.

As chairman of the basic course committee, and as an active teacher, Dr. Teare has contributed to the development of the Carnegie Plan of Professional Education.

In 1947, he received the George Westinghouse Award in recognition of his “distinguished contributions to engineering education.”

A Fellow in the AIEE, Dr. Teare was chairman of the Institute’s Committee on Education from 1948 to this year. He has been chairman of the Graduate Study Division of the American Society for Engineering Education, and is currently chairman of the Society’s Division on Relations with Industry.

Leister F. Graffis (S’43–A’45) has been appointed chief field engineer of the Bendix Radio Division of Bendix Aviation Corporation.

In his new capacity, Mr. Graffis will be in charge of field engineering service, maintenance training programs, and will direct the activities of technical representatives of the Bendix Radio Division who will assist government agencies in installation and maintenance.

Personnel of his group will be assigned to work in many parts of this country, as well as outside the U. S. borders.

Prior to his association with the field engineering group, Mr. Graffis was with the technical publications department. Earlier he was assistant service manager of the television and broadcast receiver sales department.

Before coming to Bendix he was a Lieutenant Commander in the Navy, and was engaged in the setup of search radar equipment on the west coast and the supervision of the preparation of instructional material for all radio technician schools in that area.

He attended North Dakota State School of Science, Colorado State College, and completed radar courses at Harvard and the Massachusetts Institute of Technology. He served overseas for two years, handling the maintenance and installation of electronic equipment in military aircraft.

F. C. Cahill (S’38–A’40–SM’45) supervisory of the Receiver Section at Airborne Instruments Laboratory, Mineola, L. I., N. Y., has been named supervising engineer of a combined engineering group to be known as the Radar Section. The new group, a combination of the former Receiver and Radar Sections, now comprises about 40 engineers.

Associated with Mr. Cahill in the technical operation of the new Radar Section will be assistant supervisors Richard N. Close (A’45), Matthew T. Lebenbaum (A’42–M’46–SM’47), and William R. Rambo (S’39–A’40–SM’46).

Mr. Cahill has been with AIL since November, 1945. He was experienced in designing commercial radio receivers and radar systems prior to joining the Radio Research Laboratory in 1942.
Books

**Electrical Communications by Arthur L. Albert**

This is the third edition of a work, the first edition of which appeared in 1934, and the second in 1940. The current edition has been thoroughly revised and brought up to date.

The book covers the entire field of communication, although television is treated more briefly than one might expect in view of its importance in the industry. The first portion of the book deals with the fundamentals of acoustics, electroacoustic devices, networks, lines, cables, waveguides, and various electronic devices, including recently developed techniques such as the transistor. Later chapters deal with telephone, telephone, and radio systems. The material on dial telephone and radio systems has been greatly expanded.

The book is primarily intended for use as a college text, and it should serve admirably to acquaint the students with important circuit principles, transmission systems, and terminology encountered in communication engineering. It should also be useful to one who is interested in the subject as a whole, rather than any specialized branch. The text is arranged so that the topics can be understood, even though the mathematics be ignored.

The book is thoroughly indexed, and the words and phrases listed in the index will be found printed in boldface type on the corresponding pages of the text. This is a great time-saver in using the index.

Review questions have been added to the chapters, and the problems have been revised and increased in number. Extensive and modernized lists of references are given at the end of each chapter.

**C. O. Mallinckrodt**
Bell Telephone Laboratories, Inc.
Murray Hill, N. J.

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**Principles and Applications of Waveguide Transmission by George C. Southworth**

This is an up-to-date book dealing with a new art which has had a spectacular growth during the past 15 years. During all of this period of rapid growth, the author has held a position of preeminent leadership in the development of this art.

The book appears to be particularly suitable for use as a college textbook and as a reference book of great value to practicing engineers and technicians.

Two different orders of presentation are followed. The first, which is quantitative, follows the conventional theories of electricity as they apply to lumped circuits, transmission lines, waves in free space, and to waveguides. This approach includes the basic mathematical treatment of the subject. The second approach, which is largely qualitative, may be regarded as a verbal interpretation of the first, serving to develop a physical concept of the various phenomena involved.

The general background and theory are presented in the first 178 pages of text, following which, numerous applications and waveguide devices are described, including their characteristics and design factors. Included in these are transmission lines, impedance matching devices (transformers), microwave filters, balancers, amplifiers, oscillators, antennas, resonators, microwave measurements, receiving methods, radar applications, and many others.

The paper and print are of excellent quality and the presentation is enhanced by an exceptional number (46 figures) of clean cut diagrams, curves, drawings and photographs.

**H. O. Peterson**
RCA Laboratories, Inc.
Riverhead, N. Y.

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**Frequency Modulated Radar by David G. C. Luck**

This book is concerned primarily with the results of a Navy-sponsored research and development program at RCA in the field of frequency-modulated radar, covering a period from 1938 through the war years. The manuscript was originally prepared as a final report on a Navy contract and expected, therefore, considerable emphasis is placed on the theory and design of a few specific equipments. However, since the general treatment of the subject successfully transcends specific equipments, this book represents a distinct contribution to the literature, since in most radar treatments, frequency modulation systems are passed over all too briefly.

The author has done an excellent job in presenting his material in a thoroughly readable fashion, using a clear, simple, and understandable style, markedly devoid of the stilted phrases and cliches often present in many technical books. A thorough knowledge of the techniques of radio engineering is assumed, together with some familiarity with pulse radar and servo mechanisms.

The book is apily divided into two parts. Part One is devoted to the development of the theory of frequency-modulated types of systems and to discussions of various techniques used to describe the various systems developed by RCA. Particular emphasis is given to techniques that have been developed in connection with the fabrication of operable systems. The author also presents a number of general developmental systems which were investigated but not carried to completion as production items. Finally, there is included a chapter on multiple target systems in which performance comparisons are made between frequency-modulated and pulse-type radar systems.

The author outlines some of the limitations as well as advantages of both types of systems.

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In general, it is the conclusion of the reviewer that this book is timely, and further that it provides the electronic engineer with excellent background on the subject of frequency-modulated radar with particular emphasis on unclassified aspects of airborne fire-control and bombing systems—subjects obviously difficult to discuss in full completeness because of security requirements.

**Harold A. Zabr**
James T. Evers
Signal Corps Engineering Laboratory
Fort Monmouth, N. J.

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**Super-Regenerative Receivers by J. R. Whitehead**
Published (1950) by Cambridge University Press, 51 Madison Ave., New York 10, N. Y. 137 pages $3.00.

The author brings to his writing a wealth of experiences in direct contact with the experimental development and continuing philosophical study of one of the most unusual of all radar sets—the Mark III IFF transponder. After a talk in England, this super-regenerative receiver and pulse transmitter was engineered and put in large-scale production in U. S., then installed in every allied missile and aircraft for protection against friendly fire. Its reliable, unattended operation as an adjunct to diversified types of radar, has forever dispelled the prejudice against super-regeneration as being tricky or undependable.

After an adequate introduction to orient the reader, the author proceeds with a skillful theoretical presentation of certain special topics under his subject. Each is presented with adequate mathematical derivations and formulas, mostly relying on techniques no more advanced than the Fourier integral.

The outstanding contribution of this work is the formulation of the frequency response of a super-regenerative receiver, which had been neglected in the few excellent studies before the war. Here the author has adely applied the basic principles and design formulas developed by this reviewer in Hazeltine Laboratory Reports* during the engineering of the Mark III IFF, and duly credited in other reports and publications of the author and his British associates.

Spectacular skirt selectivity is obtained by a quench wave form which provides "slope-controlled" frequency response as distinguished from "step-controlled." The properties of each are formulated and presented clearly by diagrams showing their physical significance.

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magazine articles. These sections tend to be a little more specific and less objective than they perhaps should be. However, so long as the reader is interested in utilizing the Handbook as a means of acquainting himself with the general problems that may be confronted in the development, operation and maintenance of a communication system, and does not expect an exhaustive, strictly hand-book type treatment, the Mobile Radio Handbook serves a valuable purpose. It is clearly and interestingly written and very easy to read and understand.

With the extensive use now being made of vhf-FM communication systems to satisfy the operational needs of radio, which heretofore have not been able to use radio, and with the special problems brought about by the extensive use of such systems, there is a definite need for a handbook on mobile radio and point-to-point systems to provide guidance in the direction of proper planning and sound systems engineering. The present Handbook is a step in the right direction.

C. M. JANSKY, JR.
970 National Press Building
Washington, D. C.

Published (1950) by F.M.-TX Magazine, Great Neck, L. I., N. Y.

Mobile Radio Handbook is a compilation of material of practical and technical interest to anyone considering the development of a vhf-FM communication system in a mobile field. The book contains a discussion of FCC regulatory problems such as the availability frequencies, the regulations with respect to equipment operation and operator licensing provisions. It describes in some detail any of the practical problems involved in station layout and configuration of a vhf system based upon the actual experiences of men who have been active in this field. Illustrative descriptions are given of the problems involved in antenna erection, and in the maintenance of equipment as well as with the more involved problems of frequency selection, choice of equipment, siteing, etc. The Handbook includes also a very good and comprehensive chapter on general FM theory.

Unfortunately much of the intensive development which has taken place in recent years in the mobile radio field has not been utilized upon careful over-all systems planning. Although the first chapter in the handbook deals with basic systems planning, there could well be more emphasis on his philosophy of approach and upon the importance of providing in advance for future expansion. The Handbook suffers slightly in that it is a compilation of several separate articles, some of which apparently were not prepared specifically for inclusion in the Handbook but for presentation as amateur and commercial or professional practices in attempting to predict the usefulness of certain radio frequencies. The part played by sporadic-E propagation in up-setting propagation predictions is also given attention.

Considering the pains the author has gone to in literally bringing a subject down out of the clouds, it is probably very unfair to indicate pointedly the places where excess liberties in interpretations have been made. In addition, the present state is so fluid and some of our knowledge so theoretical that an author attempting to write this type of book must be granted considerable leeway. However, for example, a somewhat more up-to-date explanation of “long-scatter” would appear to be in order.

OLIVER P. FERKELL
Radio Magazines, Inc.
RASO, 121 South Broad St.
Philadelphia 1, Pa.

Radio Engineering Handbook by Keith Henney
Published (1950) by McGraw-Hill Book Co., Inc., 330 W. 42 St., New York 18, N. Y. 911 pages 412 pages index 45 pages 1014 figures 64 x 94 $10.00.

The fourth edition of this well-known handbook has been revised and expanded to increase its usefulness. It contains nearly twice the information of the previous edition, and has entirely new chapters on "Wave Guides and Cavity Resonators," "Electron Tubes," "Radio Aids to Navigation," "Antennas," "Receiving Systems," and "Inductance and Magnetic Materials.

The object has been to keep a working handbook with an abundance of applied information for all branches of radio engineering. Naturally, in a single volume there is considerable abridgement, but most of the chapters have excellent bibliographies attached for those who require fuller information.

The reviewer was particularly impressed by the following chapters: "Combined Circuits, C, g, and R," by W. F. Lanterm; and "V.T. Oscillators," by R. I. Sanbacher and D. C. Fielder.

Both of the above are unusually complete both in text and in references.

The chapter "Antennas," by Edward A. Laport, of 75 pages, is supplemented with a bibliography of 291 items.

"Wave Guides and Resonators," by Theodore Dorenco, was excellent, well written, and terse.

"Loud Speakers and Room Acoustics," by Hugh Knowles, contains a wealth of information packed into 42 pages.

"Receiving Systems," by Charles Dean, covers the field and should constitute a valuable reference source.

"Television," by Donald Fink, is a clear exposition of basic principles which includes color basics, but not latest color systems.

"Radio Aids to Navigation," by Harry Diamond, is presented in a manner for clear, easy reading, and is comprehensive in its coverage.

In summary, the Radio Engineering Handbook is recommended as a valuable addition to any radio engineer's library.

JOHN D. REID
American Radio and TV, Inc.
Conway, Ark.

(In continued on page 211)
Measurement of Frequency and Time

1. PROGRAM FOR ATOMIC FREQUENCY AND TIME STANDARDS—A SURVEY

Harold Lyons
(National Bureau of Standards, Washington, D.C.)

A survey will be given of the NBS program on atomic clocks and oscillators. Figures for noise-limited resolving power will be given for gases, including ammonia and oxygen, for atomic beams and nuclear quadrupole absorption. The program status will be outlined for the atomic beam clock, precision spectograph and spectrum tables, new microwave amplifier, and multiplier tubes. A brief discussion of potential applications will include measurements of earth rotation, comparison of atomic time and the mean sidereal year, and a mm-band interferometer driven by an atomic clock for basing both time and length standards on one spectrum line.

2. IMPROVED NBS AMMONIA CLOCK

Benjamin F. Husten
(National Bureau of Standards, Washington, D.C.)

The absorption line of ammonia is utilized to control a quartz crystal oscillator and frequency multiplier chains by means of a servo system. The servo system is designed to correct the drift of the crystal oscillator without impairing the normal short time stability of the oscillator. The control system is analyzed for stability and attainable accuracy. Minimum allowable stability figures for the uncontrolled oscillator are obtained. The theoretical limits of stability, as imposed by thermal noise and other factors, are calculated. Circuit details and performance figures are given for the complete clock and further improvement to be made indicated.

3. THE STABILIZATION OF A MICRO-WAVE OSCILLATOR WITH AN AMMONIA ABSORPTION LINE REFERENCE

E. W. Fletcher and S. P. Cooke
(University of Cambridge, Mass.)

This paper is primarily concerned with the problem of stabilizing a microwave oscillator on the 23,870-Mc absorption line of ammonia gas. First, the various causes of instability of any stabilized microwave oscillator are examined theoretically, and means for improving the stability are described and experimental results are given. Second, the feedback loop is analyzed as a servomechanism, and its design and operation are discussed. Third, the use of a spectral absorption line as a frequency reference is examined theoretically, and the design of the Crut stabilizer is discussed. Possibilities for further improvement of absorption-line frequency references are examined. This includes a discussion of the dependence of the feedback signal on the temperature of the ammonia and the dimensions of the waveguide cell.

4. PERFORMANCE OF OSCILLATORS FREQUENCY-CONTROLLED BY GAS ABSORPTION LINES

L. E. Norton
(RCA Laboratories, Princeton, N.J.)

Frequency stabilization of an oscillator implies comparison of two frequencies, output and standard, with provision for output frequency correction derived from any difference between the two. At microwave frequencies molecular absorption lines are particularly useful frequency standards. Over-all stability of frequency-controlled oscillator is specified by three things: namely, original frequency stability of the uncontrolled oscillator, stability of a standard frequency derived from an absorption line, and a multitude of factors related to the control loop elements. Stabilized oscillator performance is predicted by calculating the error magnitude or uncertainty introduced by each of these various causes. Details of these effects are described for specific circuits.

5. MILLIMETER-WAVE MEASUREMENTS

Walter Gordy
(Duke University, Durham, N.C.)

The discussion will include methods of generating, detecting, and measuring millimeter-wave frequencies in the range of 30,000 to 150,000 Mc. A table of accurately measured spectrum lines will be given. These provide suitable frequency standards for calibration of cavity wave meters in the millimeter range. The millimeter-wave absorption of oxygen, carbon monoxide, and other gases will be discussed.

6. QUARTZ-CRYSTAL FREQUENCY STANDARDS

W. D. George
(National Bureau of Standards, Washington, D.C.)

The past and present performance of low-frequency quartz-crystal resonators and oscillators, as used in maintaining the national standard of frequency and time interval, will be summarized. Improve accuracy of the frequency standard is resulting from recent improvements in uni formity of standard time, greater reliability in temperature control and better crystal sizes and crystal components. Problems in connection with the distribution of the standard via radio broadcasts will be discussed, e.g., accuracy as received, coverage continuity, corrections, type of service, and simultaneous use of two or more stations.

7. HIGH-FREQUENCY CRYSTAL UNITS FOR PRIMARY FREQUENCY STANDARDS

A. W. Warner
(Bell Telephone Laboratories, Inc., Murray Hill, N.J.)

A new approach to the design of crystal units for primary frequency standard us has resulted in crystal units, in the 30-200 Mc frequency range, characterized by high Q and low capacitance in the series arm of the equivalent electrical circuit. By utilizing the overtone frequency of specially designed AT-cut quartz plates, both Q and the rate of impedance change with frequency are enhanced together, and in addition the stability with time of the crystal unit is increased, due to a larger frequency determining dimension. Additional characteristics of the crystal units include small size, stability under conditions of vibration and shock, and low temperature coefficient.

Stabilities of one part in 10^10 per month have been achieved without recourse to stabilized circuits.

Measurement of Impedance

8. INFLECTION-POINT METHOD OF MEASURING Q AT VERY-HIGH FREQUENCIES

Nelson E. Beverley
(Sperry Gyrocompass Company, Great Neck, L.I., N.Y.)

A new method of measuring Q has been developed for measurements at very-high and microwave frequencies. This method determines the inflection points of a resonance curve by a null indication. Q is obtained only as a function of the frequency at which these null indications occur. The method is broad in application in that it can be used to locate the inflection points of lumped-constant circuits, transmission lines, and microwave cavities. Experimental measurements have been made at vhf and microwave frequencies. The results indicate that the accuracy may be equal or better than results obtained by other known methods.
A PRECISE SWEET-FREQUENCY METHOD OF VECTOR IMPEDANCE MEASUREMENT

D. A. ALBRECHT
(Bell Telephone Laboratories, Inc., Murray Hill, N. J.)

The impedances of a two-terminal network is defined completely by the insertion loss and phase shift it produces when inserted between known sending and receiving impedances.

Recent advances in precise wide-band measurements have made it possible to use the instrument for this purpose. The circuits are free from zero-correlations as the measuring frequency is changed, which in one specific circuit can be swept continuously from 0.05 to 20 Mw while data can be recorded automatically with accuracies up to ±0.2 per cent. Active and reactive impedance corrections are read directly from tables of reference circuit charts in which frequency is not a parameter. The basic principle described promises attractive possibilities in many uses of impedance measurements at still higher frequencies, where present methods are inadequate.

PRECISION COAXIAL RESONANCE LINE FOR IMPEDANCE MEASUREMENTS

O'WARD E. SORROW, ROBERT F. HAMILTON, AND WILLIAM E. RYAN
(National Bureau of Standards, Washington, D. C.)

A description of a mechanical scanning method for photographically displaying the space patterns of microwaves and centimeter wavelength sound waves will be demonstrated. Photographs of a large variety of field patterns will be shown. The position of the individual wave crests and the direction of wave motion can be indicated by the addition of a constant amplitude signal. Simultaneous focusing of sound waves and microwaves by the same lens will be demonstrated.

Demonstration Lectures

14. MICROWAVE SPECTROSCOPY WITH APPLICATION TO CHEMISTRY, NUCLEAR PHYSICS, AND FREQUENCY STANDARDS

L. J. RUEGER, R. G. NUCKOLLS, AND HAROLD LYNX
(National Bureau of Standards, Washington, D. C.)

A Stark-modulation type of microwave spectrophotometer will be demonstrated by displaying the absorption lines of ammonia gas on a projection oscilloscope. Nuclear quadrupole hyperfine structure lines will be shown, the Stark effect, pressure broadening of the lines, and possibly power saturation. It will be shown how applications to chemical analysis, chemical reaction rates, isotopic analysis, and nuclear physics are possible. The usefulness of the lines as invariant frequency standards will be seen, and the possible application of precision designs of spectrophotograph to measurements of the rotation of the earth using these lines will be pointed out.

15. RECORDING ATMOSPHERIC INDEX OF REFRACTION AT MICROWAVES

GEORGE BIRNBAUM, S. J. KRYSER, AND R. R. LARSEN
(National Bureau of Standards, Washington, D. C.)

The recording microwave refractometer is an instrument which measures and records minute differences in frequency between a test cavity and a reference cavity. The operating principle and the applications of this instrument for research and industrial control work will be briefly described. The use of this instrument to measure and record fluctuations in the refractive index of the atmosphere will be demonstrated. The output meter of the instrument will be projected on a screen, and the variations in meter readings will be noted as someone breathes into the test cavity or a moist blotter is held near it. Recordings of fluctuations in the refractive index of the atmosphere obtained at the National Bureau of Standards will be projected, and the significance of these records will be briefly discussed.

16. MEASUREMENT OF MICROWAVE FIELD PATTERNS USING PHOTOGRAPHIC TECHNIQUES

W. E. KOCH
(Bell Telephone Laboratories, Inc., Murray Hill, N. J.)

A description of a mechanical scanning method for photographically displaying the space patterns of microwaves and centimeter wavelength sound waves will be followed by a demonstration of refraction, diffraction, and focusing of these waves by iterative metallic structures. Photographs of a large variety of field patterns will be shown. The position of the individual wave crests and the direction of wave motion can be indicated by the addition of a constant amplitude signal. Simultaneous focusing of sound waves and microwaves by the same lens will be demonstrated.

Measurements of Power and Attenuation

17. ABSOLUTE MICROWAVE POWER MEASUREMENTS

A. C. MACHESEY AND D. M. KERN
(National Bureau of Standards, Washington, D. C.)

Work done at the NBS concerning bolometers and calorimeters as devices for
precise, absolute measurement of microwave power will be reviewed. Special techniques developed for the determination of bolometer mount efficiency by means of impedance measurements will be described briefly. A different method, the calibrated microammeter, developed and used for power measurement at the milliwatt level, will also be described. A summary of measurements consisting largely of cross-checks between the bolometric and the calorimetric methods will be presented, and evidence for the failure of the imperfect method of determining efficiency for thermistors and the success of the method for platinum-wire bolometers will be discussed.

18. BROAD-BAND BOLOMETER DEVELOPMENT

W. E. WALLER
(Polytechnic Research and Development Co., Inc., Brooklyn, N. Y.)

Broad-band bolometers for high-frequency power measurements have been developed to cover the ranges 20 to 1,000 Mc, 1,000 to 4,000 Mc, and 4,000 to 10,000 Mc. All units have a VSWR under 1.3 over their specified operating ranges. Low-power and high-power elements, capable of dissipating 1 milliwatt and 100 milliwatts, respectively, have been made to the above specifications. The response and power handling capabilities of these elements to short pulses will be discussed.

19. CALIBRATING AMMETERS ABOVE 100 Mc

H. R. MEAHL AND CHARLES C. ALLEN
(General Electric Company, Schenectady, N. Y.)

A survey is made of the progress to date in calibrating current above 100 megacycles. The types of vacuum thernocouples available for ultra-high-frequency current measurement are discussed, and the several methods of calibration are reviewed. A calorimeter method and a thermistor bridge method are presented. The advantages and limitations of the calorimeter methods are brought out. The electrodynamic method is particularly suited to large currents, the calorimeter method to medium currents, and the thermistor bridge method to small currents. The importance of obtaining agreement between methods that do not depend on the same principles is emphasized.

20. A MICROWAVE OSCILLOGRAPH

W. B. SELI AND J. V. LEBACZ
(The Johns Hopkins University, Baltimore, Md.)

A cold-cathode, high voltage, single transient Rogowski oscillograph was given to The Johns Hopkins University by the Aberdeen Proving Grounds. The oscillographic chamber was redesigned to permit the direct observation of frequencies in the 10,000-Mc range. This has been accomplished in two ways: first, by velocity-modulating the beam by the E field of a waveguide; then deflecting it through a constant magnetic field; second, by using a short Lecher wire system for the transmission of the microwave energy. In this latter case, deflections due to both the E and H fields have been observed. A theory is offered which checks the E-field deflection much more closely than the predictions of Hollmann. A qualitative explanation of the H-field deflection is also given.

21. PRECISION MILLIDEICBEl WAVEGUIDE ATTENUATION MEASUREMENTS

J. H. VOGELMAN
(Watson Laboratories, Red Bank, N. J.)

The precision measurement of the attenuation of four-terminal low-loss microwave structures is based on the relationship between the attenuation and the resultant standing wave at the input terminal when the structure is terminated in a short circuit. The techniques and necessary precision measurement equipment have been developed to permit accurate measurement of attenuation values between 0.01 and 0.5 db, and with accuracy down to 0.001 db. Since the resultant VSWR values are very large, the ultimate accuracy depends on the determination of the relative magnitude of the minimum with respect to the readily measurable maximum. Techniques and equipment will be described which minimize the errors due to non-linearity of detectors, power reflections from the test sample, noise in the detector amplifiers, residual frequency modulation of signal source (long-line effects), and attenuation in measuring line. The attenuation measurement has been reduced to the measurement of two physical lengths.

22. DISSIPATIVE AND PISTON ATTENUTATOR CORRECTIONS

CHARLES M. ALLRED
(National Bureau of Standards, Washington, D. C.)

Termination impedances and corrections on rated values of dissipative-type attenuators terminated in any complex impedances will be discussed. Derivation constructional and application of several circle diagrams and nomographs will be presented, and experimental verification data shown for a wide range of frequencies and impedances. In addition, derivation and construction of nomographs will be presented, giving both cutoff frequency and skin penetration corrections for TE0 piston attenuators. Slides will be shown of the above nomographs, circle diagrams, theoretical highlights, and some of the latest NBS attenuation standard equipment.

Measurement of Transmission and Reception

23. A FIELD-STRENGTH METER FOR 600 Mc

J. A. SAXTON
(National Physical Laboratory, Teddington, England)

The equipment has been designed primarily for use in the study of radio wave propagation at 600 Mc, and has a fair wide-band intermediate frequency amplifi- er (0.5 Mc centered on 30 Mc) to ensure that a received signal remains in tune during long periods of recording. As a calibrated instrument, however, it may be used for the accurate comparison of radio field strength or powers, over a frequency range 500 to 700 Mc. It can be operated with a contin- uous wave signal, when the sensitivity (db signal equal to noise) with a dipole receive aerial is about 35 μv/m, or with a modulated signal; in the latter case a narrow-band audio-frequency amplifier is added, and all over-all sensitivity of the equipment about 18 db greater than with an unmodi- lated signal.

24. MEASUREMENT TECHNIQUES FOR BROAD-BAND LONG-DISTANCE RADIO RELAYS

W. J. ALBERSHIEIM
(Bell Telephone Laboratories, Inc., Deal, N. J.)

Adjustment and maintenance of radio relays require sensitive, yet rapid, measurements. By rapid scanning, transmission characteristics can be traced on paper strips or cathode-ray screens. Alternating switches permit superposition of reference traces. Frequency functions thus measured include gain, phase, impedance, reflection coefficient, and their rates of change; time functions include amplitude and frequency modulation; amplitude functions—FM discrimination caused by discrete frequency or noise modulation, by interference and by transmission characteristics.

Time and level distributions of atmospheric disturbances are recorded, and the effects of selective fading and echoe are evaluated by simulating them under controlled laboratory conditions.

25. WIDE-BAND SWEPT-FREQUENCY MEASUREMENTS APPLICABLE TO TRAVELING-WAVE TUBES

FREDERICK E. RADCUFFE
(Bell Telephone Laboratories, Inc., Murray Hill, N. J.)

Methods of measuring transmission and impedance of traveling-wave tubes operating in the 4,000-Mc common-carrier band are described in which the frequency is swept over a 500-Mc band. The characteristics are displayed on a standard oscilloscope.

A gain-comparator type of transmission measuring set is described in which moderate oscillator amplitude variations with frequency do not affect the accuracy of measurement. By this method transmission characteristics are measured to accuracies of about 0.25 db and return loss can be measured up to 40 db.

A new technique, which is useful in broad-band amplifier measurements in general, is described in which both the transmission and output impedance-versus-frequency characteristics of an amplifier delivering its normal power output to its load, are displayed simultaneously on the oscilloscope. Thus adjustments of the output
impedance of a multistage amplifier can be made while compensating the transmission characteristic in another part of the amplifier circuit.

26. MICROWAVE TECHNIQUES IN THE 28,000- to 300,000-MC REGION

Leonard Swern

(Sperry Gyroscope Company, Great Neck, L. I., N. Y.)

This paper will survey the techniques of microwave measurements in the millimeter region. The problems involved in using short wavelengths will be discussed, and certain solutions to these problems indicated. Several examples of new millimeter-region components will be described and illustrated by photographs. These designs will be evaluated. In addition, certain new design proposals will be described. The paper's emphasis will be on techniques fundamentally similar to those effective at lower frequencies. However, new approaches to the microwave measurements problem will be discussed, among them, optical and semi-optical approaches, and the applicability of molecular resonance absorption.

Books (Continued)

Television Installation Techniques by Samuel L. Marshall

Published (1950) by John F. Rider Publishers, Inc., 480 Canal Street, New York 13, N. Y. 336 pages + 4-page index + 272 figures. $1.50.

This outstanding book was written as a reference and handbook, primarily for the television service man, but it is of great interest to the experimenter, the engineer, and the service manager.

The first four chapters of the book present a well-balanced discussion of the nature of television, radio propagation antenna and transmission lines, and transmission and special antenna systems, supported by a clear-cut discussion of the essential theory, and supplemented by specific design methods and practical design information to meet almost any installation requirement.

The next two chapters entitled, "Materials and Methods used in Installations," and "High Mast and Tower Installations," cover the installation of antennas in primary service areas, with particular regard to safety and best installation practices. In the case of the high mast and tower installations, the principles of construction design formulas and data to take care of wind and ice loadings, and special design considerations are discussed in detail for most types of masts and towers.

Two chapters are devoted to problems arising from television installations and receiver adjustments in the home. Problems in connection with reflections, multiple installations, fringe service stations, television interference, TV filters, and the adjustment and servicing of sets in the home are covered in a most factual and satisfactory manner.

The last chapter, "Municipal Regulations," covers safety precautions in general, and the National Board of Fire Underwriters Bulletin 275, the municipal codes and television ordinances of many of the cities of the United States.

The Appendix includes a great deal of useful information in its ten tables and three charts pertaining to VHF TV stations on the air: Data on coaxial cables and transmission lines, data relative to the safe loads of anchors, bolts and guy cables, tape sizes, and a list of the various sizes and characteristics of cathode-ray picture tubes.

This book includes authoritative information describing the best field practices in the installation of antennas to meet practical field problems and the installation and servicing of receivers to give maximum satisfaction to the customer, and points out the importance of attention to details in installations, both in the interest of the customer and of the cley.

Lewis M. Clement

Avco Manufacturing Corporation

Cincinnati, Ohio

Nuclear Data is a new publication of 310 pages available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. The price of $4.25 a copy includes the cost of three supplements (about 60 pages each) which the purchaser will automatically receive at six-month intervals. Remittances from foreign countries must be made in United States exchange and must include an additional sum of one-third the publication price to cover mailing costs.

Nuclear Data is a valuable publication for nuclear physicists and engineers, radiochemists, biophysicists, and other workers in the rapidly expanding field of nuclear physics. It presents a collection of experimental values of half-lives, radiation energies, relative isotopic abundances, nuclear moments, and cross sections. Decay schemes and level diagrams, over 125 of which are included in the tables now ready, are to be provided wherever possible.

The National Bureau of Standards, with the assistance of the Oak Ridge National Laboratory, the Brookhaven National Laboratory, the Massachusetts Institute of Technology, and the University of California Radiation Laboratory, is making the first effort to present a continuing compilation in this rapidly developing field. The present tables and the supplements to follow are therefore designed for easy assimilation of new material in loose-leaf form.
The Annual Index to these Abstracts and References, covering those published in the PROCEEDINGS OF THE I.R.E. from February, 1950, through January, 1951, may be obtained for 2s.8d. postage included from the Wireless Engineer, Dorset House, Stamford St., London S. E., England. This index includes a list of the journals abstracted together with the addresses of their publishers.

534.321: 9-061.3

Rome Ultrasound Convention—G. Bradfield (Electronics Eng. (London), vol. 22, pp. 391-394; September, 1950.) Brief account of lectures and exhibited equipment, including commercial apparatus for many purposes. The advantages of the TiO ceramics for piezoelectric applications were pointed out. A method of investigating the properties of auditioning, using models and ultrasound frequencies, was described.

534.321: 9-064-14

A New Method for Measuring Velocities of Ultrasonic Waves in Liquids—B. R. Rao (Nature (London), vol. 166, p. 742; October 28, 1950.) A rapid, accurate method requiring only a very small quantity of the liquid and applicable to both opaque and transparent liquids over a wide range of frequencies is described.

534.374

Mathematical Analysis of an Acoustic Filter—N. Olson. (Canad. Jour. Res., vol. 28, Sec. A, pp. 377-388; July, 1950.) The attenuation, phase, and impedance functions are calculated for acoustic filters constructed from conduits with a series of equal wider sections at regular intervals. Theoretical impedance and attenuation curves are shown and are confirmed by measurements on filters of circular and square section. Such filters are easy to construct and terminate and may be used in parallel to form units of large cross section.

534.612-534.641

A Method for Measuring Source Impedance and Tube Attenuation—J. E. White. (Jour. Acoust. Soc. Amer., vol. 22, pp. 565-567; September, 1950.) A description of a sensitive and accurate method of determining attenuation and velocity of sound from sound-pressure measurements in gases at medium audio frequencies. By using a microphone movable along an open-ended tube, the acoustic impedance of any sound source coupled to the air column can be found if the acoustic impedance of the microphone is known. All necessary formulas are added.

534.841-884

Reverberation Time and Sound Power Required for Ordinary Rooms—E. de Gruyter. (Bull. schwiz. elektr. Tech., Ver. 10, pp. 757-761; September 17, 1949. In German.) A new interpretation of the calculated reverberation duration made in halls with good acoustical properties. Reverberation constants are derived which characterize the acoustic quality of a room for any particular musical purpose and which are independent of room dimensions.

534.884-911

A Method for Measuring Source Impedance and Tube Attenuation—J. E. White. (Jour. Acoust. Soc. Amer., vol. 22, pp. 565-567; September, 1950.) A description of a sensitive and accurate method of determining attenuation and velocity of sound from sound-pressure measurements in gases at medium audio frequencies. By using a microphone movable along an open-ended tube, the acoustic impedance of any sound source coupled to the air column can be found if the acoustic impedance of the microphone is known. All necessary formulas are added.

534.841-884

Reverberation Time and Sound Power Required for Ordinary Rooms—E. de Gruyter. (Bull. schwiz. elektr. Tech., Ver. 10, pp. 757-761; September 17, 1949. In German.) A new interpretation of the calculated reverberation duration made in halls with good acoustical properties. Reverberation constants are derived which characterize the acoustic quality of a room for any particular musical purpose and which are independent of room dimensions.
**Abstracts and References**

621.395.625.2:621.306.933  
**An Automatic Monitoring Recorder—See 207.**

621.395.92  
Among the essential qualities of any audiometric instrument, the most important is the provision of optimum volume to suit each patient in all reasonable conditions of use. In most cases this cannot be achieved without automatic volume controls. There should be no pronounced peaks in the response curve and noise should be reduced by mounting the microphone in rubber and making the surface of the case very smooth.

621.396.822:621.316.8  
A description is given, with a circuit diagram showing all component values, of a generator providing a continuous noise spectrum from 30 cps to 15 kc. Reasons for the choice of a resistor as the primary noise source are given. The current is passed through the diode at a bias voltage which is necessary with such a source are discussed and means for reducing instability are indicated.

621.396.822:621.385.38  
An argon-filled thyratron is used to generate a continuous noise spectrum for audio-frequency testing. Large unwanted ultrasonic components are removed by means of a low-pass filter cutting off at 20 kc, leaving a noise spectrum with power distributed uniformly over the audio-frequency band. Where required, the power-operated shunt can be made uniform by adding a weighting network. The output into 600Ω is 20 db with reference to 1 mw. The generator is mains operated.

**ANTENNAS AND TRANSMISSION LINES**

621.315.21:621.077.1:629.4.6  
A form of transformer is proposed which combines the advantages of a step-up, a step-down, and an impedance matching transformer. The design equations are given.

621.315.212:621.397.24:018.78†  
**Characteristics of Coaxial Pairs of Frequencies Involved in High-Definition Television Transmission**—G. Fuchs. (Câbles & Trans. (Paris), vol. 4, pp. 248–254; July, 1950.)  
The distortion, caused by irregularities of cable impedance, which would occur in the transmission of a television signal of 20-Mc bandwidth over a distance of 1,000 km is calculated, assuming unfavorable conditions and basing the calculations on experimental results for cables (a) with central conductor of diameter 5 mm and outer conductor of internal diameter 18 mm, the insulation consisting of spiral ribbons of variously formed material; (b) of correspondingly different dimensions 2.6 and 9.4 mm, diak of polythene being used for insulation. The normalized square voltage phase and amplitude distortion are 0.05 µ and 1.0 per cent respectively for a 5/18-mm pair cable. The corresponding values for a 2.6/9.4 mm pair are significantly lower: 0.001 µ and 0.04 per cent.

621.315.212.017.71  
See 3014 of 1948.

621.315.213.12:621.221:621.3.011.4  
A formula is derived for the capacitance between the two wires of a Lecher system within a sheath. The degree of approximation is considerably better than that given with Breisig's formula. A numerical example is worked. See also 2416 of 1950 (Wise).

621.392.211  
An equation (12) is derived determining the current distribution along the helix and methods for its solution are indicated. The theoretical results obtained have been confirmed experimentally.

621.392.211  
A theoretical treatment of radiation from a system of concentric circles. Series formulae are given for the radiation field produced by a specified excitation of these elements. Integral formulae are given for the required excitation to produce a desired radiation pattern. There is no consideration of how the required excitation can be produced.

621.396.07:518.566  
**Cylindrically Diverging Electromagnetic Waves in a Medium with Nonuniform Electrical Properties** (Elostat-241, 1948)  
A formula is given for the field of a vertical dipole above a flat, homogeneous, imperfectly conducting earth in a medium with refractive index decreasing exponentially on height. A geometrical-optical interpretation of the expressions is given, using the saddle-point method.

621.396.67:621.396.9  
**Radar Aerial Systems for Uniform Irradiation of a Surface—Huiyen.** (See 117.)

621.396.671  
Reprint. See 3342 of 1949.

621.396.671  
Discussion on 2134 of 1950.

621.396.677  
A comprehensive review of the subject, including theory of the principal types of lens.

621.396.677  
A discussion of the development of microwave delay lenses using parallel metal strips or waveguides
261.306.677 38 Factors Governing the Radiation Characteristics of Dielectric-Tube Aerials—D. G. Kleith. (Proc. I.R.E., vol. 38, p. 1052; September, 1950.) The effects of changes of tube length, diameter, and wall thickness on the radiation pattern were investigated experimentally. It is suggested that the mechanism of radiation of thin-walled dielectric tubes more closely resembles that of a lens than that of a leaking waveguide, such as a dielectric rod antenna. The leaky wave guide, such as a dielectric rod antenna, of length 8, diameter 1.16 A, and wall thickness 0.03 A is approximately 21 db.

261.317.69 39 Pattern Calculations for Antennas of Ellipsoidal Aperture—R. J. Adama and K. S. Kelleher. (Proc. I.R.E., vol. 38, p. 2152; September, 1950.) The aperture illumination patterns in the directions of the major and minor axes are calculated from a knowledge of the pattern on the feed horn, and then expressed as Fourier series of up to four terms. The radiation pattern is given by

\[ F(u_1, u_2) = r a b \sum_{n=-\infty}^{\infty} a_n b_n \cos(n u_1 - n u_2), \]

where \( a_n = (2 \pi s \sin \phi)/\lambda, b_n = (2 \pi s \sin \theta)/\lambda, \) and \( n \) are the semijor and semiminor axes of the aperture, and \( a_n \) and \( b_n \) coefficients of the Fourier series are a complicated function which has been tabulated elsewhere by the authors. Very good agreement with the theory was obtained in experiments on several horns.

261.317.69 40 The Radiation of Beam Aerials in Partially Large Surfaces in General—B. van der Pol. (Tijdschr. Ned. Radio-Genoot., vol. 15, pp. 151-155; July and September, 1950.) The calculation of the power radiated by a beam antenna is simplified by imagining the system of parallel-wire radiators replaced by an equivalent extended current-carrying surface. Approximate formulas are derived for the radiated power for different limiting cases of the dimensions. Where the dimensions are large compared with the wavelength is independent of \( \lambda \) and is proportional to the area of the surfaces.

261.317.677 41 Measured Directivity Induced by a Conductor Cylinder of Arbitrary Length and Spacing Parallel to a Monopole Antenna—F. R. Abbott. (Proc. I.R.E., vol. 38, pp. 1040-1041; September, 1950.) Curves are given for determining the directivity, given the separation of the parasite from the antenna and also its height.

261.317.679.4 42 Effects of Linear Distortion on a Band of Frequencies Transmitted along a Long Mismatched Line—J. Fagot. (Ann. Radiol., vol. 5, pp. 179-184; July, 1950.) The following formulas are derived for the irregularities caused by the mismatch when the frequency varies within the band considered:

\[ \text{period of variations} = \frac{\omega t}{2\pi} \]

\[ \text{max./min. amplitude variation} = \frac{\omega}{2\pi} \]

\[ \text{phase displacement or propagation-time deviation} = \frac{(p1 - p2) - 1}{r} \]

where \( p \) is the phase velocity, \( t \) the length of line, and \( r \) the arrival at the end of the line. These formulas are independent of the frequency carrier and hold for the usual practical case where the terminal impedance is not highly selective.

261.317.679 43 Study of the Effects of a Long Line on a Frequency-Modulation Signal: Distortion, Compensation and Applications—M. Denz. (Ann. Radiol., vol. 5, pp. 185-205; July, 1950.) The long feeder lines used in c.m.w. transmission are a source of distortion; this is particularly severe when the modulated oscillator is tightly coupled to the line, and a slightly modified effective remedy is the insertion of an amplifier between source and feeder. The existence of several junctions in a feeder, each causing slight reflection, may transform the line into a dispersive quadrupole, so that phase distortion occurs, accompanied in certain cases by nonlinear frequency distortion. Numerical examples show the importance of this, and that high-quality transmissions using a c.m.w. carrier with FM. Methods of correcting distortion and possible uses of long lines in measurement technique are discussed.

CIRCUITS AND CIRCUIT ELEMENTS


537.314:12 621.317.084 45 The Fundamental Limitations of the Second-Order Type of Magnetic Modulator as Applied to the Amplification of Small D.C. Signals—Williams and Noble. (See 142.)

537.314.3 621.315.466 Dynamic Amplifiers—R. M. Saunders. (Elec. Eng., vol. 69, pp. 711-716; August, 1950.) Basic principles are presented, five types are distinguished, salient features discussed, and methods proposed for predicting performance.


537.314.36 621.315.48 A New Theory of the Magnetic Amplifier—A. G. Milnes. (Proc. IEE, London, Part 11, vol. 97, pp. 460-474; Discussion, pp. 474-483; August, 1950.) Assuming that the B/H curve for the core material has a constant slope up to saturation level, followed by zero slope, flux waveforms are derived and equations developed for the magnetomotive forces operating throughout the cycle for a transistor with any degree of self excitation. Analytical expressions are then derived for the output characteristic and for the current amplification and time constant of a transistor, which are of considerable importance in design work.

537.314.36 621.315.48 49 A New Theory of the Magnetic Amplifier—A. G. Milnes. (Proc. IEE, London, Part 11, vol. 97, pp. 460-474; Discussion, pp. 474-483; August, 1950.) Assuming that the B/H curve for the core material has a constant slope up to saturation level, followed by zero slope, flux waveforms are derived and equations developed for the magnetomotive forces operating throughout the cycle for a transistor with any degree of self excitation. Analytical expressions are then derived for the output characteristic and for the current amplification and time constant of a transistor, which are of considerable importance in design work.

537.314.36 621.315.48 50 A New Theory of the Magnetic Amplifier—A. G. Milnes. (Proc. IEE, London, Part 11, vol. 97, pp. 460-474; Discussion, pp. 474-483; August, 1950.) Assuming that the B/H curve for the core material has a constant slope up to saturation level, followed by zero slope, flux waveforms are derived and equations developed for the magnetomotive forces operating throughout the cycle for a transistor with any degree of self excitation. Analytical expressions are then derived for the output characteristic and for the current amplification and time constant of a transistor, which are of considerable importance in design work.
Abstracts and References

621.392.6


621.396.611.4


621.396.611.5

High-Frequency Vibrations of Plates Made from Piezoelectric Materials—E. J. Fyfe and E. A. Gerber. (Proc. I.E.E., vol. 38, pp. 1073-1078; September, 1950.) Bevelling of crystals is described as a method for obtaining a single response even under the influence of electrical characteristics and temperature coefficients of NaClO₄, NaBrO₃, HN₃H₂PO₄ (ADP) and KH₂PO₄ (KDP) crystal units were measured. The piezoelectric constants of ADP and KDP were determined by the usual methods (see IRE Standard on Piezoelectric Crystals (655 of 1950) were used. Fair agreement was obtained with the theory presented in the paper. The NaBrO₃ thickness modes have about the same quality factor as that of quartz, the quality factor of ADP crystals being about one order of magnitude lower.

621.396.615

The Reactance-Tube Oscillator—A. Giger. (Proc. I.E.E., vol. 38, p. 1096; September, 1950.) Comment on 326 of 1950 (Chang and Rideout), pointing out that the transverse wave field of a reactance-tube oscillator has a fixed value and cannot affect the frequency. An explanation of the observed frequency variation is given. The method is based on practical work in Switzerland, where the reactance-tube oscillator has been in commercial use for years.

621.396.615.17

Calculation of the Time Delay of a Multi-vibrator—H. de Lange Dan. (Tijdschr. ned. Radiogroen., vol. 15, pp. 275-291; July and September, 1950.) A method is described for a linear differential equation of fourth order with constant coefficients by the method of variation of parameters, in which a discontinuity, of the fourth order is reduced to one of zero order during integration. The solution is applied to calculate the time delay of a multi-vibrator by means of a differential equation of fourth order.

621.396.617.755

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A Selective Relay Amplifier for Recording WWW Time-Signals—E. F. Carome and H. C. MacDonald. (Rep. Prog. Phys., vol. 12, pp. 56-79; June, 1949.) A circuit details are given of an amplifier which discriminates against all frequencies except 440 cps, the modulation frequency of the wave signals, so that the operation of a relay in the anode circuit of the output tube is unaffected by the pulses sent out at second intervals, or by abnormal electronic background noises. The selective element consists of a twin-T RC bridge.


The Amplification of Pulse-Form Modulated Voltages and the Accompanying Reduction in Time Delay—J. W. Alexander. (Tijdschr. Ned. Radiotechn., vol. 15, pp. 231-251; July and September, 1950.) In assessing the performance of an amplifier dealt with in the subject the criteria to be considered are the efficiency of the output pulse envelope and its retardation with respect to the input pulse. According to the method devised, certain factors are easier to determine than the output-pulse envelope itself. The theory is applied to amplifiers with several single-tuned circuits and to amplifiers with coupled-und stagger-tuned circuits.

The Determination of Quiescent Voltages and Currents in Pentode Amplifiers—A. J. Summins. (Electronic Eng., vol. 22, pp. 386-388; September, 1950.) A method is described for determining the quiescent voltages of anode, screen-grid and control-grid voltages and currents graphically or by calculation from a family of dynamic characteristics for various screen-grid voltages. The solution is approximate but useful for predicting the effect of coupling in circuit parameters such as cathode and screen resistances.

The Cathampifier—C. A. Parry. (Proc. I.R.E., vol. 38, pp. 199-204; August, 1950.) An amplifier circuit with high input impedance which permits push-pull operation from an unbalanced source. The input voltage is applied between earth and the grid of one of the tubes, and a voltage proportional to the total circulating current is obtained from a transformer whose center-tapped primary is connected between the two cathodes. This voltage is applied in the correct phase between earth and the grid of the other tube. A resistance shunted across the transformer primary is used to obtain anode-dc balance. Over-all performance similar to that usual in push-pull operation may be obtained. Two modes of oscillation are possible which are independently adjustable.

General Physics

Spontaneous Fluctuations—D. C. MacDonald. (Rep. Prog. Phys., vol. 12, pp. 56-79; References, pp. 79-81, 1948-49.) A survey of developments in fluctuations analysis, and review of research on fluctuation phenomena in the last decade, omitting general problems treated in standard works. The correlation function is discussed, with examples of its use. Recent developments treated are mainly concerned with thermal noise, and include discussion of thermal, shot, and low-frequency noise.

Contact-Potential Measurements on Irradiated Metal-Oxide Surfaces—H. Neuer. (Z. Naturf., vol. 38b, 1953.) A method of experimental work demonstrating that a slightly oxidized surface can be activated by uv ultraviolet radiation, or by ionic or electronic charging, or by mechanical treatment.


Theory of Photoelectric Conduction in Composite Conductors—F. Stockmann. (Z. Phys., vol. 128, pp. 185-211; July, 1950.) The fundamental equations of electrical conduction are examined for the case of circuits including electron sources and sinks. General laws for photoelectric currents are hence derived which agree with laws derived directly by other workers. The contact, ambipolar, and exponential law of loss are discussed. Non-linear conductors and semiconductors are studied as special cases.

The High-Frequency Gas Discharge—F. Kirchner. (Z. Naturf., vol. 2a, pp. 620-622; 1948.) A description is given of a simple experimental arrangement for investigating the discharge without introducing a probe. The results indicate strong positive space-charge and high positive potential within the gas. The discharge can be maintained with voltages below the ionization potential.


The Production of Ion Beams by Means of a High-Frequency Discharge—H. Neuer. (Z. Naturf., vol. 3a, pp. 310-312; 1948.) An arrangement similar to that described by Schaffs and Trendelenburg (1351 of 1946) was studied. With 100 w exciting power and 10 kv field voltage an ion current of 20 ma was obtained.

A Notation for Electrodynamic Adaptable to Any System of Units—R. Fischmann. (Z. Naturf., vol. 3a, pp. 492-495; 1948.) The fundamental formulas of four-dimensional electrodynamics are presented in a notation which is independent of the system of units and which for special cases yields the formulas valid for the usual systems of units.

Fields with and Around Cavities in a Magnetically Stratified Medium, Ponderomotive Forces acting thereon in a Magnetic Field with Current in the Cavity, and the Electric Field Generated on Movement of the Cavity—J. P. Schonbauer. (Tijdschr. Ned. Radiotechn., vol. 15, pp. 163-177; July and September, 1950.) It is shown analytically that the total electric field inside a cavity moving in a medium subjected to a homogeneous magnetic field is independent of the inhomogeneity introduced by the cavity wall, and the total mechanical force on the cavity is the same as if the medium were continuous.

Formulas and Tables for the Calculation of the Magnetic Field of Circular Filaments and Solenoids—W. G. Grover. (Trans. A.I.E.E., vol. 68, Part I, pp. 663-675; 1949.) Existing formulas are discussed and new formulas are presented. The application of the tables involved are presented in a form which facilitates routine calculations.

The Forces between Two Current Conductors—H. D. H. Telegem. (Tijdschr. Ned. Radiotechn., vol. 15, pp. 157-161; July and September, 1950.) Conditions for steady current in two conductors, nonparallel and the total force is regarded as the resultant of attractive forces and couples due to the interaction of current elements of the two conductors.

Reflection and Transmission of Electromagnetic Waves by Thin Curved Shells—J. B. Kelley. (Jour. Appl. Phys., vol. 21, pp. 896-901; September, 1950.) The scattering of an arbitrary electromagnetic wave by 2 conducting or non-conducting obstacle is investigated. The differential equations and boundary conditions satisfied by the field are transformed into a pair of inhomogeneous linear integro-differential equations for E and H. For an obstacle which is a thin shell of constant thickness, a formal procedure for obtaining a solution of these equations as power series in 1 is given. The lowest order term in this solution is the incident field. An explicit expression for the next term is found in the form of a surface integral. This integral is evaluated approximately by the method of stationary phase. The physical properties of the solution are examined in detail, and satisfactory agreement is examined in detail, and satisfactory agreement is found with many results previously obtained by other methods.

Rigorous Theory of the Diffraction of Electromagnetic Waves by a Perfectly Conducting Plane—J. P. Schonbauer. (Z. Naturf., vol. 3a, pp. 506-518; 1948.) The solution of this problem is given and extended to the related problem of diffraction by a circular aperture in a perfectly conducting plane sheet of infinite extent by a generalization of Babinet's principle.
The Characteristics of Radio-Frequency Radiation in an Ionized Gas, with Applications to the Transfer of Radiation in the Solar Atmosphere—S. F. Smed and A. C. Westfold (Phil. Mag. (5), vol. 10, pp. 831–848; August, 1949.) The function $E$ which determines the adiabaticity at any point is the ratio of the missivity to the product of the absorbing coefficient and the square of the index of refraction. The intensity of "quiet" radio-frequency solar radiation reaching the earth can be expressed in terms of $E$ and the optical depth of the various ray trajectories. Formulas are derived for emissivity, absorption coefficient and effective index, from which $E$ can be found. The formulas are expressed in terms of the electron density and the magnetic field strength, assuming a Maxwellian velocity distribution. A heuristic theory of the absorption and emission processes on a volume element is given which takes account of the effect of the surrounding particles of the medium.

The Scattering of 3-cm Radiation by Ionized Gases—S. N. Denno, H. A. Prime, and J. D. Cragg (Proc. Phys. Soc., vol. 63, pp. 772–782; September, 1950.) The scattering of wavelength 3 cm is scattered by a commercial cylindrical mercury discharge tube. Scattered at right angles to the incident radiation is received and calculated, and the received power as a function of tube current is given for radiation polarized (a) perpendicular to and (b) parallel to the tube axis, or two tubes of diameters 3.1 cm and 6.4 cm respectively. It is intended to use the information to determine the electron concentration in the discharge.


Derivation and Tabulation of the Piezoelectric Equations of State—J. F. Haskins and J. S. Hickman (Jour. Acoust. Soc. Amer., vol. 22, pp. 584–585; September, 1950.) The conservation of energy principle is applied to derive the general equations, with strain, electric displacement and entropy independent variables. The special case of constant entropy is then considered. The equations form an additional parameter, and all possible linear adiabatic equations of state are developed, using in turn as independent variables stress and electric field, strain and stress and entropy, strain and stress and electric field. Hence the relations between the electric, elastic and piezoelectric coefficients for the various pairs of independent parameters are determined and tabulated.

Piezoelectric Equations of State and their Application to Thickness-Vibration Transducers—W. G. Cady (Jour. Acoust. Soc. Amer., vol. 22, pp. 579–583; September, 1950.) The equations for the case of a given in several forms and those most appropriate in theoretical work are indicated. A detailed treatment of the thickness-vibration transducer is given, resulting in expressions for the electrical characteristics and acoustic power. Various special cases are briefly considered.

METEOROLOGICAL AND EXTRATERRESTRIAL PHENOMENA

Meteor Velocities—P. M. Millman and D. W. R. McKinley (Observatory, vol. 70, pp. 155–158; November, 1950.) The main emphasis is on methods used in the radio techniques are discussed in relation to their capabilities of detecting fast meteors.

The Effect of Turbulence on a Magnetic Field—P. A. Sweet (Mon. Not. Roy. Astr. Soc., vol. 110, pp. 69–83; 1950.) Extension of earlier work by R. H. Dicke. Theoretical analysis indicates that (a) turbulence reduces the effective conductivity in the core and in the outer layers of the sun, but sunspot fields are not affected; (b) the decay time of the sun's general magnetic field is somewhat less than $10^9$ years, while the mean field in the core, if the general field is decaying from some initial state, is irrotational; (c) the magnetic field currents in the sun can provide a general amplification of a field produced by a given emf, while turbulence in fact reduces the field.

The Solar Constant—C. W. Allen (Observer, vol. 70, pp. 154–155; August, 1950.) Discussion leads to a tentative value of 1.97 cal/cm/min.

Cosmic Radiation from the Sun—A. Ehmert (Z. Naturf., vol. 5a, pp. 227–235; 1950.) The phenomena of cosmic radiation may be related to the ionization of cosmic regions by protons accelerated in the varying magnetic fields of sunspots; in the sun, while accelerated electrons may give their energy as usw radiation.

Solar Radio-Frequency Radiation—J. L. Pawsey (Proc. IEE (London) Part III, vol. 97, pp. 300–308; September, 1950.) A survey of solar-noise research from 1932 to 1948. Observed characteristics in the wavelength range from 1 cm to a few meters are described. From the intensity, region of origin, association with visual phenomena and polarization a classification is suggested. A thermal component is recognized corresponding in intensity to a black-body radiation of a temperature that rises from $10^4K$ at a wavelength of 1 cm to $10^7K$ at wavelengths of a few meters. This is believed to be associated with a rise in the region of origin from the lower chromosphere to the corona. Non-thermal components, prominent at meter wavelengths and believed to originate from electrical disturbances in the solar atmosphere, vary randomly and have occasional power densities $10^6$ to $10^7$ times the thermal ones. 66 references are given.

The Characteristics of Radio-Frequency Radiation in an Ionized Gas, with Applications to the Transfer of Radiation in the Solar Atmosphere—Smed and Westfold (See 95.)

The Emission of Radio Waves from the Earth's Crust—J. B. M. Clegg (Phil. Mag. (5), vol. 10, pp. 631–636; August, 1950.) The intensity of radio waves varies with the square of the index of refraction, and varies with the product of the absorption coefficient and $E$. Formulas are derived which are more general than the empirical formula of Blackett.

The "Absolute Quadrupole-Moment"--a Fundamental Magnetoelastic Quantity and its Geophysical Significance—H. Macht (Z. Naturf., vol. 3a, pp. 189–195; 1948.)

Ionosonde Observations in Adélie Land—M. Barré and R. R. R. (Compt. Rend. Acad. Sci. (Paris), vol. 231, pp. 436–437; August, 16, 1950.) An interim report of observations made during the antarctic cruise of the Commandant Charcot (see also 1949 and 1950). The major events obtained during 24 hours on January 3–4, 1950 include: (a) a sporadic E-layer giving echoes at high frequencies (10 Mc); frequent stratification in this layer and increase of its height with frequency; (b) permanent diffusion of the $F$ layer, extending with increase of frequency; (c) horizontal traces resembling those of the sporadic-E layer but at heights of 250–300 km; (d) selective absorption at about 3.5 Mc masking all traces of layer.

The Pointing Vector in the Ionosphere—Scott (See 193.)


LOCATION AND AIDS TO NAVIGATION

Sound Ranging at the Morris Dam Torpedo Ranges—R. N. Skeeters (Bull. Eng., vol. 69, p. 715; August, 1949.) The TIFE Summer Meeting paper. For making accurate determinations of the trajectories of under-water missiles, the latter are caused to generate sound with the help of locally located hydrophones arrayed in groups of eight. An oscillograph record is obtained. Re-
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duction of the data is accomplished by means of a computer which is a scale model of one of the hydrophone groups.

621.359.621.396.317


Discussion on 3142 of 1949.

621.396.93

Some Experiments on the Accuracy of Bearings taken on an Aural-Null Direction-Finder—P. Horner. (Proc. IEE (London), Part III, vol. 97, pp. 359–361; Discussion, pp. 362–365; September, 1950.) The paper describes some tests to determine how accurately a bearing taken on an aural-null rotating H-Adcock direction finder is contained within the limits of the minimum and on the receiver output noise-level. The results pertain to bearings taken on a steady tone-modulated signal by an experienced observer working under good conditions. They indicate that bearings taken under these conditions will have standard deviation of about 1/20 of the arc of silence except for very small arcs, even when the bearings are derived from very few oscillations of the antenna system. Accuracy is improved if the number of complete oscillations is greater than about five. Accuracy is degraded if the angle through which the antenna is swung is increased to improve the quality of the bearings. The damping of the system has little effect on the accuracy. Differences of at least two to one in the standard deviation of observed bearings may occur between different observers, and with one observer at different times. Compared with these changes, any changes due to the use of different receiver output noise-levels are considered to be small.

MATERIALS AND SUBSIDIARY TECHNIQUES

531.787.92


533.50


533.583.621.385

A Method for Measuring the Efficiency of Getters at Low Pressures—W. S. Wager. (Brit. Jour. Appl. Phys., vol. 1, pp. 225–231; September, 1950.) The method is based on the observation that the increment of the pressure drop along a narrow tube connecting the bulb containing the getter to the manifold of the pumping system is a function of the pressure being 1.5 x 10^{-4} mm Hg.

535.37

Phosphors and Phosphorescence—G. F. J. Garlick. (Rep. Prop. Phys., vol. 12, pp. 34–53; References, pp. 53–55; 1948–49.) Recent investigations of luminescence in crystalline impurities are described, including the use of the electron-energy-band model and experimental results for which are discussed. Long-duration phosphorescence, due to electrons trapped in thermally metastable levels, correlates with thermoluminescence. Advances are reported in knowledge of the structure of luminescence emission centers in sulphide and silicate phosphors. The emission spectra of manganovan-activated silicates, recent studies of oxides and tungstates, and infrared-sensitive phosphors are treated. The latter are used to indicate a new area of activity for x-ray sensitizers; infrared light appears to have particular excitation for trapped observations, but there is no simple correlation between optical and thermal emission.

535.37: 546.472.21

Introduction of the Copper into a Luminescent Zinc Sulphide—N. Ril’ and G. Ortmann. (Compt. Rend. Sci. (URSS), vol. 66, p. 845; June 8, 1949.) If copper is introduced into diffusion into ZnS crystals it may be in two states, one causing blue luminescence and the other green luminescence. An experimental study of these effects is described.

537.311: 546.92: 541.183.56

Resistance Variation of a Platinum Foil due to Gas Adsorption—W. Braunbek. (Z. Naturf., vol. 3a, pp. 216–220; 1948.) Experiments made with Pt foil in oxygen, argon and helium indicate a marked reduction of the order of 10% as compared with the value in vacuo, the effect being greatest in oxygen.

538.221

On Ferromagnetic States—I. Giltay. (Tijdsvchr. Ned. Radiosoc., vol. 15, pp. 253–274; July and September, 1950.) The form of Maldergen’s laws is criticized and new expressions are formulated covering effects observed in ferromagnetic materials. Operating-cycle diagrams derived from auxiliary loop curves are introduced.

538.221: 538.5621

Magnetism of Permanent-Magnet Alloys—E. A. Nesbitt. (Jour. Appl. Phys., vol. 21, pp. 879–899; September, 1950.) Magnetostriction measurements were made on various alloys having coercive forces from 50 to 600 oersted. In the older carbon-hardening permanent magnets, high coercive force and high magnetostriction appear together; for the newer carbures, this coincidence does not hold. These results are discussed in the light of recent theories.

548.0: 537.228.1

Determination of the Elastic and Piezoelectric Coefficients of Monoclinic Crystals, with particular Reference to Ethylene Diamine Tetraacetic Acid. (Proc. Phys. Soc., vol. 63, pp. 577–589; August 1, 1950.) Longitudinal modes of vibration were used for narrow bars, low-frequency longitudinal and shear-wave modes for square plates, consisting of the axis of symmetry, which modes for square plates perpendicular to the axis of symmetry, and thickness-mode plates for square plates containing the axis of symmetry. The values of the coefficients and their temperature coefficients are given for EDT. Some properties are considered for EDT, where evaporating square plates of EDT rotated about the axis of symmetry as functions of the orientation, and of Y-cut plates as functions of the width-to-length ratio.

548.0: 549.451


620.193: 621.351.61

Methods for Determining the Effect of Contaminants on Electrical Insulation—K. N. Mathews and P. M. G. Jackson. (Trans. A.I.E.E., vol. 68, Part I, pp. 113–118; Discussion, pp. 118–119; 1949.) The results of tests made under laboratory conditions with carefully controlled mixtures of such contaminants as are commonly encountered on board ship are tabulated according to the effects on the physical and electrical properties of insulating materials, showing the influence of break-down voltage, dimensional stability, and so forth.

621.315.61: 621.317.331

Some Measurements of the Resistivity of Good Insulators—N. W. Ramsey. (Proc. Phys. Soc., vol. 63, pp. 590–594; August 1, 1950.) A method dependent on the loss of charge on a capacitor was used. The resistances of amber, alkahestine, distrene and perspex increased over a period of weeks, the final values being considerably higher than previously published figures.

621.315.612.011.5

Ceramic Dielectrics with High Permittivity—T. A. Dainian. (Ann. Radiol., vol. 5, pp. 230–242; July, 1950. Onde Lact., vol. 30, pp. 228–258 and 335–340; June and July, 1950.) The mode of preparation of ceramic dielectrics is described and the properties of normal mineral insulating materials and of, of titanates is compared. Crystal structure and anomalous temperature coefficients are discussed and measured limits are obtained. A few typical dielectric constant are outlined. Titanates are broadly classified into two groups and applications are listed.

621.315.612.14: 621.310.11.5


621.319.4: 621.793: 621.315.614.6

Metallized Paper for Capacitors—D. A. McLean. (Proc. I.R.E., vol. 38, pp. 1010–1014; September, 1950.) An account of de-icing and potentiometer work. The authors are intended to afford a preliminary guide to the published work on the subject.

666.103.7

The Physical Aspect of Glass/Metal Sealing in the Electronic Valve Industry: Part 2—W. J. Jackson. (J. Inst. Electr. Engrs., vol. 5, pp. 243–258; July, 1950.) The processing technique for the glass alone is discussed: graphs show the optimum annealing temperature and duration, and optimum cooling rate, for glasses of different thicknesses and expansion coefficients. The effects of annealing on the quality of seal are discussed. Graphs based on polarization measurements show the effects on the stresses produced in the seal in numerous cases. A table summarizes the effects of the different variables in the annealing cycle and also of the intrinsic properties of the materials. Part 1: 2253 of 1950.

666.1526: 666.1037.5: 621.385.832

Stainless Steel for Television—A. S. Rose. (Met. Prog., vol. 3, pp. 761–764; June, 1950.) The use of an alloy containing only 17 per cent Cr for the metal cones of large cathode-ray tubes is described. The 75 references given enable the results of tests made under laboratory condi-
Abstracts and References

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2.31 On Certain Polynomials Introduced by

and Thoma. Publisher: J. A. Barth, Leipzig 5th edn., 1950, pp. 46.80 DM. (Tech. Mitt. zw. T. Telev.-Teleph. Verw. Vol. 28, pp. 335–336; August 1, 1950. In German.) This edition of "Die speziellen Funktionen der Ingenieure," newly revised by Thoma, is a comprehensive textbook in eight parts dealing with the subject from elementary differential and integral calculus, differential equations, Fourier series, variational calculus and integral equations. Graphical and mechanical methods of solution are described in addition to analytical methods. The book is clearly written and is recommended both for the beginner and the practicing engineer.


520.1:529.786 w On a Periodic Fluxuation in the Length of the Day—H. F. Finch. (Mon. Not. R. Astr. Soc., Vol. 110, pp. 3–14; 1940–1941.) From a study of the influence of various types of clocks used in the Greenwich Time Service, and annual periodic fluctuation in the length of the day is deduced. The variation is of the order of ±0.001 sec and has an accumulated effect in time of approximately ±0.060 sec. This is in very close agreement with results obtained from independent data by N. Stoyko and demonstrates the persistent character of the phenomenon. See also 2275 of 1950 (Scheibe and Adelberger).

ted in 137 of 1950.

621.3.088:621.314.12 The Fundamental Limitations of the second-Harmonic Type of Magnetic Modulator as Applied to the Amplification of Small D.C. Signals—F. C. Williams and S. W. Noble. (Proc. IEE (London), Part II, Vol. 97, pp. 445–459; Discussion, pp. 474–483; August, 1950.) The advantages of the second-harmonic type of magnetic modulator over the conversion of d.c to a.c are discussed and theoretical analysis is presented for an idealized modulator of this type, with particular reference to the influence of various control parameters on the signal-to-noise ratio and the zero error. Experimental work is described which confirms qualitative verification of the theory when allowance is made for the simplification of a. simplified H configuration for the core material. Great care is exercised in the design, particularly in the choice of the magnetic materials used, in the design, and in the construction of the magnetic circuits which are necessary to eliminate additional sources of noise and zero error. In apparatus described the noise output is mainly caused by signal fluctuations which are equivalent to a signal input of about 10⁻¹⁴ W for a bandwidth of 1 kHz and 1 µW being equivalent to an input of about 3X10⁻¹⁴ W over a 2-hour period.

621.3.2:621.397.62 Television Laboratory Equipment—W. Werner. (Bell. Syst. Tech. Journ. Vol. 40, no. 5–6; April–May, 1961.) This paper was presented at the International Television Conference, Zürich, 1948. Short descriptions of the special features and the uses of video signal generator, video distribution amplifier, high-frequency signal generator, microcrocro for observing a small portion of a television waveform, wide-band radio, sine-wave signal generator (up to at least 5 MHz), high-voltage voltmeter, film scanner, camera and studio-lighting equipment.

621.3.324(083.74)† Two Standard Field-Standard Meters for Very-High-Regret—R. H. D. King. (Proc. I.R.E., Vol. 38, pp. 1048–1051; September, 1950.) "Methods of field-strength measurement are reviewed briefly and the design of field meters conforming closely to those ideals is indicated. The antenna theory is considered. Two instruments approaching ideal theoretical conditions and suitable for reference standards are described. The first of these contains an adjustable matching network. The second utilizes very fine wires on a styrofoam support."

621.3.353.2+621.396.11:551.510.535 Ionospheric Cross-Modulation: Techniques of Measurement—C. C. Newton, F. J. Hyde, and H. G. Foster. (Proc. Phys. Soc., Vol. 63, pp. 616–623; August 1, 1950.) The techniques described were used for measurements noted in 1949 (Raffclle and Shaw), 1949 (Huxley, Foster, and Newton) and 1220 of 1950 (Huxley). The transmitted modulation was successfully measured at the receiver measurements of the carrier voltage and the phase of the wanted signal. The phase of the measured modulation relative to that of the directly received disturbing signal was determined by forming a Lie
dois figure: a phase changer was used to measure the phase difference. A development is described which permits modulation depth and phase to be displayed on a single curo.

621.3.411+621.317.43 Measurement of Permeability and Magnetic Loss of Soft-Steels and Other Steel Samples—P. M. Prache and R. Cazeneuve. (Cables & Trans. Paris.) Vol. 4, pp. 216–233; July, 1950.) Advantages are gained by using a straight rod of the material under test in place of the toroidal sample normally introduced into the magnetic circuit. The calculation involved, and the interpretation of results are simplified by considering the cylindrical sample replacement. Particulars are shown to be used to determine permeability and loss coefficients.

621.3.43 Magnet for Magnetic Testing at Magnetizing Forces up to 300 Oersted—R. L. Sanford and P. H. Winter. (Bur. Stand. Jour. Res., Vol. 45, pp. 17–21; July, 1950.) An instrument designed to test specimens up to 3 cm wide by 1 cm thick, with a preferred length of 28 cm. It is simpler and more rapid in operation than the Burrows permeameter and requires only a single specimen. Accuracy is within 1 percent.

621.3.444† Underwater Gaussmeter—L. Vranic and P. Jolivet. (Rev. sci. Élec., Vol. 59, pp. 405–408; September, 1950.) The instrument described comprises an air-driven rotor of special design located in the unknown field and having two collector brushes connected by line to a fluxmeter. The brushes are periodically short-circuited, so that the fluxmeter needle has a steady deflection proportional to the unknown field and independent of the duration of the deflection or the speed of rotation of the rotor. Results are reported of measurements made at Abbeville in 1940, of the vertical component of the earth's magnetic field at various depths in the vicinity of a destroyer.
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621.317.723 159
A Simple Vibrating Condenser Electrometer—D. G. A. Thomas and H. W. Finch. (Electro-Techn. Quart., vol. 39, pp. 395–399; September, 1950.) The dc input is converted to ac by applying it through a series resistor to the plates of a capacitor consisting of a stainless-steel diaphragm vibrating at 550 cps on a polished steel disk. The resultant alternating voltage is amplified, rectified and fed back to cancel the input voltage, the electrometer acting as a dual-beam galvanometer. The input signal at a 1 mv full scale sensitivity of 30 mv. An important application is to the measurement of ionization currents.

621.317.725 160

621.317.725.029.5 161
A Thermal Millivoltmeter for Measuring Radio-Frequency Voltages—N. Coulson. (Proc. IEE (London), Part 111, vol. 97, pp. 344–348; September, 1950.) The measuring element is a thermocouple milliammeter. The input impedance is varied by means of a turrent switch which connects resistors in series or in parallel with the milliammeter, so that the output voltage of a source may be measured with various loads. At frequencies up to 100 Mc the error is less than 1 per cent for purely resistive 70-ohm source, the instrument amounting to 0.5 per cent when reactive elements are present.

621.317.727.025 162
The Polar Ammeter as an A.C. Potentiometer—The Synchronopotentiometer—E. B. Brown. (Jour. Sci. Instr., vol. 27, pp. 251–252; September, 1950.) Description of experiments showing that the voltage generated in the moving coil of a polar ammeter (1084 of 1948) can be varied both in phase and magnitude, so that the instrument can fulfill the functions of an ac potentiometer. An almost linear variation of amplitude can be obtained by moving the pointer over the scale. The phase can be varied by angular adjustment of the crudely synchronous motor. Results are quoted and a description is given of the apparatus.

621.317.73 163
A Direct-Reading Impedance-Measuring Instrument—D. H. F. Reeve and R. Thurston. (Gen. Radio, Exp., vol. 24, pp. 1–7; May, 1950.) This null-type instrument measures, on scales independent of frequency, conductances and susceptances of either element, from 1 to 400 million at frequencies from 70 to 1,000 Mc. Three coaxial lines, one terminated by a resistance equal to its characteristic impedance, the other terminated by a known resistance, are fed at a common junction from a common source and have adjustable pickup loops which are so oriented that their combined output is zero. The loop-position scales are calibrated to read susceptance and conductance directly.

621.317.733.089.6:621.318.018.78:621.318.018.78 164
A Method for Calibrating Distortion-Measurement Bridges—W. Hübner. (Arch. TECH. METMEN, pp. 773–774; July, 1950.) Measurement of distortion with an ac bridge-comparator is feasible with respect to the order number of the harmonics present. In the calibration and test method described the measurement bridge is connected in the fourth arm of a resistance bridge to which, after balancing, a voltage of fundamental frequency is applied across one diagonal and a known harmonic voltage across the other diagonal. The distortion factor of the voltage appearing across the measurement bridge is thus known accurately.

621.317.755:621.310.3 165
Technique of Autosynchronous Observation of Transients—F. Lepri, I. F. Quercia, and B. Negro. (Nuovo Cim., vol. 5, pp. 384–385; December 1, 1948.) Discussion of modifications to a circuit previously described (ibid., vol. 5, p. 384; 1948) to make the whole of the transient (before the echo) triggered by the transient, which passes through a delay line before being applied to the y-plates of the oscillograph. Operation of the bootstrap, Miller, and phantom sawtooth-wave generators and the design of delay lines are considered.

621.317.755:621.317.791 166

621.317.757 167
A Frequency-Spectrum Analyzer for Radio Signals—J. Marique. (HF, Brussels, pp. 177–184; 1950.) An account is given of an instrument for analysis of signals from a distance. The principal ac-circuit results and the use of indicator filters are indicated. Various examples of measurements are illustrated.

621.317.78.029.64 168
The Measurement of Microwave Power at Wave Lengths of 3 cm and 10 cm—R. Street (Proc. IEE, vol. 63, pp. 623–624; August 1, 1950.) A magnetron or klystron was connected via a waveguide to a matched-knob constant-flow calorimeter. A direction-coupling input and a signal-coupling output was inserted in the waveguide. The absolute power delivered to a milliampere meter matched to the low-power guide of the coupler can be calculated. For three typical coupling ratios of absolute to indicated power were respectively 1.04, 1.04 and 1.10. The accuracy of the measurements is within about 2 per cent.

621.317.79:551.504.6 169
A Subjective Method of Measuring Radio Noise—S. F. Greenhall. (Ann. Phys., vol. 1, pp. 102–109; 1950.) The subjective method is used to determine the amount of noise in a system. A loudspeaker is connected to the output of the noise generator, and the sound produced is heard, using a standard telephone. The sound pressure is then compared to that of a standard oscillator.

621.317.79:621.396.933 170
Monitoring Airways Radio—(Wireless World, vol. 56, p. 335; September, 1950.) A short account of the work carried out at the frequency-measurement station of the Ministry of Civil Aviation at Pailton, near Rugby, with illustrations of some of the equipment. Records are kept of all routine measurements and a monthly chart gives a day-to-day record of the frequencies of all the navigational beacons.

621.395.61.089.6 171
American Standard Method for the Pressure Calibrations of Laboratory Standard Microphones: 224.4—1940 (Abridged)—Bera- nek, Cook, Romanow, Wiener, and Bauer. (See 19.)

621.395.623.54.089.0 172
American Standard Method for the Coupler Calibrations of Telephone Microphones: 224.5—1949 (Abridged)—Bera nek, Cook, Romanow, Wiener, and Bauer. (See 21.)

621.383.833 181
58.565

**Formulation of Huygens' Principle—W. Franz.** (Z. Naturf., vol. 3a, pp. 500–506; 1948.) Making use of Green's dyad, a formulation of Huygens' principle for thin waves is derived which, like Kirchhoff's scalar formula, makes it clear that for selected boundary values the wave equations are satisfied. Kirchhoff's theory does not solve a boundary-value problem. In contradistinction to Kottler, the discontinuity is regarded as basic to Kirchhoff's theory and not as a property of the 'black' screen.

58.566:551.510.535

**The Poynting Vector in the Ionosphere—J. C. W. Scott.** (Proc. I.R.E., vol. 38, pp. 1057–1068; September 1950.) Formulas and curves are given for calculating the polarization and complex Poynting vector of a radio wave in the ionosphere in terms of the refractive index. Deviations are made concerning the direction of energy flow for the ordinary and extraordinary modes in a parabolic distribution of ionization, for vertical incidence. When collision is taken into account the deflection from the vertical has a small westward component for both modes. The normal ionization gradient with altitude in the lower levels of the E layer is shown to be due to the variation in the total path deflection. See also 2156 of 1949.

58.566:621.390.67

**Cylindrically Diverging Electromagnetic Waves in a Medium with Nonuniform Electric Properties (Elias-Layer) above a Semi-conducting Earth—van der Wyck.** (See 32.)

621.391:523.74/75

**Solar Notes—Newton.** (See 106.)

621.391:621.317.353.9


621.317.41


621.387.41

**After-Effects in Ultraviolet-Sensitive Counters—I. Neuert.** (Z. Naturf., vol. 3a, pp. 221–245; 1948.)

51.142:533.0

**Electric analogue computing techniques or Complex vibration and Aeroelastic problems—G. J. McCann and R. H. MacNeal.** (Elect. Eng., vol. 69, p. 724; August, 1950.) Summary of AIEEE Summer General Meeting paper.

218.364.61


218.385.833


**Propagation of Waves**

A Radio Meteorological Investigation in the South Island of New Zealand—B. Milnes and R. S. Unwin. (Proc. Phys. Soc., vol. 63, pp. 595–612; August 1, 1950.) Investigations in New Zealand, particularly with offshore wind conditions, are favourable to the formation of radio ducts. Modern techniques were used to explore thoroughly the atmospheric duct, but a discontinuity problem. In contradistinction to Kottler, the discontinuity is regarded as basic to Kirchhoff's theory and not as a property of the 'black' screen.
62.1.39.682: 537.523.3 205

62.1.39.626 206
Reduction of Interference from Radio-Frequency Heating Equipment — W. G. Klingman, et al. (Trans. AIEE, vol. 68, Part I, pp. 718-724; Discussion, p. 724, 1949.) Discussion of the causes of the generation of very high frequencies by radio-frequency heating equipment, and of measures for its reduction, particular attention being given to harmonic suppression and effective screening.

62.1.39.933: 621.39.625.2 207
An Automatic Monitoring Recorder — (Engineer, London), vol. 190, p. 186; August 18, 1950, Short description of equipment for continuous recording of speech transmitted from an aircraft to a ground control station. The speech-frequency range is limited to 500-3,000 c.p.s. Recording is on standard Kodak film, in a phone output produced largely indents, without cutting. The recording head is traversed across the film to obtain 120 sound tracks on each side, so that 120 ft of film suffices for a 24-hour period. Any portion of the record can be reproduced without interrupting the recording.

STATIONS AND COMMUNICATION SYSTEMS

621.39.001.11 208
Photon and Waves — D. Gabor. (Nature, London, vol. 166, pp. 724-727; October 28, 1944.) A paper read at a lecture delivered in Paris, May 9, 1950, on ‘La Théorie des Communications et la Physique.’ A comparison is made of the quantum and classical methods of describing signals. The ‘information cell’ is taken as a convenient unit for discussing communication problems; by the classical method this has two data associated with it, an amplitude and a phase, but by the quantum method only one datum, of the nature of an amplitude. More information, however, is gained by the latter method since the total number of distinguishable steps of the single datum is greater than the product of the number of distinguishable steps of the two data in the classical method. The theory is illustrated by a determination of the optimum conditions for interchange of energy between a weak signal and a transverse electron beam in a waveguide.

62.1.39.001.11: 535.42 209
Diffraction and Quantity of Information— A. Blinc-Lapierre and M. Perrot. (Compt. Rend. Acad. Sci., (Paris), vol. 231, pp. 539-541; September 11, 1950.) The system considered is that constituted by an aperture, an object at infinity composed of incoherent sources, and a diffraction image at infinity. From the correspondence between image and object, the concept of information transmitted by the aperture is deduced.

62.1.39.011: 621.317.35 210

62.1.39.44: 621.315.052.63 211

62.1.39.61.62 212
A Frequency-Modulated Transmitter-Receiver for Motor Cycles — (Engineer, London), vol. 190, p. 172; August 18, 1950.) A 27-tube equipment in two units, one mounted on either side of the motor, with crystal controlled and has an FM radio-frequency output of 10 w on a spot frequency in the band 68-100 Mc. Sensitivity is 1 μv carrier input for 10 dB quieting. The signal consumption is only 18 w. The equipment can be used within the temperature range -40°C to 70°C. In conjunction with a 20-μw control transmitter it has a maximum range of 20 miles. A selective calling system enables any one, or all, of 90 such units to be called from the control station.

62.1.39.619: 621.39.52 213
Polyphase Modulation as a Solution of Certain Signal Problems in Telecommunication — I. F. Macdiarmid and D. G. Tucker. (Proc. IEE, Part III, vol. 97, pp. 349-358; September, 1950.) An important class of interworking problems in telecommunication is associated with frequency changing; it includes the generation and demodulation of single-sideband carrier channels and the elimination of image-frequency interference in heterodyne demodulators, such as the superhetodyne radio receiver or the conventional wave analyzer. Filters for these applications are often difficult to design or realize, or may be inconvenient on account of variable tuning, and so forth.

Polyphase modulation can be used as part of the frequency-changing process with great advantage. It can eliminate the need for difficult or inconvenient filters, although other design problems are introduced which may sometimes be solved. The basis of the advantages gained by polyphase working is that polyphase signals possess an identifying property additional to that of frequency, namely phase. By means of circuits which distinguish between signals of the same frequency but opposite sequence, it is possible, without any preliminary filtration, to separate signals which lie in the same frequency band after modulation, and which, therefore, could not be separated by normal means only by filters before the modulation stage.

The first section of the paper outlines the main filtration problems which can be tackled by polyphase methods, and then the necessary polyphase theory is given. This is followed by a discussion of the possibilities for polyphase modulation and sequence discrimination. The list of 30 references shows that there have been many publications covering some of the separate applications of this work, but the paper is believed to present for the first time a comprehensive theory of polyphase modulation embracing all the known applications.

62.1.39.619.10: 621.39.41 214

62.1.39.65 215
A Microwave Communication Relay System — W. P. Boothroyd and H. J. Churchill. (Trans. AIEEE, vol. 68, Part I, pp. 637-644; 1949.) An incoming FM radio-frequency carrier causes deviation of the output of a local oscillator in accordance with the modulation of the incoming carrier, the output being amplified and radiated as the repeated signal. The whole system constitutes a negative feedback amplifier and a study of its performance as a repeater is made on this basis. The extreme simplicity of its electrical and mechanical design makes the use of a tower relay in the antenna pole being sufficient to support the repeater equipment.

62.1.39.65 216
Problems to be Solved in the Application of Microwave Equipment — R. C. Cheek. (Elec. Eng., vol. 69, p. 718; August, 1950.) Summary of AIEEE Summer General Meeting paper. Points to be dealt with in establishing a microwave channel include determination of frequency band, selection of terminal sites, and calculation of inherent losses.

62.1.39.65: 621.39.63.029.6 218

62.1.39.65: 621.39.63.029.6 218

62.1.39.65.029.6 218

The link considered is between two stations in Morocco 15 km apart in mountainous country. Two intermediate relay stations are used. At one of these, duralumin mirror of area 10 m² is mounted in a rigid frame 2 m above the ground. At the other, two similar plane mirrors are supported in an open cage on a 40-m pole.

Both mirrors are hinged to facilitate adjustment. Terminal transmitter and receiver antennas use parabolic mirrors of 10-m aperture. Polarization is vertical, λ=9.5 cm. Using a 1-W FM signal and a 1.5-mc pasband in the receiving comunication has been maintained since 1949 in extremely climatic conditions. Calculated field strength and noise level are in fair agreement with actual values.

62.1.39.632 218

SUBSIDIARY APPARATUS

62.1.526 222

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Analyzing Contact Servomechanisms by Frequency-Response Methods — J. Kochenburger. (March 6, 1950.) See 697-702; August, 1950.) An approximation method which facilitates the selection of compensating networks for improving the performance of contact servomechanisms.

62.1.514 225
New Developments in Rectifier Technique — F. Kesselring. (Tech. Mitl. schweiz. Telegr.-, February.)
Abstracts and References

High reference potential for a series-parallel type of voltage regulator.

Special Purpose Batteries—A. Fischbach.

Electric Batteries: Recent Patents—L. J. Janu. (Rev. gén. Éléct., vol. 59, pp. 372-378; September, 1950.) Developments in primary batteries, chiefly of the dry type, are reviewed. See also 3177 of 1950.

Power Supplies for Microwave Transmitting Systems—H. M. Ward. (Trans. AIEE, vol. 68, Part 1, pp. 631-636; 1949.) Interruption of the main ac supply causes the load to be transferred to a battery-operated inverter in under 0.02 second. This is cut out when the petrol-electric set, whose start is delayed 15 seconds to avoid unnecessary starting during very short power failures, reaches a steady operating condition. All of the equipment are described. Performance data for various radio-beam links indicate the high degree of reliability achieved.

An Electro-optical Shutter for Photographic Purposes—A. M. Zatman, F. R. M. Mallie, and F. L. Poole. (Trans. AIEE, vol. 68, Part 1, pp. 84-91; 1949.) A description of the development of a simple and reliable optical shutter using a Kerr cell as a light tube, with photographs showing the principle of operation of the shutter. Discharges have been made using an effective exposure time of 0.04 µ second. The control can be made sufficiently positive and accurate to permit initiation of operation at any previously selected instant to within about 0.005 µ second.

Innovations in the use of facsimile transmission systems with 30-40 MGD cathode-ray tubes. The cathode-ray tube is 6 cm X 9 cm in size and the screen is 6 cm square. The raster is 6 cm X 9 cm and the screen is of the low-persistence type. Experiments showed that a ZnO phosphor gave a much higher degree of modulation than other phosphors tested. Operation of the equipment, using a flat type of photocell with a semitransparent photo layer about 6 cm in diameter, was satisfactory for both carrier-frequency and low-frequency scanning.


Filip, Vers., vol. 28, pp. 297-303; August 1, 1948. In French and German.) Description of a new type of rectifier. The first is a vibrating mechanism. The interrupter tongues are primed and weigh about 60 mg; enclosed in a stainless steel container with inert gas under pressure they can withstand over 10 kw. Models developed include a 200-A and 1,000-A type. The second design is a grid-controlled rectifier tube in Cs-vapor filling. Operating voltage is 8,000-3,000 v. Tubes passing A have been constructed; a 150-A type is under development.

216.355.7 226

Electrical Timing Devices—F. E. Rees. (IeElectr. Eng., vol. 42, pp. 114-116; September, 1950.) Timing devices to be considered in the selection and application of electrical time signals are enumerated and a chart is given outlining the operational characteristics of commercially available equipment.

216.372.1 227

A New Precision A.C. Voltage Stabilizer—N. Patchett. (Proc. IEE, Part II, vol. 97, no. 5, pp. 529-538; discussion, pp. 538-540; August, 1950.) Various types of stabilizer are discussed and the choice of equipment is given as the design of a performance of a stabilizer for meter tests; application uses which a temperature-compensated thermostat is provided. The stabilizing ratio for a 1,000-v nominal load is about 1,100. An output of 2 kw can be obtained.

216.372.1 228

A Simple Form of Voltage Stabilizer—N. K. Bha, B. S. Chandrasekhar, and M. K. Sun- 77.36.537.228.4 235

44.621.396.652 234

An Electro-optical Shutter for Photographic Purposes—A. M. Zatman, F. R. M. Mallie, and F. L. Poole. (Trans. AIEE, vol. 68, Part 1, pp. 84-91; 1949.) A description of the development of a simple and reliable optical shutter using a Kerr cell as a light tube, with photographs showing the principle of operation of the shutter. Discharges have been made using an effective exposure time of 0.04 µ second. The control can be made sufficiently positive and accurate to permit initiation of operation at any previously selected instant to within about 0.005 µ second.

216.371.2 236

Power Supplies for Microwave Transmitting Systems—H. M. Ward. (Trans. AIEE, vol. 68, Part 1, pp. 631-636; 1949.) Interruption of the main ac supply causes the load to be transferred to a battery-operated inverter in under 0.02 second. This is cut out when the petrol-electric set, whose start is delayed 15 seconds to avoid unnecessary starting during very short power failures, reaches a steady operating condition. All of the equipment are described. Performance data for various radio-beam links indicate the high degree of reliability achieved.

216.371.2 237

New Facsimile System—M. Frank. (Ann. Geol., vol. 2, pp. 532-544; October, 1949.) Suitable for transmission of weather maps, graphs, and printed matter of size up to 25 cm X 30 cm, by telephone line or radio link. An electromechanical recording system is used, the modulated subcarrier being obtained by interrupting the electrical signal at 25 lines per second. The number of scanning lines can be 4 mm or less. The subcarrier frequency, after frequency division, is used to synchronize the movements of transmitter and receiver drums. Several copies can be produced simultaneously at the receiving end.

216.371.24 238


216.371.24 239


216.370.24 240

Characteristics of Triode Pairs at Frequencies Involved in High-Definition Television Transmission—Fuchs. (See 27.)

216.371.26 241

The Kilovolt Mixer Applied to Television Relaying—Learned. (See 275.)

216.371.26 242

First Results of Stratovistor Tests in the United States of America—E. J. Aubort. (Elect. Eng., Vol. 48, no. 12, pp. 653-657; August 20, 1949. In French.) Paper presented at the International Television Conference, Zürich, 1948. An account of tests carried out near Pittsburgh with the relay aircraft at a height of 8,000 m, when the useful ground range exceeded 400 km. A map showing the earth's surface in Europe for an aircraft at the same height is given and it indicates the possibilities of international program exchange in Europe, using seven aircraft and taking account of the coaxial cable envisaged by the CCIF for 1952. See also 3801 of 1946, 3279 of 1947 (Nobles) and 233 of 1949 (Sleep.)

216.371.331.2 243


216.371.331.2.778.5 244


216.371.331.2.778.5 245

Luminous-Screen Screen 875-Line Scanning of Film Pictures—A. Karlous. (Bull. schwiss. elektrotech. Ver., vol. 40, pp. 566-569; August 20, 1949. In German.) Paper presented at the International Television Conference, Zürich, 1948. A description of the apparatus, with a diagram illustrating the general layout, is given. The cathode-ray tube is identical in construction with the usual type of projection tube and is operated at 25-40 kv. The raster surface is 6 cm X 9 cm and the screen is of the low-persistence type. Experiments showed that a ZnO phosphor gave a much higher degree of modulation than other phosphors tested. Operation of the equipment, using a flat type of photocell with a semitransparent photo layer about 6 cm in diameter, was satisfactory for both carrier-frequency and low-frequency scanning.

216.371.331.2.778.5 246


216.371.5 247

ticularly the choice of the line standard and the question of interlacing.

621.307.5 248

621.307.5 249
The Present Status of Color Television—(Proc. I.R.E., vol. 38, pp. 1003–1009; September, 1950.) The report of the Senate Advisory Committee on Color Television, given in full. A bandwidth of 6 Mc is considered adequate, representing an optimum compromise between quality and quantity of service. The general principles of the CTT line-segmental system, the CBS field-segmental systems involving line and dot interface, and the RCA system employing a dot-segmental system with the method of mixed highs to increase definition, are explained in detail and performance characteristics, such as color fidelity, flicker, resolution and break-up of the picture for moving objects, are tabulated for each system. Appendices reproduce official correspondence concerning the report, and also the results of tests of flicker and color fidelity by the National Bureau of Standards.

621.307.5 250
Mixed Highs in Color Television—A. V. Bedford. (Proc. I.R.E., vol. 38, pp. 1003–1009; September, 1950.) Tests on the human eye, using projected color-test slides, are described in detail; these indicate that the acuity for resolving color differences is less than half as great as that for differences in brightness, so that the bandwidth used for the color transmission must be correspondingly reduced.

621.307.5 251

621.307.5 252
The Schmidt Optical System—Rinna. (See 82.)

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621.307.6 255
Television Laboratory Equipment—Werner. (See 113.)

TRANSMISSION

621.396.142.2 256
The Klystron Mixer Applied to Television Relaying—V. Learned. (Proc. I.R.E., Vol. 38, No. 9, pp. 1033–1035; September, 1950.) The phase-modulation sidebands obtained from a klystron amplifier are used to drive mixing action, and the output resonator is used to select one of the sidebands. The construction and operating details are given for a klystron amplifier, Type SAC-19, with a mixer output of 1 over a 20-Mc band centered at about 6,000 Mc.

TUBES AND THERMIONICS

533.723+ 257
Spontaneous Fluctuations—MacDonald. (See 79.)

621.314.65/67

621.383.4

621.385.020.63/65
The Anticyclotron, a New Type of Traveling-Wave Valve with Magnetic Field—G. Mourier. (Ann. Radioelec., Vol. 5, pp. 206–219; July, 1950.) Valve conditions appropriate for tubes in magnetic fields are discussed. The principle of the projected tube, which is ring shaped and has no radial field, is analogous to that of the cyclotron, but in this case the electron beam is slowed down as a result of its synchronism with a retarded traveling wave.

621.385.061/64
Small-Signal Theory of Wave Propagation in a Uniform Electron Beam—G. G. Macfarlane and A. M. Woodward. (Proc. IEEE, Part 111, Vol. 97, pp. 322–329, September, 1950.) Analysis is presented for the three systems constituted by a planar uniform beam (a) between conducting sheets, (b) in free space, and (c) between reactive-impedance sheets, the cast being a simple form of traveling-wave tube. For small signals, the em field in a traveling-wave tube may be split up into an infinite set of modes and for each mode there can be two forward and two reverse waves. The amount of each mode present depends on the method of excitation. At high frequencies the maximum amplification occurs when the ratio of beam velocity to phase velocity is slightly greater than unity.

621.385.029.63/64: 537.525.92
On Certain Effects of the Space Charge & Traveling-Wave Valves—R. Berterrottière and G. Konwont. (Ann. Radioelec., Vol. 5, pp. 108–178; July, 1950.) The effects of space charge are investigated theoretically by introducing into the equations for the electron dispersion a complex coefficient analogous to the coupling reactance for the beam and field. Electron trajectories are assumed to be rectilinear. For signals of small amplitude the theory may be applied up to the limiting case of a very weak focusing field, when space-charge effects are negligible. In the case of signals of large amplitude the effects are complex and may result in increased efficiency.

621.385.032.216
The Barium-Oxide-on-Tungsten Cathode in Practice—E. J. H. Affleck. (J. Appl. Phys., Vol. 21, pp. 938–939; September, 1950.) The compound formed at the interface between a w cathode base and its BaO coating has been identified, by X-ray diffraction, as a pure BaO. Corresponding tungsten compounds are found when Sr0 or the solid solution (BaSr)O is used for the coating.

621.385.032.24: 537.311.315
Variations of Grid Contact Potential and Associated Grid Currents—H. B. Michaelson. (J. Frank. Inst., Vol. 249, pp. 455–470; June, 1950.) A review of the subject, with comprehensive bibliography. The grid-cathode Volta potential, or ‘true contact potential’, is shown to be a function of the functions of the grid and cathode; it differs essentially from the quantity called ‘contact potential’ that is generally measured in routine tests. When the potential of the grid is negative, the current in the external grid circuit consists of several small currents due to various causes which change during the life of the tube and thus alter the tube characteristics.

Methods that have been suggested for controlling these changes are outlined. Thermionic work functions are listed for 44 pure metals, for mixtures of these with Ni, Mo or other metals and bases, and also for oxide coatings. Another list gives the effect of various gases and vapors on the work function of 15 metals.

621.385.4
The Internal Resistance of a Pentode—J. L. H. Jonkers. (J. Inst. Elec. Eng., Vol. 99, pp. 479–490; July and September, 1950.) For output pentodes the main factor determining the internal resistance is the direct effect of anode voltage on cathode current. For high-frequency pentodes two further effects are of importance, viz., (a) the absorption by the screen grid of electrons repelled by the suppressor, and (b) the absorption by the screen grid of electrons reflected by the anode and transmitted by the suppressor. Both these effects again depend on the anode voltage. Measured values of the resistance are compared with values calculated from theory, and the discrepancies are related to the simplifying assumptions made regarding the operation of the tube.

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621.396.061.4
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"Discussion and Demonstration of Microwave Techniques," by R. E. Horner and J. S. Hollis, State Broadcasting Experiment Station; November 17, 1950.

BALTIMORE

BRAMANT-TOR ARTHUR
Election of Officers; December 7, 1950.

BOSTON

BUFFALO-NIAGARA
"Instrumentation of the Twelve-Foot Variable Density Wind Tunnel at Cornell Aeronautical Laboratory," by Robert MacArthur, Cornell Aeronautical Laboratory; December 13, 1950.

CEDAR RAPIDS

CLEVELAND

COLUMBUS

CONNECTICUT VALLEY
"Magnetic Amplifiers," by W. A. Geyer, United States Naval Ordnance Bureau; December 14, 1950.

DALLAS-FORT WORTH
"High-Fidelity Phono Systems," by E. J. O'Brien, Faculty, Southern Methodist University; November 16, 1950.

DENVER
"Recent Organizational Developments in The Institute of Radio Engineers," by T. A. Hunter, Hunter Manufacturing Company; December 8, 1950.

DES MOINES-AMES
"Electronic Instrumentation," by Alfred Crossley, Alfred Crossley and Associates Company; Business Meeting; October 31, 1950.

(Continued on page 38A)
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MODEL 300

<table>
<thead>
<tr>
<th>MODEL</th>
<th>FREQUENCY RANGE</th>
<th>VOLTAGE RANGE</th>
<th>INPUT IMPEDANCE</th>
<th>ACCURACY</th>
<th>PRICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>10 to 150,000 cycles</td>
<td>1 millivolt to 100 volts</td>
<td>1/2 meg. shunted by 30 mfd.</td>
<td>2% up to 100 KC, 3% above 100 KC</td>
<td>$210.</td>
</tr>
<tr>
<td>302B Battery Operated</td>
<td>2 to 150,000 cycles</td>
<td>100 microvolts to 100 volts</td>
<td>2 meg. shunted by 8 mfd., on high ranges and 15 mfd., on low ranges</td>
<td>3% from 5 to 100,000 cycles, 5% elsewhere</td>
<td>$225.</td>
</tr>
<tr>
<td>304</td>
<td>30 cycles to 5.5 megacycles</td>
<td>1 millivolt to 100 volts except below 5 K C where max. range is 1 volt</td>
<td>1 meg. shunted by 9 mfd., on low ranges, 4 mfd., on highest range</td>
<td>3% except 5% for frequencies under 100 cycles and over 3 megacycles, and for voltages over 1 volt</td>
<td>$225.</td>
</tr>
<tr>
<td>305</td>
<td>Measures peak values of pulses as short as 3 microseconds with a repetition rate as low as 20 per sec. Also measures peak values for sine waves from 10 to 150,000 cycles</td>
<td>1 millivolt to 1000 volts Peak to Peak</td>
<td>Same as Model 302B</td>
<td>3% on sine waves 5% on pulses</td>
<td>$280.</td>
</tr>
<tr>
<td>310A</td>
<td>10 cycles to 2 megacycles</td>
<td>100 microvolts to 100 volts</td>
<td>Same as Model 302B</td>
<td>3% below 1 MC, 5% above 1 MC</td>
<td>$235.</td>
</tr>
</tbody>
</table>

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(Continued from page 38A)

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"Radio and Television as of Today," by Sidney Curtis, Stromberg-Carlson Company; December 12, 1950.

SALT LAKE

SAN DIEGO

SAN FRANCISCO


SCHENECTADY
"Nuclear Instrumentation," by F. A. White and F. G. LaViolette, Knolls Atomic Power Laboratory; December 11, 1950.

SEATTLE
"Airplane Antennae, Their Development, Types, and Uses," by Gerald Weinstein, Boeing Airplane Company; December 1, 1950.

SYRACUSE
"Solar Noise," by Lief Owen, Faculty, University of Oslo; on leave at Cornell University; November 30, 1950.

TORONTO

TWIN CITIES

Tests and Demonstrations by representatives of Alfred Crosley and Associates; November 1, 1950.

VANCOUVER

"Some Electronic Instruments Used in Nuclear Physics," by F. K. Bowers, Faculty, University of British Columbia; November 20, 1950.

WILLIAMSPORT
"Applications of Magnetotrotation," by B. H. Buehler, Jr., Faculty, Bucknell University December 6, 1950.
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<table>
<thead>
<tr>
<th>VA capacity</th>
<th>150</th>
<th>250</th>
<th>2000</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic Distortion</td>
<td>3% max.</td>
<td>2% max.</td>
<td>3% max.</td>
<td>3% max.</td>
</tr>
<tr>
<td>Regulation accuracy</td>
<td>±0.1% against line or load</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Input voltage</td>
<td>95-130 VAC; also available for 190-260 VAC single phase 50-60 cycles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage</td>
<td>Adjustable between 110-120; 220-240 in 230 VAC models</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load range</td>
<td>0 to full load</td>
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<tr>
<td>P.F. range</td>
<td>Down to 0.7 P.F. All models temperature compensated</td>
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</tbody>
</table>

**NOTE:** THREE PHASE AND 400 CYCLE REGULATORS ALSO AVAILABLE. ALL REGULATORS CAN BE HERMETICALLY SEALED.

Write for Complete Literature

For regulated DC problems investigate Sorensen's line of Voltage Reference Standards, DC Supplies, and NOBATRONS

Sorensen and Company, Inc.
375 Fairfield Ave., Stamford, Conn.

Manufacturers of AC Line Regulators, 60 and 400 Cycles; Regulated DC Power Sources; Electronic Inverters; Voltage Reference Standards; Custom Built Transformers; Saturable Core Reactors

(Continued from page 40A)

STUDENT BRANCH MEETINGS

**UNIVERSITY OF ALBERTA, IREE BRANCH**
"Industrial Relations," by L. Pugh, Chairman, Board of Industrial Relations; December 5, 1950.

**UNIVERSITY OF CALIFORNIA, IREE-AIEE BRANCH**

"Dynamic Balancing of Large Rotors," by P. E. Shields, Faculty, Pennsylvania State College; "Through the Swiss Alps Via the Ionosphere," by A. H. Wainright, Faculty, Pennsylvania State College; December 12, 1950.

**LONG ISLAND**

**MID-HUDSON**
"Electronic in Medicine," by Stanley Briller, Bellevue Medical Center; and Nathan Marcindale, Sylvanian Electric Products Inc.; November 15, 1950.

**NORTHERN NEW JERSEY**

**UNIVERSITY OF MONTANA, IREE BRANCH**
"Patents and Inventions," by Frank Record, Faculty, Clarkson College of Technology; December 14, 1950.

**UNIVERSITY OF COLORADO, IREE-AIEE BRANCH**

(Continued on page 44A)
We are ready NOW...

Can we serve YOU?

For IMMEDIATE ACTION, phone—wire—or write direct to the attention of Mr. Albert Finkel, Vice-President.

JFD ...World’s largest producer of television antennas and accessories, has allocated a most substantial portion of its facilities for prime and sub-contract orders.

We offer:

EXPERIENCE! Leaders in the industry whom we have serviced in the past, include such outstanding organizations as RCA, PHILCO, ADMIRAL, MOTOROLA, BENDIX, EMERSON, PILOT, STROMBERG-CARLSON, etc.

80,000 square feet of floor space with modern production machinery and high-speed assembly lines.

TRAINED manufacturing personnel geared to the type of mass-production that meets “deadlines” and lowers costs.

EXCELLENT sources of supply for raw material.

KNOW-HOW in purchasing and delivery expediting.

FINANCIAL resources that are ample and liquid.

DIVISION OF CONTRACT OPERATIONS

JFD MANUFACTURING CO., Inc.
6137B 16th AVENUE, BROOKLYN 4, N. Y.
FIRST in Television Antennas and Accessories
Flexible and Rigid WAVEGUIDE COMPONENTS

Send for AIRTRON Engineering Data on Microwave Plumbing

Special Microwave Mixer-Duplexer Assembly Designed by AIRTRON

(Continued from page 44A)

STUDENT BRANCH MEETINGS

(continued from page 44A)

COOPER UNION, IRE BRANCH


UNIVERSITY OF DENTON, IRE-AIEE BRANCH

DREXEL INSTITUTE OF TECHNOLOGY, IRE-AIEE BRANCH
"Microwave Communications," by J. Williams, Philco Corporation; November 16, 1950.

UNIVERSITY OF FLORIDA, IRE-AIEE BRANCH
"Presenting a Technical Paper," by H. Constans, Faculty, University of Florida; December 5, 1950.

GEORGIA INSTITUTE OF TECHNOLOGY, IRE BRANCH
Business Meeting; October 24, 1950.


Film: "Power in the South"; November 1950.

Business Meeting; December 5, 1950.

ILLINOIS INSTITUTE OF TECHNOLOGY, IRE BRANCH

UNIVERSITY OF KENTUCKY, IRE BRANCH

MANHATTAN COLLEGE, IRE BRANCH
"Color Television, Three Systems," by George Anner, Faculty, New York University; December 1950.

UNIVERSITY OF MARYLAND, IRE-AIEE BRANCH

UNIVERSITY OF MIAMI, IRE BRANCH
Election of Officers; November 3, 1950.

"Construction of an FM Station," by Bill Aderman, Radio Station WGST; November 1, 1950.

"Demonstration of an Electronic Counter," by C. N. Hoyt, RCA Laboratories; Film: "Analog Computer"; December 8, 1950.

MICHIGAN COLLEGE OF MINING AND TECHNOLOGY, IRE-AIEE BRANCH
Business Meeting; Film: "Power Station at Its Problems"; November 14, 1950.

UNIVERSITY OF MICHIGAN, IRE-AIEE BRANCH

MISSOURI SCHOOL OF MINES & METALLURGY, IRE-AIEE BRANCH
"Electronic Research at Midwest Research Institute," by H. L. Stout, Faculty, Midwest Research Institute; November 30, 1950.

(Continued on page 46A)

PROCEEDINGS OF THE I.R.E. February, 1951
DESIGNED FOR SERVICE

More Rugged Electrically
More Rugged Mechanically
More Rugged in Safety Factor
More Rugged for Longer Life

A dependable control or resistor costs but a few cents. But an uncertain control or resistor that fails out in the field can cost you thousands of dollars by way of impaired reputation.

The fact that Clarostat controls and resistors are used in the majority of today's TV, radio and electronic assemblies, speaks for itself. Clarostat not only supplies such initial equipment but also the service replacements for the further protection of the manufacturer's good name and good will.

Designed for Service! That's precisely what you are demanding and getting, when you simply specify CLAROSTAT for controls and resistors.
PUT OUT A STRONGER SIGNAL... INCREASE YOUR SERVICE AREA

with ANDREW Low Loss, High Economy Coaxial Cable

- 1/3 to 1/2 Less Loss than same diameter plastic type cables because 96% of insulation is air — the most effective insulation.
- No maintenance or operational costs. This advantage for offsets slightly greater original cost. Seamless cable and fittings remain completely gas tight and weatherproof indefinitely.
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- TO INSTALL — JUST UNCOIL INTO PLACE. Each coil contains up to 2,000 feet of seamless semi-flexible tubing. No soldering. No splicing. Bends easily around corners or obstructions. Shipped under gas pressure at no extra cost when pressure-tight end fittings are ordered.

Low loss and economical operation will add extra miles to your service radius as well as give you a stronger signal in your present area. There’s no waste. You get the greatest possible range and strength from your available power.

Whether you need transmission line for your Communications, AM or FM transmitter, Directional Antenna System, or Rhombic Receiving Array, the solution to your problem is ANDREW low loss, high economy, semi-flexible transmission line. Write for further information on Types 737 and S-450 TODAY.

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TRANSMISSION LINES FOR AM-FM-TV • ANTENNAS • DIRECTIONAL ANTENNA EQUIPMENT
ANTENNA TUNING UNITS • TOWER LIGHTING EQUIPMENT
The sensational, extra-fast washing and trouble-free efficiency of our newest type glass-blank washing machine allows us to take care of the tremendous demand for Sheldon Television Picture Tubes...and to maintain the perfect screen quality of these tubes.

This specially designed automatic washing machine actually washes our glass-blanks in three cycles: First, the inside face of the glass-blank gets an acid wash; then it is rinsed with water. Next, the inside face is given a caustic wash, and then rinsed again with water. As the final step, the inside face is rinsed for several minutes with a high pressure stream of "thirsty water" — water from which all minerals and foreign substances have been removed by our special equipment and techniques.

When the glass blank leaves our washing machine, the inside surface of the glass-blank is bacteriologically clean and medically pure...so pure, in fact, that it is "thirsty" or "hungry" to reabsorb foreign substances...PRIMED to receive the phosphor coating. The phosphor coating is applied over this "thirsty" surface to consistently produce the uniformly perfect blemish-free, "TELEGonic" screen for which Sheldon Picture Tubes are famous.

WRITE today for the latest "Sheldon 'TELEGonic' Picture Tubes—General Characteristics & Dimensions Wall Chart" containing the new Sheldon VITATRON Glass-Metal 19AP4B and 19AP4D, and the New Rectangular 20CP4!

TELEVISION MIS-INFORMATION NO. 4 is off the press! Write for your copy today!

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VISIT SHELDON BOOTH NO. 390-1-2 AT THE RADIO ENGINEERING SHOW, MARCH 19-22, GRAND CENTRAL PALACE, N. Y.
you get MORE PERFORMANCE for LESS MONEY with the NEW Browning OSCILLOSYNCHROSCOPE

For only

$485.00

this new five-inch Browning scope gives you the basic laboratory equipment for pulse work — in a single, compact unit with:

• Triggered sweep rate continuously variable from 1.0 to 25,000 microseconds per inch.
• Sawtooth sweep rate 10 cycles to 100 KC.
• Sweep calibration (triggered and sawtooth) in microseconds per screen division accurate to ±10%.
• Vertical amplifier flat within 1 db from 5 cycles to 5 megacycles.
• Sensitivity 0.075 volts RMS per inch.
• Horizontal amplifier d.c. to 500 KC, sensitivity 2 volts per inch.
• Self-calibrating on both X and Y axis.
• Readily portable... weighs but 50 pounds.

plus these ELECTRICAL and MECHANICAL features

• SUP1 cathode-ray tube operates at accelerating potential of 2600 volts
• Sweep starting time is approximately 0.1 microsecond
• Sweep may be triggered or synchronized by positive or negative sine-wave or pulse signals of 0.5 volts (external) or 0.75 inches deflection (from vertical amplifier)
• Three-step attenuator — 100:1, 10:1, and 1:1, plus continuous adjustability over entire range
• Peak-to-peak vertical calibration voltages of 0.2-20.2-200 at accuracy of ±10%.
• Cathode connection, brought out to front panel, allows external blanking and marker connection
• All deflection plates are available for direct connection
• Steel cabinet finished in black wrinkle
• Steel panel finished in black leatherette
• Copper-plated steel chassis with lacquer finish
• Controls grouped by function for operating convenience
• Free-view screen has graduated X- and Y-axis scales
• Size: 10" wide, 14½" high, 16½" deep
• Instrument draws 180 volt-amperes at 115 volts 60 cycles.

NET PRICE, F.O.B. Winchester, Mass. $485.00

FREE BULLETIN gives further data on this new, low-cost, versatile oscillosynchoscope. Ask for data sheet ON-54
Ferramics are soft magnetic materials featuring:
HIGH PERMEABILITY
HIGH VOLUME RESISTIVITY
HIGH EFFICIENCY
LIGHT WEIGHT
ELIMINATE LAMINATIONS

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>UNIT</th>
<th>A 34</th>
<th>B 90</th>
<th>C 159</th>
<th>D 216</th>
<th>E 174</th>
<th>G 254</th>
<th>H 419</th>
<th>I 141</th>
<th>J 472</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial permeability at 1 m/sec</td>
<td>—</td>
<td>15</td>
<td>95</td>
<td>220</td>
<td>410</td>
<td>750</td>
<td>410</td>
<td>850</td>
<td>600</td>
<td>330</td>
</tr>
<tr>
<td>Maximum permeability</td>
<td>—</td>
<td>97</td>
<td>183</td>
<td>710</td>
<td>1030</td>
<td>1710</td>
<td>3300</td>
<td>4300</td>
<td>1010</td>
<td>750</td>
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<tr>
<td>Saturation flux density</td>
<td>Gauss</td>
<td>840</td>
<td>1900</td>
<td>3800</td>
<td>3100</td>
<td>3800</td>
<td>3200</td>
<td>3400</td>
<td>1540</td>
<td>2900</td>
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<tr>
<td>Residual magnetism</td>
<td>Gauss</td>
<td>615</td>
<td>830</td>
<td>2700</td>
<td>1320</td>
<td>1950</td>
<td>1050</td>
<td>1470</td>
<td>660</td>
<td>1600</td>
</tr>
<tr>
<td>Coercive force</td>
<td>Oersted</td>
<td>3.7</td>
<td>3.0</td>
<td>2.1</td>
<td>1.0</td>
<td>0.65</td>
<td>0.25</td>
<td>0.18</td>
<td>0.40</td>
<td>0.80</td>
</tr>
<tr>
<td>Temperature coefficient of initial permeability</td>
<td>°C</td>
<td>0.65</td>
<td>0.04</td>
<td>0.4</td>
<td>0.3</td>
<td>0.25</td>
<td>1.3</td>
<td>0.66</td>
<td>0.3</td>
<td>0.22</td>
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<tr>
<td>Curie point</td>
<td>°C</td>
<td>280</td>
<td>260</td>
<td>330</td>
<td>165</td>
<td>160</td>
<td>160</td>
<td>150</td>
<td>70</td>
<td>180</td>
</tr>
<tr>
<td>Volume resistivity</td>
<td>Ohm-cm</td>
<td>1x10⁹</td>
<td>2x10⁵</td>
<td>2x10³</td>
<td>3x10⁷</td>
<td>4x10⁵</td>
<td>1.5x10⁸</td>
<td>1x10⁴</td>
<td>2x10⁵</td>
<td></td>
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<tr>
<td>Loss Factor:</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td>at 1 m/sec</td>
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<td>at 5 m/sec</td>
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<td>at 10 m/sec</td>
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General OFFICES and PLANT: KEASBEY, NEW JERSEY

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PROCEEDINGS OF THE I.R.E. February, 1951
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PROCEDINGS of the I.R.E.
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ELECTRONIC ENGINEER
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Project and senior engineers desired for work on several theoretical and experimental programs of diversified nature involving military applications of electronics. Applicants should have 3 or more years of experience in research and development in some branch of electronics and preferably advanced graduate training. Command of physical fundamentals and analytical ability important. Small, expanding company located in college town. Opportunities of graduate study. Reply Personnel Manager, Haller, Raymond and Brown, Inc., State College, Pa., stating education, experience, salary expected.

(Continued on page 52A)

ELECTRONICS ENGINEERS FOR SOUTHWEST ATOMIC ENERGY INSTALLATION
2 to 10 years experience in research, design, development, or test
A variety of positions open for men with Bachelor's or advanced degrees qualified in one or more of the following fields:

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- TELEMETERING
- RELAYS
- LOW POWER APPLICATION
- INSTRUMENTATION
- STATISTICAL ANALYSIS
- TEST EQUIPMENT RELATING TO ABOVE FIELDS

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MAKE APPLICATION TO:

PROFESSIONAL EMPLOYMENT DIVISION
SANDIA CORPORATION
SANDIA BASE
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are needed for enlargement of an important research and development program on government and industrial projects. Applied physicists, electronic engineers, and applied mathematicians are sought. Considerable advanced development experience and advanced degrees are desirable.

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Aerodynamacists
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Mechanical Engineers
Servo-mechanisms, Engineering Design

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challenging research and advanced development in fields of


Scientific or engineering degree and extensive technical experience required.

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Manager, Engineering Personnel
BELL AIRCRAFT CORPORATION
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VIBRATION ENGINEER

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Sylvania Electric Products, Inc.
40-22 Lawrence St.
Flushing, N.Y.

PROCEEDINGS OF THE I.R.E. February, 1951
another great new G-E triode for FM and TELEVISION

- Has an output over one-third higher than the famed GL-9C24, its predecessor.
- Requires 1,100 watts less filament power, or a 75-percent reduction.

RATINGS

<table>
<thead>
<tr>
<th>Feature</th>
<th>GL-6039</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filament voltage</td>
<td>5 v</td>
</tr>
<tr>
<td>Filament current</td>
<td>78 amp</td>
</tr>
<tr>
<td>Grid-plate transconductance</td>
<td>11,000 micromhos</td>
</tr>
<tr>
<td>Interelectrode capacitances:</td>
<td></td>
</tr>
<tr>
<td>Grid-filament</td>
<td>24 micromicrofarads</td>
</tr>
<tr>
<td>Grid-plate</td>
<td>15.7 micromicrofarads</td>
</tr>
<tr>
<td>Plate-filament</td>
<td>0.47 micromicrofarads</td>
</tr>
<tr>
<td>Type of cooling</td>
<td>water and forced air</td>
</tr>
<tr>
<td>Plate ratings per tube, Class B r-f power amplifier (video service, synchronizing peak conditions):</td>
<td></td>
</tr>
<tr>
<td>Max voltage</td>
<td>6,000 v</td>
</tr>
<tr>
<td>Max current</td>
<td>2.25 amp</td>
</tr>
<tr>
<td>Max input</td>
<td>13.5 kW</td>
</tr>
<tr>
<td>Max dissipation</td>
<td>7 kW</td>
</tr>
<tr>
<td>Power output, typical operation (at 5,000 v and 2.2 amp, band width 5 mc)</td>
<td>5.4 kW</td>
</tr>
<tr>
<td>Plate ratings per tube, Class C r-f power amplifier (key-down conditions without amplitude modulation):</td>
<td></td>
</tr>
<tr>
<td>Max voltage</td>
<td>7,500 v</td>
</tr>
<tr>
<td>Max current</td>
<td>2.25 amp</td>
</tr>
<tr>
<td>Max input</td>
<td>16 kW</td>
</tr>
<tr>
<td>Max dissipation</td>
<td>7 kW</td>
</tr>
<tr>
<td>Power output, typical operation (at 7,000 v and 2.08 amp)</td>
<td>12.8 kW</td>
</tr>
<tr>
<td>Includes power transferred from driver to output of grounded-grid amplifier.</td>
<td></td>
</tr>
</tbody>
</table>

lenty of output... Two GL-6039's will put out 25 kw in FM—10 kw in television. Here's sufficient output for medium-size transmitters or output to spare for the intermediate stage of large commercial installations.

low operating cost... The modest 5-v., 78-amp requirement of the GL-6039's filament, slashes by three-quarters the watts needed for Type GL-9C24, itself a pioneering FM-TV triode with fine performance. Thoriated-tungsten construction, among other filament features, cuts your power bills materially.

Real v-h-f operation... 220 mc at max plate input gives you full FM-TV band coverage.

easy to install... The GL-6039 needs no neutralizing, when employed in a properly designed grounded-grid amplifier circuit. Features which help make the tube so efficient, are its low lead inductance, the fact that all outer metal parts are silver-plated to cut r-f losses, and the large terminal-contact areas made possible by G-E ring-seal design.

Sturdy, dependable... Newest of a family of modern G-E power tubes for FM-TV that has proved its worth in hard station service, Type GL-6039 is engineered to stand up! The tube is trim, with real built-in structural strength—mounts solidly and closely in today's compact transmitters. You can rely on its full-time, full-life performance. Ask for a visit by a G-E tube engineer, to prove that the GL-6039 will give your new circuit peak power, improved economy! Electronics Department, General Electric Company, Schenectady 5, New York.

GENERAL ELECTRIC

PROCEEDINGS OF THE I.R.E. February, 1951
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2. Outstanding record of ingenuity
3. Ph.D., M.S. or equivalent

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Long term program of research and development in the fields of Radar, Guided Missiles, Computers, Electron Tubes, and related equipment.

Please do not answer unless you meet the above requirements.

RESEARCH AND DEVELOPMENT LABORATORIES Hughes Aircraft Company CULVER CITY, CALIFORNIA
NEW... JAN COMPONENT STANDARDS BRING DEPENDABILITY

All components meet the latest JAN (Joint Army-Navy) specifications. This means maximum resistance to wear, corrosion, humidity, fungus, temperature, and time. Thus, equipment failure is minimized and maintenance and replacement costs are reduced to the absolute minimum.

- Temperature—equipment operates dependably from -55°C to +75°C (-67°F to +167°F).
- Humidity—equipment performs normally at 100% humidity with condensation.
- Altitude—equipment operates at full power at altitudes up to 10,000 feet (3,048 meters), and withstands shipping altitudes up to 30,000 feet (9,144 meters).

NEW... UNIT CONSTRUCTION PROVIDES OPERATING FLEXIBILITY

A flexible, multifrequency station can be formed from a combination of 96D and 96-200C Transmitters, one or two 50M Modulators and a 16D Rectifier. This provides for either simultaneous transmission on several frequencies or the selection of an individual frequency best suited to your particular communication problem.

NEW... FRONT CONTROLS PROVIDE ADJUSTMENT CONVENIENCE

All controls are located on the front of the transmitter: all R.F. stages and antenna tuning, under and overload and tone-keying adjustments, selection switch for external frequency shift excitation, rotary meter switch, exciter output control.

NEW... DRAWER-TYPE CONSTRUCTION MEANS EASY MAINTENANCE

Ball bearing, drawer-type construction permits the transmitter to be quickly withdrawn from cabinet. All components are instantly accessible... no components are hidden or buried.

Write Today
for complete information and specifications.

WILCOX ELECTRIC COMPANY
KANSAS CITY 1, MISSOURI • U.S.A.
Electronic Engineers
Bendix Radio Division
Bendix Aviation Corporation

PRODUCTION DESIGN RESEARCH
Openings for experienced engineers or recent graduates who are seeking a permanent position in a modern, well-equipped electronics organization working with a specialized and highly technical professional group.

Positions available for work on: Search and Airport Surveillance Radar; G.C.A.; Communication and Navigation Equipment; Broadcast and Television; Mobile Equipment; Test Equipment.

Housing and rentals in area are plentiful.

Send resume to:
MR. W. L. WEBB, Director
Engineering and Research
BENDIX RADIO DIVISION
Baltimore 4, Maryland

An invitation from Lockheed in California to

SENIOR ELECTRONIC SYSTEMS ENGINEERS

Lockheed invites you to participate in its long-range production program, developing the aircraft of the future.

Lockheed offers an attractive salary commensurate with your ability and background, a future in aeronautical science. In addition, Lockheed provides generous travel allowances for those who qualify.

If you have:
1. An M.S. or Ph.D. in Electrical Engineering or Physics—
2. A minimum of three years' experience in advanced electronic systems development, including radar microwave techniques, servomechanisms, computers and fire control—
3. Familiarity with airborne electronics equipment requirements—

Write today—giving full details as to education, experience and salary requirements. Address:
Karl R. Kunze, Employment Manager
LOCKHEED Aircraft Corporation
Burbank, California

Position available in the midwest for a competent electronics circuit engineer. Duties consist of directing the operation of an electronics instrument group in an A.E.C. laboratory. The candidate should have broad experience in electronic circuitry, particularly that used in connection with nuclear physics measurements. Salary commensurate with qualifications.

Box 647

The Institute of Radio Engineers, Inc.
1 East 79th Street, New York 21, N.Y.

NATIONAL UNION RESEARCH DIVISION

Senior engineers and physicists are needed for research and development of Cathode Ray, Subminiature, Secondary Emission and highly specialized types of Vacuum Tubes.

Junior Electrical Engineers are desired for training as tube or circuit design engineers.

Men qualified by virtue of education or experience to handle problems in the field of tube or circuit design are invited to send their resumes to:

Divisional Personnel Manager
National Union Research Division,
350 Scotland Rd., Orange, N.J.

ENGINEERS
ELECTRONICS
RESEARCH AND DEVELOPMENT
In Baltimore, Maryland
Career Positions for
Top Engineers and Analysts in
Radar Pulse, Timing and Indicator Circuit Design Digital and Analogue Computer Design Automatic Telephone Switchboard Design

Also
Electro-Mechanical Engineers
Experience in servomechanism, special weapons, fire control, and guided missile design.
Recent E.E. graduates and those with at least one year electronics research and development work will also be considered.

Salary commensurate with ability. Housing reasonable and plentiful. Submit resume outlining qualifications in detail. Information will be kept strictly confidential. Personal interviews will be arranged.

THE GLENN L. MARTIN COMPANY
Employment Department
Baltimore 3, Maryland

PROCEEDINGS OF THE I.R.E. February, 1951
Certainly...

Bendix Specialized Dynamotors are made for the Job!

Whenever DC power is required at other than the supply voltage, Bendix® Specialized Dynamotors function as DC transformers. They can be wound for any input or output voltage between 5 and 1200 volts, and they can deliver power up to 500 watts. Multiple outputs can be supplied to correspond with several secondaries on transformers, and their output voltages can be regulated within close limits regardless of input voltage or load variations. Bendix Specialized Dynamotors are tailored to the exact requirements of each application by the design of the windings used in standardized frames. This reduces the cost, size and weight to an absolute minimum, consistent with the operational requirements. Compliance with Government specifications is assured by the choice and treatment of materials and the basic design. A complete description of your requirements will enable our engineers to make concrete recommendations... All orders are filled promptly and at moderate cost.

**ENGINEERING OPPORTUNITIES IN Westinghouse**

**Wanted:**
- Design Engineers
- Field Engineers
- Technical Writers

Must have at least one year's experience.
- For work on airborne radar, shipborne radar, radio communications equipment, microwave relay, or micro-wave communications.

Good pay, excellent working conditions; advancement on individual merit; location Baltimore.

Send resume of experience and education to: Manager, Industrial Relations, Westinghouse Electric Corp., 2519 Wilkens Ave., Baltimore 3, Maryland.

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**OPPORTUNITIES FOR ENGINEERS—SCIENTISTS**

**GENERAL ELECTRIC COMPANY,** Electronics Dept., has excellent opportunities for experienced technical personnel in the following areas:
- ADVANCED DEVELOPMENT DESIGN—CIRCUIT, COMPONENT, AND PRODUCT
- FIELD SERVICE
- TECHNICAL WRITING

These positions available in the following fields:
- TRANSMITTERS, RADAR, TUBE, RECEIVERS—TELEVISION AND COMMUNICATIONS

If you have a bachelor's or advanced degree in Electrical or Mechanical Engineering, Physics, Metallurgy, or Physical Chemistry and experience in the electronics industry it will be worth your while to investigate these opportunities.

Send complete resume (Listing salary requirements and availability) to: TECHNICAL PERSONNEL, ELECTRONICS PARK, SYRACUSE, N.Y.

General Electric Co.

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**PHYSICISTS AND ENGINEERS**

You can find plenty of positions where you will work on minor improvements on radar, telemetering systems, and other conventional devices. However, you will find very few positions where you can break ground in new fields having tremendous significance. This you can do at the JACOBS INSTRUMENT COMPANY, whose entire effort is devoted to pioneering activities in new fields that it has opened up itself. One of these fields, for example, is that of ultra-high speed, ultra-compact digital computers and controllers. This company's JAICOMP family of computers dominates this field. Other equally important fields are being developed. Engineers and physicists with sound backgrounds and experience in the design of advanced electronic circuits or precision mechanical instruments may qualify, also individuals with good backgrounds in applied physics. A few openings exist for outstanding junior E.E.'s and physicists, also experienced technicians; applicants for these positions must apply in person.

JACOBS INSTRUMENT CO.
4718 Bethesda Ave.
Bethesda 14, Maryland

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**PROJECT ENGINEERS**

An Invitation is Extended to ELECTRONIC & RADIO ENGINEERS ATTENDING THE IRE CONVENTION

TO VISIT OUR PLANT AND INVESTIGATE THE OPPORTUNITIES AVAILABLE AT PRESENT IN OUR ENGINEERING DIVISION

APPLY OR PHONE FOR APPOINTMENT

EMPLOYMENT OFFICE SPERRY GYROSCOPE CO. DIVISION OF THE SPERRY CORP. GREAT NECK, L.I., N.Y.

---

**RESEARCH OPPORTUNITIES**

The University of Michigan is expanding its research organization and will have a number of excellent opportunities open in important research programs for ENGINEERS, PHYSICISTS AND MATHEMATICIANS. Work classifications are in the field of:
- Electronics Systems Analysis
- Simulation and Automatic Computation
- Propulsion and Combustion
- Servo-mechanisms

Researchers have an opportunity to complete their requirements for graduate degrees while employed. Salaries are commensurate with training and experience. Applicants are invited to send a resume of education, background and experience to

Personnel Office
University of Michigan
Ann Arbor, Michigan

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**POSITIONS OPEN**

(Continued from page 56A)

high as $6400. Men with specialized experience in the video or the instruments fields are urgently required. Attractive openings exist for men with inclinations in other directions. Address: Personnel Department, Atten: UT. Naval Ordnance Laboratory, White Oak, Silver Spring 19, Maryland.

**ELECTRONIC ENGINEERS**

At least three (3) years' post-college experience in development, DC amplifier, digital computers, pulse and servo design. Establish Company, New York City, Box 640.

**ELECTRONICS ENGINEERS**

Sales, design and application engineering. Positions open in Sales and Engineering Depots of manufacturer of communications equipment. Salary commensurate with experience. Location Chicago. Box 642.

**TELEVISION ENGINEER**

For design and development of Television and Radio Receivers by one of Chicago's oldest Television and Radio manufacturers. Applicant required to have college degree or equivalent. Experience necessary in design and measuring technique. Give age, experience, reference, etc. Salary open. Apply box 643.

(Continued on page 68A)
low loss miniature
TUBE SOCKETS

OFFER ALL THESE ADVANTAGES:

- CLOSER TOLERANCES
- LOWER DIELECTRIC LOSS
- HIGH ARC RESISTANCE
- HIGH DIELECTRIC STRENGTH
- GREAT DIMENSIONAL STABILITY
- IMMUNITY TO HUMIDITY
- HIGH SAFE OPERATING TEMPERATURE

-cost no more than

PHENOLIC TYPES

These glass-bonded mica sockets are produced by an exclusive MYCALEX process that reduces their cost to the level of phenolic sockets. Electrical characteristics are far superior to phenolics while dimensional accuracy and uniformity exceed that of ceramic types.

MYCALEX miniature tube sockets, available in 7-pin and 9-pin types, are injection molded with great precision and fully meet RTMA standards. They are produced in two grades, described as follows, to meet diversified requirements.

MYCALEX 410 conforms to Grade L-4 specifications, is priced comparable to mica-filled phenolics. Loss factor is only .015 at 1 mc, insulation resistance 10,000 megohms.

MYCALEX 410X is low in cost but insulating properties greatly exceed those of ordinary materials. Loss factor is only one-fourth that of phenolics (.083 at 1 mc) but cost is the same. Insulations resistance 10,000 megohms.

MYCALEX TUBE SOCKET CORPORATION
Under Exclusive License of MYCALEX CORPORATION OF AMERICA
30 ROCKEFELLER PLAZA, NEW YORK 20, N.Y.

MYCALEX TUBE SOCKET CORPORATION
30 ROCKEFELLER PLAZA, NEW YORK 20, N.Y.

MYCALEX TUBE SOCKET CORPORATION
30 ROCKEFELLER PLAZA, NEW YORK 20, N.Y.

SINCE 1919
MYCALEX
THE INSULATOR
TRADE MARK REG US PAT OFF

MYCALEX CORPORATION OF AMERICA
“Owners of 'MYCALEX' Patents.”
Executive Offices: 30 Rockefeller Plaza, New York 20 • Plant and General Offices: Clifton, New Jersey

SCIENCE PROCEEDINGS OF THE I.R.E. February, 1951
The little **SHURE** cartridges that fill the Big need for High Fidelity

**Phonograph Reproduction . . .**

**THE NEW SHURE** "**VERTICAL DRIVE**"

**CRYSTAL PICKUP CARTRIDGES**

Big things often come in little packages . . . So it is with the superlative new Shure "Vertical Drive" Crystal Cartridges. They reproduce all the recorded music on the new fine-groove recordings—a reproduction that meets the strict requirements of high compliance and full fidelity. The "Vertical Drive" cartridges are requisite for the critical listener—the lover of fine music. They are especially recommended for those applications where true fidelity is essential.

![Image of a cartridge](attachment:image.jpg)

**W 22 A** for standard width-groove records.

**W 22 A** and **W 22 AB** for both standard and fine-groove records.

Unusually highly compliant, these "Vertical Drive" Cartridges will faithfully track standard records with a force of only 6 grams—micro-groove records with a force of only 5 grams (an added protection for treasured recordings). Will fit standard or special mountings. Have more than adequate output for the average audio stage.

**SHURE BROTHERS, INC.**

Microphones and Acoustic Devices

225 WEST HURON STREET, CHICAGO 10, ILL.  
CABLE ADDRESS: SHUREMICRO

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**Positions Open**

(Continued from page 58A)

**ELECTRONICS ENGINEERS**

A large Cleveland manufacturer of Automotive and Aircraft Engine Parts is entering the Electronics Field. Development Engineers and Laboratory Technicians are needed to conduct development testing of qualification test samples, design and build test setups, writing reports etc. Work is original in the field of high frequency signal transmission (frequencies up to 11,000 mega-cycles per second). Reply should give training, experience in detail, past employers, earnings and other pertinent facts. Thompson Products, Inc., 2196 Clarkwood Road, Cleveland 3, Ohio.

**ENGINEERS**

Four senior electronics research and development engineers with a minimum of five years' experience in pulse and general radar design. Assignments will include microwave test equipment projects and guided missile development. Degree essential. Excellent opportunity for advancement in rapidly expanding company. Modern plant of 250 workers located in Los Angeles area. Three experienced junior engineers also required. Send resume of education, experience, salary desired, to Box 644.

**ELECTRICAL ENGINEER**

B.S. or M.S. to work with group on circuits and miniaturization problems relating to electronic equipment and technique. Must be capable of job planning and project control. Minimum 5 years experience.

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**PHYSICISTS AND SENIOR RESEARCH ENGINEERS**

**POSITIONS NOW OPEN**

Senior Engineers and Physicists having outstanding academic background and experience in the fields of:

- Microwave Techniques
- Moving Target Indication
- Servomechanisms
- Applied Physics
- Geophysical Equipment
- Optical Equipment
- Computers
- Pulse Techniques
- Radar
- Fire Control
- Circuit Analysis
- Autopilot Design
- Applied Mathematics
- Electronic Subminiaturization
- Instrument Design
- Automatic Production Equipment
- Test Equipment
- Electronic Design
- Flight Test Instrumentation

are offered excellent working conditions and opportunities for advancement in our Astrophysics Laboratory. Salaries are commensurate with ability, experience and background. Send information as to age, education, experience and work preference to:

**NORTH AMERICAN AVIATION, INC.**

Astrophysics Laboratory  
Box No. N-4, 12214 South Lakewood Blvd. Downey, California
for Accuracy in Attenuators

RF Attenuation Network

This equipment is an exclusive Daven development. It is a moderately priced attenuator incorporated in an RF Attenuation Box to insert accurate losses from D.C. to 225 MC. The unit has many applications where attenuation of UHF is desired, since it can be utilized as an all-purpose laboratory and test instrument.

**Specifications:**

- **Zero Insertion Loss Over Entire Frequency Range.**
- **Frequency Range:** Zero to 225 MC.
- **Impedance Accuracy:** Within ±5% over frequency range.
- **Attenuation Accuracy:** ±5% over frequency range.
- **Connectors:** receptacles are supplied. Cable plugs, if required, will be supplied at a slight additional cost. When ordering, specify which type connector is desired—either Series "BNC" (UG-185/U) or Series "N" (UG-58/U).
- **Circuit:** Constant input and output impedance (unbalanced). Zero initial loss.
- **Resistor Accuracy:** ±2% at D.C.

Carrier Frequency Decade Attenuator

This equipment is particularly applicable to extremely accurate measurements from D.C. to 200 kc, and can be used up to the lower radio frequencies. The Decade type switches make the box convenient to use. In addition, there are switch stops which prevent return from full to zero attenuation when making adjustments. A total of 110 Db. is available in 1.0 Db. steps, or 111 Db. is available in 0.1 Db. steps. Both of these types may be obtained in either a balanced H or an unbalanced T network.

**Specifications:**

- **Accuracy:** Each individual resistor is adjusted within ±0.25% of its correct value. The error in attenuation is less than ±1% of the indicated value, provided the output is matched by a pure resistance.
- **Frequency Error:** At frequencies below 200 kc., the total error in attenuation will not be greater than ±1% of the indicated value.

for many years Daven has been known for the quality of its attenuators. And, although production has grown to include a wide variety of instruments for the electronics industry, the development of its attenuators has not slackened. Much of the testing equipment used by Daven to guide them in the manufacture of attenuators has been developed by the company's own engineering specialists. As a result, these attenuators have become the standard of the industry, by which all other similar equipment is measured. Shown and described here are two of the newest units that are typical of the latest Daven line of attenuators. Your inquiry for specific information to apply to your own particular problems is invited. Let Daven send you with completely detailed catalog information.
KINGS

Microwave Equipment

KINGS proudly introduces a new and complete line of microwave equipment. Many improvements in design and construction are your assurance of the finest in precision instrumentation. Our engineering department is ready to cooperate on your most exacting microwave and research problems. Inquiries are invited.

KINGS

Microwave CO., INC.

50 Marbledale Road, Tuckahoe 7, N. Y.
an affiliate of Kings Electronics Company, Inc.

Positions Open

(Continued from page 60A)

experience in both audio and TV circuits and tube component design or equipment production. Prefer engineering physicist or electrical engineer with some mechanical design experience and major interest in circuits. Position is with physics Laboratory. Sylvania Electric Products Inc., Bayside, Long Island. Please address replies to Personnel Manager, 40-22 Lawrence Street, Flushing, New York.

ELECTRONICS SALES ENGINEERS

Positions open for mature graduate sales engineers over 28 years of age, preferably with practical experience in application of dielectric heating to industrial problems. Excellent opportunities for type of individuals interested in affiliation with successful rapidly expanding organization. Locations in Chicago and other territories. Box 646.

PHYSICIST

To conduct research on gaseous discharges. Prefer man with PhD in Physics with courses in Atomic Physics, Spectroscopy and Chemistry, or M.S. with 2 years experience in nuclear research or gas discharges or thermionic emission. Position is with Long Island Laboratory of nationally known electronics company. Box 645.

ENGINEERS AND PHYSICISTS

Electrical engineers and physicists in University connected Research Institute outside continental United States. Min- (Continued on page 63A)
Positions Open

(Continued from page 62A)

Positions Wanted

By Armed Forces Veterans

In order to give a reasonably equal opportunity to all applicants, and to avoid overcrowding of the corresponding column, the following rules have been adopted:

The Institute publishes free of charge notices of positions wanted by I.R.E. members who are now in the Service or who have received an honorable discharge. Such notices should not have more than three lines. They may be inserted only after lapse of one month or more following a previous insertion and the maximum number of insertions is three per year. The Institute necessarily reserves the right to decline any announcement without assignment of reason.

Electronics Engineers

B.E.E. 1942. Age 30, married, 1 child. Five years' experience in research and development. Experience includes UHF, microwaves and servomechanisms. Interested in changing position. Box 495 W.

Engineer

Mature engineer, age 40, broad experience including industrial design, field engineering, foreign experience. B.S. in E.E., University of Illinois, UHF major. Now completing work for M.S. in E.E., physics emphasis in research. Domestic or foreign deployment (supervision of overseas branch) will be considered. Box 496 W.

KINGS

COAXIAL CONNECTORS

preferred by engineers everywhere

From coast-to-coast, engineers in all fields look to Kings Electronics for the finest coaxial connectors.

Special problems in design and fabrication receive the wholehearted cooperation of Kings own engineering department.

For precision-made, pressurized R.F. Connectors call on Kings—the leader. Quotations on request.

Kings Electronics

811 Lexington Avenue, Brooklyn 21, N.Y.
WHEN YOU NEED A MINIATURE TRANSFORMER

CHECK THESE FEATURES OF THE HORNET

 SIZE AND WEIGHT  Because they are designed for high operating temperatures, Hornet Transformers and Reactors have only about one-fourth the size and weight of Class A units of comparable rating.

 VOLTAGE RATINGS  Designs are available for RMS test voltages up to 10,000 volts at sea level, and up to 5,000 volts at 50,000 feet altitude. Power ratings from 2VA to 5KVA.

 POWER FREQUENCIES  These units are designed to operate on 380/1600 cps aircraft power supplies, 60 cps power supplies, and any other required power frequency.

 AMBIENT TEMPERATURES  Hornet Units can be designed for ambient temperatures up to 200 deg. C. Size for any given rating depends upon ambient temperature and required life.

 LIFE EXPECTANCY  Extensive tests indicate that the life expectancy of Hornet units at continuous winding temperatures of 200 deg. C. is over 50,000 hours.

 MOISTURE RESISTANCE  Since Hornet Transformers and Reactors contain only inorganic insulation, they are far more moisture resistant than conventional Class A insulated units.

 EFFICIENCY  Regulation and efficiency of Hornet Transformers compare favorably with Class A units.

 SPECIFICATIONS  Hornet Transformers meet the requirements of Government specifications covering this type of equipment.

 Bulletin B300, containing full electrical and dimensional data on Hornet units, is now available. Write for it, or tell us your specifications for special units.

NEW YORK TRANSFORMER CO., INC.
ALPHA NEW JERSEY

Positions Wanted (Continued from page 63A)

ELECTRICAL ENGINEER
B.S.E.E. Columbia, Tau Beta Pi, 31, married. Seven years' development and administrative experience. Wide shop background, inventive ability to solve problems. Designed, developed and manufactured electronic controls, machinery, precision electro-mechanical devices. 2½ years Navy, radar and sonar instructor. New York metropolitan at Box 499 W.

COMMUNICATIONS TECHNICIAN
Age 31, married. Extensive experience in maintenance, installation, D.S.B. S.S. Diversity communications receivers; dio-telephone terminal units, etc., radio-facsimile specialist. Six years' experience in circuit design, seven years' analyzing and repair TV and radio. Five years' British communicative company. Consider suggestions for 1951. Canada preferred. Box 505 W.

ENGINEER

MEMBERSHIP

(Continued from page 48A)

Patterson, T. C., "Vindomora," Gillis Lane (E Houghton-Lee-Spring, Co. Houlton, Me. 5.
Pedersen, 0. C., 1830 S. 54 Ave., Chicago 50, Ill. 5.
Seal, R. K.F., 3513 Idaho Ave., N.W., Wash., D.C.
Smith, H. M., Box 229, Sackville, N. B., Canada 7.
Smuith, E. D., Massachusetts Institute of Technology, Cambridge, Mass.
Stewart, N. H., Westinghouse Electric Corporation, Bloomfield, N. J.

Admission to Senior Member
J. N.
Gree, W. J., Box 2515, Houston 1, Tex.
Kearney, J. P., 2315 Westbrooke Dr., Toledo, Ohio.
Mostafa, A. E., Faculty of Engineering, Cairo University, Alexandria, Egypt.
Soffit, M. E., R. D. 1, Lansdale, Pa.
Temt, A., 1048 Norwood Ave., Elberon, N. J.

(Continued on page 56A)

PROCEEDINGS OF THE I.R.E.
February, 1951
INCREDUCTOR

—newest component in the electronic field

INCREDUCTOR is the trademark designating a new type variable inductor that is:

—electrically controlled—no moving parts
—variable over a useful inductance range of 100 to 1—or 200 to 1—or even more in some applications
—low in loss—maintains high Q even at megacycles
—controlled with minimal power, compact and light in weight
—the result of years of intensive research by C. G. S. engineers*

These valuable characteristics of the INCREDUCTOR are attained by the use of separate control and signal windings, specially arranged on a ceramic core having unusual magnetic properties.

Alternating or direct current variations through the low power control winding produce corresponding variations in the inductance of the INCREDUCTOR signal winding.

The standard line of C. G. S. INCREDUCTORS now available includes units with a wide range of starting inductances and frequencies. For those applications in which the standard C. G. S. INCREDUCTORS will not provide the requisite characteristics, C. G. S. will design and produce INCREDUCTORS to meet your specific requirements.

Write us on your letterhead for a descriptive bulletin, including information and prices on standard units, together with helpful design data.**

* Pat. applied for.
** See also "300 to 4000 Kc Electrically Tuned Oscillator" by A. I. Pressman and J. P. Blewett, Proc. I. R. E. January 1951.

C. G. S. LABORATORIES, INC.
390 Ludlow Street
Stamford, Connecticut
DIRECTONAL ANTENNAS

Workshop directional (and bi-directional) antennas are designed expressly for point-to-point communications, particularly — railway, highway patrol, public safety, police, utility, pipe lines, forestry, and other similar uses. Their high gain and sharp directivity provide strong, clear reception and long-range coverage at minimum cost. Rugged, heavy-gauge aluminum elements and enameled steel supports guarantee long, dependable service with no maintenance expense. Installation is very simple, requiring only an iron pipe mast and cable. Ten different models are available, one for each operating band.

GAIN — Conservatively rated at 7.6 db over a 1/2-wave dipole; 15.2 db for system when used in pairs — one at each end of circuit

RUGGED CONSTRUCTION — Withstands steady 65 mph wind with 1/2" radial ice; 85-90 mph without ice with adequate safety factor

1/2-POWER ANGLES — 64° Horizontal, 68° Vertical

FRONT-TO-BACK RATIO — 20 db, measured

VSWR — Less than 1.5:1

IMPEDANCE — 52 ohms

VERTICAL POLARIZATION — Horizontal on request

MOUNTING — 1/2" standard threaded pipe

ENGINEERING and CONTRACT SERVICE. The WORKSHOP handles scores of special government and commercial antenna problems every year from design through production. If your product or service requires high-frequency antennas — research, design, or production — get in touch with the WORKSHOP. Write, or phone Needham 3-0005. No obligation.

The WORKSHOP ASSOCIATES, Inc.
Specialists in High Frequency Antennas
135 Crescent Road, Needham Heights 94, Massachusetts

(Continued on page 684)
SPECIFY Simpson

for Accurate, Dependable Electrical Measurements

BECAUSE—Simpson has developed quality control to a new modern high with this successful production policy. Design everything that goes into an instrument—make everything that goes into an instrument—keep designing for the future—keep quality steadily higher—keep prices consistent with material and labor costs without exploitation. This quality control is evident in every Simpson instrument whether panel or switchboard, custom-built or stock. The instruments illustrated in panel below are only a few of the wide variety of instruments in the complete Simpson line. Let Simpson engineers help you solve your panel instrument problems—and for your standard instrument requirements take advantage of our large stock.
The following elections to Associate grade were approved and are effective as of January 1, 1951:

Boedeker, H. F., 5023 N. Broadway, Chicago, Ill.
Brown, E. A., 519-B E. Smith St., Angelo, Tex.
Burbridge, M. M., 40 Featherbed Lane, New York 52, N. Y.
Carlson, R. C., 1816 Lamont St., Washington, D. C.
Cerrutti, I. 1222 Van Pelt Ave., Los Angeles 63, Calif.
Colton, L., 1846 26th St., Brooklyn 14 N. Y.
Coyle, P. L., 1508 N. Washburne, Chicago 22, Ill.
Daheim, D. T., 7965 Earl St., Oakland 5, Calif.
Dolman, J. P., 3548 Douglas Rd., Toledo, Ohio
Donnenna, D. L., 746 Maple St., Bridgeport 8, Conn.
Dooley, R. P., Box 8144, Albuquerque, N. Mex.
Rash, G. H., 845 W. Woodruff Ave., Toledo 7, Ohio
English, E. H., 160 St. James St., Burnley, Lancs., England
Feudor, F. H., 636 Anderson Ave., Jiribaf Park 2, N. J.
Flynn, M. W., 24 Fairbank Ave., Toronto 10, Ont., Canada
French, J. C., 449 Poplar St., Hazard, Ky.
Gopalakrishnun, E. S., 7 Hunters Rd., Madras 7, India
Hackett, C. B., 5647 W. North Ave., Chicago 39, Ill.
Hallisey, R. J., 5 California Ave., Saco, Maine
Hancock, J. B., 404 Seventh St., Modesto, Calif.
Hanna, R. N., 908 Prospect Ave., Toledo 6, Ohio
Heron, L. R., Electronics Division, Naval Air Station, Squamuit, Mass.
Herrick, K. R., 2516 Fulton, Toledo 19, Ohio
Hickerson, J. E., Albany Post Rd., Wappingers Falls, N. Y.
Hillers, G. R., 108 E. Broadway, Abilene, Calif.
Hill, E. W., 2502 St. Isabel St., Tampa 7, Fla.
Hines, L. J., 712 E. Ogden Ave., Milwaukee 2, Wis.
Hollowed, R. J., 1327 N. Massasoit Ave., Chicago 51, Ill.
House, H. J., 19 Grove Ave., Auburn, N. Y.
Irikakis, M. A., 65 Ag. Meletiou, Athens, Greece
Ingersoll, G. F., 634 Spencer, Toledo, Ohio
James, F. L., 6172-May Way, Honolulu, Oahu, T. H.
Jensen, R. E., 5633 N. Mozart St., Chicago 43, Ill.
Johnson, C. L., 324 S. Grand, Independence, Mo.
Jones, C. W., Box 305, Paris, Tenn.
Kaeli, E., 29-04 169 St., Flushing, L. I., N. Y.
Karr, R. J., 1060 W. Winona, Chicago 8-3, Ill.
Kennelwell, E. M., 3 Highway Grove, E. Prahran S. I., Victoria, Australia
Kerlin, J. F., Millbrook, N. Y.
Kerfoot, J. H., 23 Kings Lynn Rd., Toronto 18, Ont., Canada
Klein, J., 2400 W. Wilson Ave., Chicago, Ill.
Kolker, J. A., 68 Lafayette Ave., Maywood, N. J.
Kounalis, L. E., 155 N. Main 64, Salt Lake City, Utah.
Kronewold, M., Video Corporation of America, 229 W. 26 St., New York 1, N. Y.
Lambert, R., 3736 Leigwood Dr., Cincinnati 7, Ohio
Makleff, P., 1168 50 St., Brooklyn, N. Y.
Markowitz, R. S., 4948 Routhston St., Philadelphia 20, Pa.
Marshall, W. F., 398 N. Seaville Ave., Oak Park, Ill.
Martin, P. E., Bendix International, 72 Fifth Ave., New York, N. Y.
Mason, N. G., 239 E. 211 St., Cleveland 13, Ohio

(Continued page 664)
The Berkeley Events-Per-Unit-Time® Meter will automatically count and display the number of events that occur during a precise one second interval at rates up to 100,000 per second. Accuracy is ± 10/µsec. These events may be any mechanical, electrical, or optical occurrences regularly or randomly spaced that can be converted into changing voltages. Thus the EPUT becomes an extremely flexible tool which may be used as a precision electronic tachometer, a secondary frequency standard, a device for rapid determination of unknown frequencies or simply a multi-purpose general laboratory instrument.

AUTOMATIC: This unit will count for a precise one second interval, display the results in direct reading form for a period variable from one to five seconds, and then automatically recycle. On “Manual” operation the instrument will count for one second and display the result indefinitely until the “reset-count” button is again depressed.

SELF-CHECKING: Important test feature permits one-second check of the entire circuit with the exception of the 100 kc crystal itself. A panel “test” switch allows the instrument to count its own 100 kc crystal and display the “00000” result directly.

MODIFICATIONS: Standard modifications available: a selectable 0.1, 1, and 10 second time base; addition of mechanical register for extended range; addition of panel switch to permit use as straight counter; scanning feature to provide a time base in any multiple of 10 seconds. Special modification including accessories such as tachometer pickups and photocell arrangements can be supplied to meet specific requirements.

The Berkeley Time Interval Meter®, Model 510, provides a direct reading of elapsed time between any two events in the range of 0.000010 to 10.000 seconds. Accuracy of measurement is ± 10/µsec. Any occurrences that can be translated into changing voltages may be timed. Timing may be started and stopped by independent voltages. The polarity of these control voltages may be selected by means of toggle switches so that the unit may be started and stopped by either positive or negative pulses. A sensitivity control permits selection of the amplitude of the start or stop voltages at optimum level for elimination of interference.

OPERATION: By use of photocell attachments the interval between two separate light flashes may be timed. Similarly by use of an added photocell and a single photocell duration of a light period or a dark period may be determined.

MODIFICATIONS: Standard modifications available; addition of a photocell channel; the addition of a mechanical register to extend range to 10 seconds; threshold control to permit selection of precise amplitude of input pulse so unit may be made to operate at any desired position on sine wave; panel switch to permit use as straight counter.

For complete information, write for Bulletins IRE-510 and IRE-554

Berkeley Scientific Corporation
2200 Wright Ave. • Richmond, Calif.
Microwave "Shutter"  
by TERPENING

The "shutter" you see in the waveguide section above is designed to close automatically when the radar is not operating. This prevents damage to the crystal detector, which might be caused by radiation from other nearby radars.

Specifications called for very high attenuation when closed, extremely low attenuation when open, and fully automatic operation.

As designed and produced in quantity in our plant, the performance of this component exceeded our customer's expectations. For example:

- with the solenoid-actuated shutter in closed position, attenuation is greater than 40 db,
- with shutter open, attenuation is negligible—a few hundredths of one db.

This is a typical example of the work we are set up to handle—from design through production—from single component to entire transmission line. Although our engineering staff, laboratories, and fully equipped shop are usually busy on government contracts, our unusual facilities may permit us to work with you on special components for military microwave systems. We shall be happy to talk with you about your present and/or future needs.

Investigate MULTI-SWAGE

Economy Way to Get Volume!
If it's VOLUME you need on small tubular metal parts similar to these, be sure to look into Bead Chain's MULTI-SWAGE Process. Send the part (up to 3/8" dia. and to 1 1/2" length) and your specs for a quotation. Chances are you'll find a new way to effect important savings.

Much Cheaper Than Solid Pins
Many prominent users of solid pins for electronic and mechanical purposes have cut costs by switching to Multi-Swaged tubular pins . . . without sacrificing strength or accuracy. Often this is possible to accomplish.

Typical Applications—
As terminals, contacts, bearing pins, stop pins, male-female connections, etc., in a wide variety of electronic and mechanical products:—Toys . . . Business Machines . . . Ventilator louvres . . . Radio and Television apparatus . . . Terminal-boards . . . Electric Shavers . . . Phono Pick-ups, etc. For DATA BULLETIN, write to

L. H. TERPENING COMPANY
DESIGN • RESEARCH • PRODUCTION
Microwave Transmission Lines and Associated Components
16 West 61st St. • New York 23, N. Y. • Circle 6-4760

The BEAD CHAIN Mfg. Co.
11 Mountain Grove St., Bridgeport 5, Conn.
Manufacturers of BEAD CHAIN—the kinkless chain of a thousand uses, for fishing tackle, novelty, plumbing, electrical, jewelry and industrial products.
Specify CP TEF-LINE
SUPER TRANSMISSION LINE

A new transmission line based upon a new plastic—TEFLON

CP TEF-LINE transmission line, utilizing DuPont Teflon insulators, greatly reduces high frequency power losses. Furthermore, operation of transmission line at frequencies heretofore impossible owing to excessive power loss now becomes easily possible. For TV, FM and other services utilizing increasingly high frequencies, TEF-LINE by CP is a timely and valuable development worthy of investigation by every user of transmission line.

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COMMUNICATION PRODUCTS COMPANY, INC.
KEYPORT, N.J. NEW JERSEY

We will be grateful if you will mention PROCEEDINGS of the I.R.E. when writing to our advertisers.
Specify BREEZE "Monobloc" Waterproof and Pressure Sealed CONNECTORS

The only APPROVED Monobloc System for Advanced Radar, Communications, and Electronic Equipment

Breeze "Monoblocs", with single piece plastic inserts, offer outstanding advantages in assembly, wiring, mounting and service in the field.

Single piece inserts make a tighter unit, eliminate the air spaces within conventional multiple-piece inserts, greatly reduce the opportunity for moisture shorts.

Removable contact pins make possible bench soldering of leads, quick, error free assembly of Breeze Waterproof Connectors and panel-type "Monobloc Miniatures."

Single-Hole Panel Mounting is all that is required for either Waterproof or Pressure Sealed types.

Pressure Sealed types are available for values up to and including 75 psi, or they can be specially engineered for greater pressures. They meet specified requirements of shock, vibration, salt spray, humidity and temperature cycling from $-65^\circ$ to $+185^\circ$ F.

Breeze "Monobloc" Waterproof and Pressure Sealed Connectors are engineered to your requirements in aluminum, brass or steel—in all sizes and capacities. They are fully tested and approved...cost no more than ordinary types.

Write for Details If you have a tough connector problem, ask BREEZE for the answer!

In only 1 SECOND! COMPLETE AUDIO WAVEFORM ANALYSIS with the AP-1 PANORAMIC SONIC ANALYZER

Provides the very utmost in speed, simplicity and directness of complex waveform analysis. In only one second the AP-1 automatically separates and measures the frequency and amplitude of wave components between 40 and 20,000 cps. Optimum frequency resolution is maintained throughout the entire frequency range. Measures components down to 0.1%.

- Direct Reading
- Logarithmic Frequency Scale
- Linear and Two Decade Log Voltage Scales
- Input voltage range 10,000,000:1

AP-1 is THE answer for practical investigations of waveforms which vary in a random manner or while operating or design constants are changed. If your problem is measurement of harmonics, high frequency vibration, noise, intermodulation, acoustics or other sonic phenomena, investigate the overall advantages offered by AP-1.

Write NOW for complete specifications, price and delivery.

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ACTUATORS: All types, sizes. Complete control systems engineered to requirements. Above: Landing gear actuator Fairchild Packet.

RADIO SHIELDING: For any type of high or low tension system. New type "unit leads" or re-wirable leads. Flexible shielded conduit.

"AERO-SEAL" Worm-Drive Hose Clamps. Vibration proof, uniform clamping, use again and again. All clamps have stainless steel bands.

BREEZE CORPORATIONS, INC.
41G SOUTH SIXTH ST., NEWARK, N.J.
Just 60 SECONDS
from now…

…a finished
print!!!

…with the camera that brings a new speed and
efficiency to oscillograph-recording techniques

The DU MONT TYPE 297
Oscillograph-record Camera

The Type 297 is an inexpensive
oscillograph-record camera, greatly
improved for general-purpose appli-
cation with any standard 5-inch cath-
ode-ray oscillograph. It incorporates
a compact, all-metal, 35mm camera,
calibrated shutter and a high-quality
1/2.8, 75mm, coated lens which in-
creases its capability 57% over the
Type 271-A which it supersedes. Con-
struction is rugged and durable; op-
eration simple and foolproof. The
Type 297 weighs only 4 1/2 lbs.

PRICE…$149.50

S P E C I F I C A T I O N S

PRINT SIZE—3 1/4 x 4 1/4 in.—one, two,
three, or more exposures per print.

IMAGE REDUCTION RATIO—2.25:1.

PHYSICAL SIZE—Length, 14 1/4 in.; height,
10 in.; width, 6 in.

WEIGHT—12 lbs.

PRICE….…. $285.00 with 1/2.8 lens
$355.00 with 1/1.9 lens

Write for bulletin on photographic techniques.
Here is reliable vibration protection for base-mounted airborne electronic equipment... and for other apparatus which must function properly above and below usual temperatures. And TEMPROOF Mountings are priced to meet the needs of manufacturers in competitive markets.

TEMPROOF Mountings provide superior protection by maintaining their high vibration-isolating efficiency from $-80^\circ F$ to $+250^\circ F$. Selective-action friction dampers prevent excessive movement at resonant frequencies. Equipment does not sag or droop... mounting drift is negligible. The unusually wide load range of TEMPROOF Mountings makes it possible to standardize on one mounting for several types of equipment, and to effect additional economies in purchasing, storage and assembly.

For complete information on TEMPROOF Mountings, or for specific recommendations concerning their use, write to Product Sales Engineering Department. A quantity of Vibration Isolation and Natural Frequency Charts in full color is available. Copy of each will be sent free upon request.

LORD MANUFACTURING COMPANY • ERIE, PA.
Canadian Representative: Railway & Power Engineering Corp., Ltd.

**LOW-COST PROTECTION for Airborne Electronic Equipment**

**New LORD TEMPROOF Mountings**

- Exceed AN-E-19 Drop Test Requirements
- Designed for JAN-C-172A Equipment
- Maintain Efficiency from $-80^\circ F$ to $+250^\circ F$

**Electronics Counter Tachometer**


Fundamentally, the instrument totals the number of counts derived from the source being measured during a precisely established time interval of 0.6 second (0.01 minute). This reading is displayed on a direct-reading, four-digit electronic counter using ten neon glow lamps for each digit. After each measurement and display period, the instrument automatically resets and recycles. The display time is adjustable over a period of from 0.5 second to 4 seconds, or can be set to hold the count indefinitely.

The 0.6-second time interval is established by counting 60,000 cps of the 100-kc crystal oscillator contained in the unit.

The instrument can be used to measure frequencies up to 100,000 cps with an accuracy of $\pm 1$ cps. In addition to the electronic counter registration of the measured frequency, the unit also includes a count rate meter which can be used when the unknown frequency source is being adjusted. This type of indication reflects instantaneous changes and is useful when the source of frequency must be manually adjusted to a specific point.

**Two-Signal Audio Generator**

A new Type 1303-A, two-signal audio generator, designed specifically for supplying the test signals necessary in the various methods of measuring intermodulation distortion in audio systems, has been developed by General Radio Co., 775 Massachusetts Ave., Cambridge 39, Mass.
After 3,000,000
SARKES TARZIAN "Centre-Kooled" RECTIFIERS
(Radio, Television and Electronics)

NOW in service
the Sarkes Tarzian
Centre-Kooled
POWER RECTIFIER

with the high quality Sarkes Tarzian has offered in radio-type rectifiers

- For all current and voltage ranges
- Revolutionary center cooling allows complete sealing against humidity
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Sarkes Tarzian inc.

RECTIFIER DIVISION Dept. K, 415 North College Avenue, Bloomington, Indiana

PROCEEDINGS OF THE I.R.E. February, 1951
Type 310-A Z-Angle Meter —
30 to 20,000 c.p.s.
Measures impedance directly in polar coordinates as an impedance magnitude in ohms and phase angle in degrees (θ). Measures with equal ease, pure resistance, inductance, capacitance or complex impedances comprised of most any RLC combinations. Range: Impedance (Z), 0.5 to 100,000 ohms; Phase Angle (θ), +90° (XL) through 9° (R) to —90° (XC). Accuracy: Within ±1% for impedance and ±2° for phase angle. Price: $470.00.

Type 410-A R.F. Oscillator —
100 kc to 10 mc. (Special models 4.45 kc to 4.65 mc available.)
Power oscillator for use as bridge driver and general laboratory measurements. Features: High stability, high output (approximately 30 volts), 5000:1 output impedance, expanded frequency scale, direct reading output voltmeter, compact design. Price: $385.00.

Type 500-A Wide Band Decade Amplifier
Designed for use with the phase meter at voltage levels below one volt and as a general purpose laboratory amplifier—features high gain negligible phase shift and wide band width. Unique circuitry—which employs three cathode followers—offers wider frequency range, higher input impedance and lower output impedance than other types. Panel switch selects proper feedback compensation when either optimum amplification or phase shift operation is desired. Outstanding specifications: Amplification—10; 100; 1000 selected by rotary switch . . . Accuracy—±1%; Nominal . . . Frequency response—0.5 db from 5 cycles to 2 mc on gain of 10; +0.5 db on 5 cycles to 1.5 mc on gain of 100; —0.6 db from 5 cycles to 1 mc on gain of 1000 . . . Phase shift—0±3° from 20 cycles through 1000 cycles. Gain stability—constant with line voltages (105-125V).

Technical catalog—yours for the asking. Contains detailed information on all TIC Instruments, Potentiometers and other equipment. Get your copy without obligation—write today.

INSTRUMENTS THAT BELONG IN YOUR LABORATORY

TECHNOLOGY INSTRUMENT CORP.
531 Main Street, Acton, Massachusetts

News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 71A)

This generator can also be used as a general purpose laboratory high-frequency oscillator. This oscillator will supply any of the following signals: A single low-distortion sinusoidal voltage adjustable in frequency from 20 c/s to 40 kc in two ranges, 20 c/s to 20 kc, and 20 kc to 40 kc; two low-distortion sinusoidal voltages, each separately adjustable, one to 20 kc and the other to 10 kc, and two low-distortion sinusoidal voltages, with a fixed difference in frequency maintained between the two as the frequency of one voltage is varied. The fixed difference frequency is adjustable up to 10 kc, and the lower of the two frequencies is adjustable up to 20 kc.

The output of the oscillator is continuously adjustable up to 10 milliwatts into 600 ohms with less than 0.25 per cent distortion, and up to 1 watt with less than 0.5 per cent distortion. Output is calibrated both in volts and in db with respect to 1 milliwatt in 600 ohms.

Plant Expansion

Radio Receptor Co., Inc., 84 N. 9th St., Brooklyn 11, N. Y., announces purchase of new manufacturing plant — a 90,000 square foot facility at Wythe Ave. & N. 3 St., Brooklyn, N. Y., to increase space for their manufacture of rectifiers, hf heat sealing machines, and airport radio equipment.

Nuclear Test Equipment

Four new radiation detecting instruments, are now available from the General
Electric Co., Electronics Park, Syracuse, N. Y.

The small radiation monitor measures the total amount of gamma radiation in a given area over a period of time. It is self-contained, and because it has no batteries or tubes is not susceptible to moisture or dirt. Charging is immediately accomplished by inverting the device.

The portable alpha-survey meter completely self-contained, is for the detection and indication of alpha radiation. It utilizes a proportional counting chamber as the detector. Output is given quantitatively on a meter and audibly on headsets.

(Continued on page 79A)
Ant-Corona high heat-resistant compounds for Fly Back Transformers.

Waxes and compounds from 100° F to 285° F Melting Points for electrical, radio, television, and electronic components of all types.

Pioneers in fungus-resistant waxes.

Our efficient and experienced laboratory staff is at your service.

ZOPHAR MILLS, INC.
112-130 26th Street,
Brooklyn 32, N.Y.
The Burlington "Hermetically Sealed" Instrument was designed and is manufactured to conform to JAN specifications for sealed instruments.

- Steel case with heavy copper-cadmium plate and black finish.
- Excellent shielding due to case material and construction.
- Double strength clear glass.
- Black satin anodized aluminum bezel.
- Glass to metal seal under controlled humidity and temperature conditions.
- D'Arsenval permanent magnet type movement for DC applications.
- Designed to enhance panel appearance.
- Available in 1/2" square, 2 1/2" and 3 1/2" round case types.
- Guaranteed for one year against workmanship and materials.

BURLINGTON INSTRUMENT COMPANY
DEPT. 1-21, BURLINGTON, IOWA

INTERMODULATION METER Model 31

- Completely Self-Contained
- Direct Reading For Rapid, Accurate Measurements

To insure peak performance from all audio systems; for correct adjustment and maintenance of AM and FM receivers and transmitters; checking linearity of film and disc recordings and reproductions; checking phonograph pickups and recording styli; checking record matrices; adjusting bias in tape recordings, etc.

MEASUREMENTS CORPORATION
BOONTON NEW JERSEY

GENERATOR
LOW FREQUENCY: 60 cycles.
HIGH FREQUENCY: 3000 cycles.
LF/HF VOLTAGE RATIO: Fixed 4/1.
OUTPUT VOLTAGE: 10v. max. into high impedance or +5 DBM matched to 600 ohms.
OUTPUT IMPEDANCE: 2000 ohms.
RESIDUAL IM: 0.2% max.
*(Other frequencies on special order)

ANALYZER
INPUT VOLTAGE: Full scale ranges of 3, 10 and 20 volts RMS. Less than one volt of mixed signal is sufficient for operation.
INPUT IMPEDANCE: Greater than 400 K ohms.
INTERMODULATION: Full scale ranges of 3, 10 and 30%.
ACCURACY: ±10% of full scale.
OSCILLOSCOPE connection at meter.

HUGHEY & PHILLIPS
TOWER LIGHTING DIVISION
326 N. LA CIENEGA BLVD. LOS ANGELES 48, CALIF.

60 E. 42ND ST., NEW YORK 17, N.Y.

PROCEEDINGS OF THE I.R.E. February, 1951
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 76A) phones. The semilog meter covers two decades without range switch. Power supply is by storage type batteries. The instrument is calibrated from four to five mv.

The explosion proof ionization chamber instrument is a survey meter suitable for use in class I, group D hazardous atmospheres. Indication of all types of radiation is on a standard 3½ inch instrument. It is pressurized to 15 pounds per square inch and has a pressure relief valve and pressure operated switches to open battery circuit upon loss of pressure. Conductive rubber bumpers insure against accumulation of electrostatic charge.

The beta-gamma survey meter utilizes two Geiger-Mueller tubes operating from an electronic high-voltage supply to provide high sensitivity over a wide range of levels. The compact unit features a scale changing meter, the selecting switch also selecting the G-M tube to be used for each of the four ranges from 0 to 500 milliroentgens per hour. A detachable probe also contains a G-M counter. Battery voltage is regulated electronically to provide long-term metering accuracy, and battery condition is indicated on a meter. The instrument is furnished calibrated in milliroentgens per hour using a radium source. Calibration of each range can be individually varied.

(Continued on page 80A)

SYNTRON
SELENIUM
RECTIFIERS

1/2" sq. to 12" x 16" cells—in stacks, or single cells for customer assembly.

Made by a new process to a uniform, high quality for continuous, heavy-duty service.

Write for literature

SYNTRON CO.
242 Lexington, Homer City, Pa.

Here's why those in the know—are making a special request for Cannon plugs.

Rigid mounting for both plug and receptacle

Tapered shell design centers to engage contacts automatically.

High-voltage contact—7000 volts, 60-cycle, AC peak on special order.

Socket contacts are full-floating—turn through 360°. Quick, self-centering—eases inspection.

Hand-tinning keeps solder inside cups.

All contacts, precision-machined from solid bar stock, electroplated with silver or gold.

Insert arrangements are available with 2 to 45 contacts ranging from 15 amp to 200 amp capacity. Continuous shielding available in Coaxial and Twinax. Metal finish on shells for shielding and bonding... tin plating on aluminum. Other finishes available on special request.

Inserts of latest approved high dielectric materials.

Your requirements are responsible for the 8 to 10 design advantages found in each type of Cannon Plug. That's why engineers know the specification is right when it calls for CANNON. The DP Connector Series is just one of many Cannon types—world's most complete line. Request bulletins by required type or describe connector service you need.

CANNON
ELECTRIC

Since 1915

LOS ANGELES 31, CALIFORNIA
REPRESENTATIVES IN PRINCIPAL CITIES
ARE USED IN THIS
ULTRA SENSITIVE
ELECTRONIC PHOTOMETER

In this instrument—designed for measurement of very low light values—S.S.White Resistors serve as the grid resistance in the all-important high-gain D.C. amplifier circuit. The manufacturer, Photovolt Corp., New York, N.Y., reports that the resistors "work very satisfactorily"—which checks with the experience of the many other electronic equipment manufacturers who use S.S.White resistors.

WRITE FOR BULLETIN 4906
It gives essential data about S.S.White Resistors, including construction, characteristics, dimensions, etc. Copy with price list on request.

Photo courtesy of Photovolt Corp., New York, N.Y.

S.S.WHITE RESISTORS
are of particular interest to all who need resistors with inherent low noise level and good stability in all climates.

HIGH VALUE RANGE
10 to 10,000,000 MEGOHMS

STANDARD RANGE
1000 OHMS to 9 MEGOHMS

THE S.S.White INDUSTRIAL DIVISION
DENTAL MFG.CO.
Dept. G-R, 10 E. 40th St.
NEW YORK 16, N.Y.

FOR BETTER PERFORMANCE
BETTER BUY

Acme Electric
TRANSFORMERS

You write the specifications and Acme engineers will design a transformer with the exact output characteristics to provide "top" performance for your product. And remember, in addition to quality performance, Acme also can provide quality production in custom designed electronic transformers.

ACME ELECTRIC CORPORATION
442 Water St., Cuba, N.Y., U.S.A.
**LANGEVIN ELECTRONIC ASSOCIATES, INC.**

LONG BRANCH NEW JERSEY

**ELECTRONIC ASSOCIATES, INC.**

**LONG BRANCH NEW JERSEY**

— For complete information write for Bulletin G8

**Lambda Electronics Corporation**

—— NEW YORK

**Lambda Electronics Corporation**

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**ELECTRONICALLY REGULATED LABORATORY POWER SUPPLIES**

- INPUT: 105 to 125 VAC, 50-60 cy
- OUTPUT #1: 200 to 325 Volts DC at 100 ma regulated
- OUTPUT #2: 6.3 Volts AC CT at 3A unregulated
- RIPPLE OUTPUT: Less than 10 millivolts rms

For complete information write for Bulletin G8

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For broadcast, public address, recording, and music services — custom designs for special applications.

**LANGEVIN TRANSFORMERS**

Open-core, encased, hermetically sealed, high-temperature, built to your own or MIL-T-27 specifications.

**LANGEVIN ENGINEERING**

Available for the development and manufacture of special electronic devices.

For detailed information on our products and services, write to

**LANGEVIN MANUFACTURING CORPORATION**

37 W. 65th St., New York 23, N. Y.

**PROCEEDINGS OF THE I.R.E.** February, 1951

**The Model 205 Variplotter, highlighting accuracy, speed, and versatility, brings to industry and laboratory a new tool with a wide field of application.** This instrument will present on a 30-inch square plotting surface a precise graphic representation of one variable as a function of another variable, requiring only that the variables be expressed by d-c voltages.

**ACCURACY**

The static accuracy is 0.5 percent of full scale at 70°F. The dynamic accuracy averages 0.5 percent of full scale plus the static accuracy at a writing speed of 6½ inches per second.

**SENSITIVITY**

The standard sensitivity of the Variplotter is fifty millivolts per inch with other ranges of sensitivity available.

**RESPONSE**

The maximum pen and arm accelerations are 350 and 150 inches per second squared, respectively. Swinging speeds of both pen and arm are 10 inches per second.

The Variplotter may be adapted for special use by the addition of accessories selected from our standard line—such as multiple variable conversion kits, low-drift d-c amplifiers, analog computer components; or components designed for your specific need.

**YOUR INQUIRIES ARE CORDIALLY INVITED**
The
Twin Tube
Pocket Scope
by Waterman

A new concept in multiple trace oscilloscopes made possible by Waterman developed RAYONIC rectangular cathode ray tube, providing for the first time, optional screen characteristics in each channel. S-15-A is a portable twin tube, high sensitivity oscilloscope, with two independent vertical as well as horizontal channels. A "must" for investigation of electronic circuits in industry, school or laboratory.

Vertical channels: 100mv rms/inch, with response within —20dB from DC to 200k, with pulse rise of 1.8µs. Horizontal channels: 1v rms/inch within —20dB from DC to 150k, with pulse rise of 3µs. Non-frequency discriminating attenuators and gain controls, with internal calibrations of traces. Repetitive or trigger time base, with linearization, from 3µs to 50k, with sync. A Metal shield. Filter graph screen, and a host of other features.

E-I
HERMETIC
SEALING
COMPONENTS

Announcing: AN IMPORTANT ADDITION
TO THE E-I FAMILY OF SEALED LEADS—

NEW R and RR SERIES TERMINALS

A completely new line of double barrel terminals that provide added protection against flashover without any appreciable increase in terminal size. The double barrel results in a longer leak path on both ends of the terminal while the upper barrel increases the mechanical strength of the terminal and facilitates soldering. For information call or write today.

Write for These Descriptive Bulletins:
849 — Hermetically Sealed Terminals
850 — Hermetically Sealed Headers
851 — Gasket Type Bushings

WATERMAN PRODUCTS CO., INC.
PHILADELPHIA 25, PA.
CABLE ADDRESS: POCKETSCOPE

WATERMAN PRODUCTS INCLUDE:
S-10-B GENERAL
S-11-A INDUSTRIAL
S-14-A HIGH-GAIN
S-14-B WIDE BAND
S-21-A LINEAR TIME BASE
Also RAK SCOPES, LINEAR AMPLIFIERS, RAYONIC® TUBES
and other equipment
News—New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 80A)

The machine operates at high speed, winding 1,000 turns per minute on either straight or skewed armatures. Very tight armatures may be wound because of the uniform tension with which the wire is automatically guided and laid in the slots. Amount of tension is limited solely by the strength of the wire. Positive control over number of turns is attained by automatically winding a predetermined number of turns. Armature is also automatically indexed.

Frequency Shift Converter

A small frequency shift converter has been designed and manufactured by Northern Radio Co., Inc., 143 W. 22 St., New York 11, N. Y., for single and diversity receiving systems.

The Type 107 Model 2 is a dual channel unit which converts mark and space tones into dc pulses and drives teleprinters, tape and other recorders directly. Its integral 2-inch oscilloscope provides a tuning pattern for precise receiver adjustment, during initial setup and while keying. This unit may also be used as a make and break cw or icw demodulator. Other specifications of this unit are: input FS limits, 100- to 1,000-cps frequency shift; mark frequency set at 2,975 cps. The cw-icw input, 400 to 7,500 cps. Output (1) neutral dc pulses, 60 ma in 1,800 ohm load, one side grounded; (2) polar dc pulses, ±30 ma in 1,800 load, center grounded; (3) may be operated into any impedance from 100 to 100,000 ohms.

Compact Four-Decade Audio Oscillator

The new Model 510-A audio oscillator, with a frequency range from 18 to 210,000 cps in four decades, is available from The Electronic Workshop, Inc., 351 Bleecker St., New York 14, N. Y.

The unit (dimensions 4½×5½×4 inches) will deliver 10 volts into 10,000 ohms, with output constant within 0.5 db over the entire frequency range. Distortion at this amplitude is less than 0.3 per cent from 100 to 15,000 cps and rises to no more than 0.5 per cent at 30 cps. Source impedance of the cathode-follower output is 560 ohms; a matching transformer will be made available to feed low-impedance balanced lines. The total frequency error due to drift and dial calibration is less than ±2 per cent; the 320° dial gives a scale length

(Continued on page 84A)

Looks like FUN in '51

Events are changing so rapidly from day to day that it is difficult to predict what will happen next . . . material may be restricted or abundant . . . prices may be higher or lower . . . deliveries may be better or worse . . . your guess is as good as ours. However, in spite of unsettled conditions, we may be in a position to give you just what you want. So send in your orders or call us when you need radio and electronics components or sheet metal products. We'll be honest with you and tell you exactly what we can do for you.

You will always make more sales and more profits when you sell BUD Products. First of all, you sell the highest quality, precision made parts. Second, you save time and money by getting so many of your items from one source of supply . . . because BUD makes the most complete line in the field. Third, you get more store traffic because BUD has the most "wanted" products. You will do a bigger business and have more satisfied customers when you standardize on BUD Products.
A Wide Band Sweep With Markers For Aligning Radar IF Amplifiers. DisplaysAmplitude vs. Frequency Response on Standard Oscilloscope

**Features:**
- Increases Production Speed when substituted for conventional CW point-by-point methods
- Wide Band Linear Sweep
- Pulse Type Crystal Positioned Marks at Specified Frequencies
- Marks Individually Switched On or Off
- Output Amplitude Remains Virtually Constant While Sweeping
- Output Level Control on IF and Pulse Outputs

**THE RADA-SWEEP**

**NEW**

**Elec**

**KAY COMPANY**

14. Maple Avenue

Phone Caldwell 8-4000
Universal dependability

The "Planet" trade name marks the most completely reliable line of popular type, dry electrolytic condensers that high-quality materials, the best workmanship, and long experience can produce.

All "Planet" Capacitors carry a 1-year replacement guarantee, are attractively packaged, and manufactured in specifications and mounts best suited to your needs.

For complete information write today for our latest catalog "C-2".

MODEL 300
VARIABLE ELECTRONIC FILTER

Two simple controls are all that are necessary to operate the Model 300 Variable Electronic Filter. With the variable frequency dial and range switch any cut-off frequency from 20 cps to 200 KC may be quickly and accurately selected and reslected. With the range switch either low-pass or high-pass filter action may be chosen. In either case the rate of attenuation is 18 db per octave and the insertion loss 0 db. For higher rates of attenuation or continuous band pass operation two or more sections can be cascaded. Its low noise level and flexibility of operation make the Model 300 indispensable in geophysical and acoustic research, industrial noise measurements, in the automotive and aircraft industries as well as in the radio broadcasting, recording and motion picture studio.

Write for further information today.

SPECIFICATIONS
- CUT-OFF RANGE
  20 cps to 200 KC
- ATTENUATION RATE
  18 db per octave
- SECTIONS
  Single, can be high pass and low pass
- INSERTION LOSS
  0 db
- PASS BAND LIMITS
  2 cycles to 4 MC
- NOISE LEVEL
  80 db below 1 volt

SKL SPENCER-KENNEDY LABORATORIES, INC.
181 MASSACHUSETTS AVE., CAMBRIDGE 39, MASS.

PROCEEDINGS OF THE I.R.F. February, 1951
N E Y Precious Metals in Industry

YOUR DESIGN PROBLEM SIMPLIFIED WITH THE
USE OF ONE OF OUR STANDARD CONTACTS

HEADED AND FORMED WIRE CONTACTS

This simplified chart shows the form and overall dimensions of a few of the many types of contacts made from Ney Precious Metal Alloys with electrical and physical properties that have proved exceptionally satisfactory for brush or wiping contact applications. Full technical and test data are available on request. Other Ney Precious Metal Alloys have solved many special industrial application problems. Consult us freely without obligation.

The J. M. Ney Company
171 Elm Street • Hartford 1, Conn.
Specialists in Precious Metal Metallurgy Since 1812

SUPPRESS RADIO INTERFERENCE
...Eliminate Errors in Critical RF Measurements

Reduce the area background level of radio interference to a negligible minimum for critical tests and measurements! Ace Pre-Built Screen Rooms are moderately priced—suppress interference far more efficiently than ordinary screen rooms or enclosures—and provide for a high degree of accuracy by eliminating gross systematic errors in your test setup and calculations. They're easy to install and easy to enlarge or move. Write, wire or 'phone for further details.

ATTENUATIONS of 100 to 140 db.
FROM 0.15 to 10,000 mc.
PARTRIDGE

the

AUDIO TRANSFORMERS

that pass

all tests!

...The test of time, no less than test by leading technicians, has proved the range of Partridge Audio Transformers to be the most efficient and reliable in the world. For example the famous

*WILLIAMSON Output TRANSFORMER, of which there is no U.S. equivalent (vide "Audio Engineering" Nov. 1949) is produced to the original specification and comes to you for $21.00, mail and insurance paid. Then there is the

*PARTRIDGE CFB 20 Watt output type, universally accepted as without rival anywhere. Here are some brief figures: Series leakage induct. 10 m.H; primary shunt induct. 130 H, with 'C' core construction and hermetically sealed—to you for $30.00, mail and insurance paid.

...send for fullest data, including square wave tests, distortion curves etc. We'll rush this Air Mail together with list of U.S. stockists.

DO YOU KNOW?

that a PILOT LIGHT CAN IMPROVE YOUR PRODUCT . . . . . . add attraction — safety — service?

Ask DIALCO

— what lamp to use
— how to use it
— what it will do
— what it will cost

THIS MAY BE THE ONE
Designed for low cost NE-51 Neon
• Built-in Resistor  • Patented
• U/L Listed  • Rugged
Catalogue Number 521308 — 997
for 110 or 220 volts.

SAMPLES
for design purpose
NO CHARGE

NEW! Write for the
"HANDBOOK OF PILOT LIGHTS."
Write us on your design problems.

The DIAL LIGHT COMPANY of AMERICA
Foremost Manufacturer of Pilot Lights.
900 BROADWAY, NEW YORK 3, N. Y. TELEPHONE SPRING 7-1300

INCREASED ACCURACY

• SWEEPS .01 sec/cm to .1 µsec/cm
  Accuracy 5% or greater.

• .04 µsec RISE TIME

• FULLY REGULATED POWER SUPPLY.

• VOLTAGE CALIBRATOR
  5% Full Scale Accuracy.

TEKTRONIX TYPE 511 AD OSCILLOSCOPE
Price $845.00 f. o. b. Factory

Increased accuracy in sweep time calibration is made possible by the use of dual Sweep Multiplier dials. The 2 megohm variable carbon resistor formerly used has been replaced by a combination of 1% fixed resistors and a variable element which comprises only 10% of the total. Electronic regulation of all DC voltages preserves the inherent accuracy regardless of severe line voltage variations.

Write for further information on the Type 511 AD and other Tektronix instruments.

TEKTRONIX, INC.

712 S.E. Hawthorne Blvd. Portland 14, Ore.
**NEW! FREQUENCY AND TIME MEASUREMENTS ACCURATELY . . . CONVENIENTLY!**

Model 801 by **Potter**

- **Frequency Measurements**
  - 0 to 1 mc range by counting cycles per pre-selected time or by measuring time per pre-selected count
  - Accuracy 0.001%, minimum

- **Time Interval Measurements**
  - 0 to 10 seconds ± 10 micro seconds

- **Frequency Ratio Measurements**
  - Ratio of two external frequencies can be measured

- **Secondary Frequency**
  - 100 kc crystal oscillator with divided frequencies available at 10, 1 kc and 100, 10, 1 cps

- **Totalizing Counter**
  - Six decades, pulses 0 to 1 mc
  - Time delay 10 cps to 1 mc

- **Direct RPM Reading Tachometer**
  - Through the use of an external 50 count per revolution photodisc disc generator on accuracy of ± 1 rpm is obtained

Please address inquiries to Dept. 5-F

---

**Gold Plated TUNGSTEN and MOLYBDENUM GRID WIRE**

Made to meet your specifications . . . for gold content, diameter and other requirements.

**SINCE 1901**

**SIGMUND COHN CORP.**

44 GOLD ST. NEW YORK

---

**Announcing! A NEW, IMPROVED OVEN . . . the JKO7E**

**With Thermostat Sealed In Helium**

Here’s another important JAMES KNIGHTS development, the JKO7E Oven. It features a thermostat that’s sealed in a glass envelope that has been filled with helium. Contact arcing is eliminated—temperature differential is greatly minimized by providing closer thermo-coupling to the thermostat! In addition, it’s completely dust and tamper proof.

The new design results in greater frequency stability—an added bonus! In addition to mercury thermostats, the JKO7E is available with either a 6.3 volt 10 watt heater, or a 115 volt 12 watt heater. It’s broadcast, FM & TV, F.C.C. approved.

**Additional JKO7E Specifications**

- Will hold any JK type crystal except H-4, H-18 and H-19
- Normal operating temperature 50° C ± 3° C
- Will hold any temperature as much as 75° C above the ambient
- Supplied complete with Johnson No. 237 Socket

**Also Ideal As Frequency Standard When Used With JK Stabilized H-18**

The JKO7E, when used with the JK H-18, 100 KC Crystal, or similar type, is also ideal for extremely accurate frequency measurements.

**JK Stabilized H-18 Specifications**

- **Frequency Range:** 80 KC to 2 MC
- Hemispherical metal holder
- Wire mounted silver plated crystal
- Octal base

Complete Information On Request

**The James Knights Company**

SANDWICH, ILLINOIS
Behind the Scenes at the Radio Engineering Show

Power can be a problem at the annual Radio Engineering Show! It takes as much as 235 kw to run and light the exhibits in addition to the normal lighting of the halls.

A Caterpillar standby installation "saved the day" for IRE in March 1950. New York City was observing an amusement brown-out due to the coal strike when the last show opened. Faced with a power reduction to 25% of its needs, the Show turned to one of its exhibitors for help.

The Caterpillar Tractor Company of Peoria, Illinois, was exhibiting standby diesel power plants in the show. William C. Copp, Exhibits Manager, appealed to the firm for use of the model to be displayed, but found it was to be a non-operating, cut-away display unit. However, The Caterpillar Company flew in its standby experts and shipped units to carry the load—enough electric power generators to carry a small midwestern town.

The picture shows Chief Engineer E. Olin switching in the first unit only twenty hours after the "Cats" left Peoria. The whole battery was composed of four 45 kw units and one 65 kw giant. The unit in the picture is a self-regulating ac 45 kw diesel generator.

The installation carried the load for two days. When the "brown-out" was lifted, standard power was resumed but only because five big diesels in a tiny court between two high buildings naturally were noisy. Another few hours and the big "residential mufflers" which arrived later would have cured this.

The "Cats" solved a crisis in the nick of time and demonstrated conclusively that as exacting a power requirement as the Radio Engineering Show could be met. The Caterpillar Tractor Company contributed the entire installation and travel costs to IRE.

"A Parcel or Two!"

This is what that beautiful Amphenol exhibit looks like before it is all assembled. Floor crew handlers bring in 35,000 boxes, crates and packages to set up the Radio Engineering Show. About 180 truck loads of equipment worth over seven million dollars come into the show each year.

COMING AGAIN

September 1951
(Closing May 30)

712 PAGES

- Lists 19,049 Engineers
- Directory to 2500 Firms
- Indexes 75 Engineering Product Classes
- Goes to Every IRE Engineer. Distributors Edition 1500
- Hundreds of sub-classifications

FILL OUT NEW 1951 PRODUCT LISTINGS ON NEXT PAGE

- Size 8½" x 11"
- Print Page 7½ x 11"

All advertising faces listings except spreads and catalogs

Complete Catalog Section

Manufacturers have created in the IRE DIRECTORY a most useful section! In 1950, twenty-four firms placed 124 pages of "Complete Catalog Data" in the form of spreads and catalog inserts in this book. Altogether, 212 firms placed advertising in the directory, providing IRE members with a well organized and permanently accessible file of product illustrations, specifications and "where-to-buy" information of the utmost practical value.

Rates for display advertising and for catalog inserts are economical. Write "Advertising Department" for details.

THE INSTITUTE OF RADIO ENGINEERS

Established 1913

A Balanced Promotion Package
"Proceedings of the I.R.E." The IRE Yearbook
The Radio Engineering Show
303 West 42nd Street, New York 18, N. Y.
Circle 6-3026
## Industry Research Division Information Service

### 1. Amplifiers

- In Stock ( ) Yes ( ) No.
  - (a) Broadcast Speech Input Equipment.
  - (b) Dynamic Noise Suppressors.
  - (c) High Fidelity.
  - (d) Intercommunication Systems.
  - (e) Medical Equipment.
  - (f) Peak Limiting.
  - (g) Phonograph Pre-amplifiers.
  - (h) Power Amplifiers.
  - (i) Pre-amplifiers.
  - (j) PA Systems.
  - (k) Recording Amplifiers.
  - (l) L. Television.

### 2. Antennas

- In Stock ( ) Yes ( ) No.
  - (a) AM Broadcast.
  - (b) FM Broadcast.
  - (c) Miscellaneous.
  - (d) Receiving Types.
  - (e) Rotary Systems.
  - (f) Television Broadcast.
  - (g) TV Multiple Outlet Distribution Systems.
  - (h) UHF-VHF.

### 3. Antenna Accessories

- In Stock ( ) Yes ( ) No.
  - (a) Feeders Systems.
  - (b) Insulators.
  - (c) Phasing & Tuning Equipment.
  - (d) Support Towers.
  - (e) Tower-Lighting Equip.

### 4. Attenuators

- In Stock ( ) Yes ( ) No.
  - (a) Audio Frequency.
  - (b) Radio Frequency.

### 5. Batteries

- In Stock ( ) Yes ( ) No.
  - (a) Flashlight & Miscellaneous Dry.
  - (b) Hearing Aid.
  - (c) Portable Radio.
  - (d) Storage.

### 6. Blowers & Cooling Fans

- In Stock ( ) Yes ( ) No.

### 7. Books & Book Publishers

- In Stock ( ) Yes ( ) No.

### 8. Cabinets & Consoles

- In Stock ( ) Yes ( ) No.
  - (a) Metal.
  - (b) Plastic.
  - (c) Wood.

### 9. Cable & Wire

- In Stock ( ) Yes ( ) No.
  - (a) Coaxial Cable.
  - (b) Copper.
  - (c) Mica.
  - (d) Oil Filled.
  - (e) Paper.

### 10. Capacitors: Fixed

- In Stock ( ) Yes ( ) No.
  - (a) Ceramics.
  - (b) Electrolytic.
  - (c) Mica.
  - (d) Oil Filled.
  - (e) Paper.

### 11. Capacitors: Resistive

- In Stock ( ) Yes ( ) No.
  - (a) Air Conditioning Controls.
  - (b) Burglar Alarm & Protection Devices.
  - (c) Combustion & Smoke Elimination.
  - (d) Fire Prevention & Detection.
  - (e) Production Controls.
  - (f) Variable Speed Regulators.
  - (g) Voltage Control & Stabilization.

### 12. Ceramics

- In Stock ( ) Yes ( ) No.
  - (a) Coil Forms.
  - (b) Custom Fabrication.
  - (c) Rods.
  - (d) Sheets.

### 13. Chassis & Relay Racks

- In Stock ( ) Yes ( ) No.
  - (a) Open. Stock.
  - (b) Custom Fabrication.

### 14. Coils

- In Stock ( ) Yes ( ) No.
  - (a) AF Chokes.
  - (b) Miscellaneous.
  - (c) RF Chokes.
  - (d) Toroids.
  - (e) Transformer Coils.
  - (f) Tuning.

### 15. Computers

- In Stock ( ) Yes ( ) No.
  - (a) Analog.
  - (b) Digital.

### 16. Connectors

- In Stock ( ) Yes ( ) No.
  - (a) AN Standard Types.
  - (b) Coaxial.
  - (c) Microphone.
  - (d) Power.

### 17. Consulting Engineers

- In Stock ( ) Yes ( ) No.
  - (a) Acoustical.
  - (b) Electrical.
  - (c) Mechanical.
  - (d) Radio.

### 18. Converters

- In Stock ( ) Yes ( ) No.
  - (a) Frequency.
  - (b) Vocoder.

### 19. Cores & Core Materials

- In Stock ( ) Yes ( ) No.
  - (a) Complete Cores.
  - (b) Laminations.
  - (c) Powdered Steel.

### 20. Crystals

- In Stock ( ) Yes ( ) No.
  - (a) Germanium & Silicon.
  - (b) Oscillating Quartz.
  - (c) Piezo-Electric.

### 21. Crystal Holders

- In Stock ( ) Yes ( ) No.

### 22. Distribution

- In Stock ( ) Yes ( ) No.
  - (a) Transformers.
  - (b) Manufacturing Processes.
  - (c) Medical Applications.

### 23. Electronic Control Equipment

- In Stock ( ) Yes ( ) No.
  - (a) Cloth.
  - (b) Glass.
  - (c) Mica.

### 24. Equalizers

- In Stock ( ) Yes ( ) No.
  - (a) Dialogue.
  - (b) Line.
  - (c) Magnetic Reproducer Types.
  - (d) Sound Effects.

### 25. Fabricators

- In Stock ( ) Yes ( ) No.
  - (a) Contract Assemblers.
  - (b) Electro Plating.
  - (c) Hermetic Sealing Service.
  - (d) Metal Spinners.
  - (e) Plastic Moulders.
  - (f) Stamping.
  - (g) Metal (Laminated Plastic

### 26. Facsimile Equipment

- In Stock ( ) Yes ( ) No.

### 27. Filters

- In Stock ( ) Yes ( ) No.
  - (a) Band Pass & Band Rejection.
  - (b) Dividing Networks.
  - (c) Noise Elimination.
  - (d) Signal Effects.

### 28. Fuses & Fuse Holders

- In Stock ( ) Yes ( ) No.

### 29. Graphic Recorders

- In Stock ( ) Yes ( ) No.
  - (a) Industrial.
  - (b) Medical.

### 30. Hardware & Manufacturing Aids

- In Stock ( ) Yes ( ) No.
  - (a) Adhesive Lables.
  - (b) Bushings.
  - (c) Cans.
  - (d) Dials.
  - (e) Gaskets.
  - (f) Grommets.
  - (g) Knobs.
  - (h) Metal Bolts, Nuts, Rivets, Screws, Studs, etc.
  - (i) Terminals.
  - (j) Other.

### 31. Induction Heating Equipment

- In Stock ( ) Yes ( ) No.

### 32. Distribution

- In Stock ( ) Yes ( ) No.

### 33. Jacks & Jack Fields

- In Stock ( ) Yes ( ) No.

### 34. Keys

- In Stock ( ) Yes ( ) No.

### 35. Laboratories & Custom Builders of Equipment

- In Stock ( ) Yes ( ) No.

### 36. Lacquers & Paints

- In Stock ( ) Yes ( ) No.

### 37. Loudspeakers & Headphones

- In Stock ( ) Yes ( ) No.

### 38. Machinery & Tools

- In Stock ( ) Yes ( ) No.

### 39. Magnets

- In Stock ( ) Yes ( ) No.

### 40. Metals: Base

- In Stock ( ) Yes ( ) No.

### 41. Meters

- In Stock ( ) Yes ( ) No.

### 42. Microphones

- In Stock ( ) Yes ( ) No.
   ( ) a. Frequency.
   ( ) b. Modulation.
   ( ) c. Television.

   ( ) a. Dynamos.
   ( ) b. Frequency.
   ( ) c. Motor-Generators.
   ( ) d. Rotary Converters.

   ( ) a. Blower Motors.
   ( ) b. Syncro Controls.
   ( ) c. Timing Devices.

   In Stock ( ) Yes ( ) No.
   ( ) a. Cabinets.
   ( ) b. Insulators.
   ( ) c. Knobs & Parts.
   ( ) d. Proprietary Mouldings.
   ( ) e. Special Fabrication.

7. Optical Systems, Mirrors, Screens, & Accessories.
   In Stock ( ) Yes ( ) No.
   Oscillators, see 46a, 46b, c, d, e.

8. Oscillographs & Accessories.
   In Stock ( ) Yes ( ) No.
   ( ) a. General Purpose, Cathode Ray.
   ( ) b. Recording.
   ( ) c. Recording Cameras.
   ( ) d. Synchroscopes, Cathode Ray.
   ( ) e. UHF-C R Equip.

   In Stock ( ) Yes ( ) No.
   ( ) a. Crystal Pick-ups.
   ( ) b. Magnetic Pick-ups.
   ( ) c. Phonograph Motors.
   ( ) d. Playback Arms.
   ( ) e. Record Changers.
   ( ) f. Stylus.
   ( ) g. Turntables, complete, Pre-Amplifiers, see 11.

    In Stock ( ) Yes ( ) No.
    ( ) a. Incandescent.
    ( ) b. Neon.

11. Plastics.
    In Stock ( ) Yes ( ) No.
    ( ) a. Raw Powders for Moulding.
    ( ) b. Rods.
    ( ) c. Sheets.

12. Point To Point Communication Equipment.
    In Stock ( ) Yes ( ) No.
    ( ) a. Aircraft & Airport Equipment.
    ( ) b. Citizen Radio.
    ( ) c. Emergency Communications.
    ( ) d. Fleet Dispatching.
    ( ) e. Police & Fire Department Equipment.
    ( ) f. Ship to Shore Equipment.
    ( ) g. Telemetering Equipment.

13. Power Supplies.
    In Stock ( ) Yes ( ) No.
    ( ) a. Electrically Powered.
    ( ) b. Gasoline Driven.
    ( ) c. Voltage Regulated Output types.

54. Receivers.
    In Stock ( ) Yes ( ) No.
    ( ) a. Broadcast.
    ( ) b. Communications.
    ( ) c. Fixed Frequency.
    ( ) d. Frequency Modulation.
    ( ) e. Radar.
    ( ) f. Special Purpose.
    ( ) g. Television.
    ( ) h. UHF-VHF.

55. Recording Equipment.
    In Stock ( ) Yes ( ) No.
    ( ) a. Disc Recorders.
    ( ) b. Magnetic Tape Recorders.
    ( ) c. Magnetic Wire Recorders.

56. Recording Accessories & Supplies.
    In Stock ( ) Yes ( ) No.
    ( ) a. Blanks.
    ( ) b. Cutting Needles.
    ( ) c. Disc Recording Heads.
    ( ) d. Magnetic RecordingPlayback & Blazing Heads.
    ( ) e. Magnetic Recording Tape.
    ( ) f. Magnetic Recording Wire.

57. Rectifiers.
    In Stock ( ) Yes ( ) No.
    ( ) a. Metallic.
    ( ) b. Vacuum Tube, Regulators, Voltages, see 74.

58. Relays.
    In Stock ( ) Yes ( ) No.
    ( ) a. Hermetically sealed.
    ( ) b. Instrument.
    ( ) c. Keying.
    ( ) d. Mercury.
    ( ) e. Power Control & Overload.
    ( ) f. Stepping.
    ( ) g. Telephone Types.
    ( ) h. Time Delay.

    In Stock ( ) Yes ( ) No.
    ( ) a. Automatic Tuning Mechanisms.
    ( ) b. Flexible Shafts.
    ( ) c. Remote Controls.
    ( ) d. Switching Functions.
    ( ) e. Servo-Mechanisms.

60. Resistors.
    In Stock ( ) Yes ( ) No.
    ( ) a. Carbon Fixed.
    ( ) b. Carbon Variable.
    ( ) c. Potentiometers.
    ( ) d. Precision.
    ( ) e. Printed Circuit.
    ( ) f. Rheostats.
    ( ) g. Vacuum Sealed.
    ( ) h. Wire Wound, Fixed.
    ( ) i. Wire Wound, Variable.

61. Schools & Institutions, Technical.

62. Sockets, Vacuum Tube.
    In Stock ( ) Yes ( ) No.
    ( ) a. Receiving Tube Types.

63. Solder.
    In Stock ( ) Yes ( ) No.
    ( ) a. Acid Cored.
    ( ) b. Plain.
    ( ) c. Precious Metal.
    ( ) d. Pre-forms.
    ( ) e. Rosin Cored.
    ( ) f. Special Types.

64. Switches.
    In Stock ( ) Yes ( ) No.
    ( ) a. Band Switches.
    ( ) b. Circuit Breaking.
    ( ) c. Key.
    ( ) d. Mercury Switches.
    ( ) e. Momentary Contact.
    ( ) f. Power.
    ( ) g. Precision Snap-Acting.
    ( ) h. Rotary.
    ( ) i. Time Delay.
    ( ) j. Toggle & Push Button.

65. Television Equipment.
    In Stock ( ) Yes ( ) No.
    ( ) a. Cameras.
    ( ) b. Camera Chains.
    ( ) c. Color Adaptors.
    ( ) d. Color Converters.
    ( ) e. Projectors.
    ( ) f. Studio Lighting Equipment.
    ( ) g. TV Tuners.

    In Stock ( ) Yes ( ) No.
    ( ) a. Frequency Oscillators.
    ( ) b. Distortion & Noise Analyzers.
    ( ) c. Intermodulation Distortion Analyzers.
    ( ) d. Resistance Capacity Oscillators.
    ( ) e. Square Wave Generators.
    ( ) f. Wave Form Analysis Equipment.

    In Stock ( ) Yes ( ) No.
    ( ) a. Bridges, all types.
    ( ) b. Capacitance Decades.
    ( ) c. Capacitor Testers.
    ( ) d. Multi-meters.
    ( ) e. Resistance Decades.
    ( ) f. Resistor Testers.
    ( ) g. Scleroscopes.
    ( ) h. Tube Testers.
    ( ) i. Vacuum Tube Voltmeters.
    ( ) j. Vibratin Testing Equipment.

68. Testing & Measuring Equipment: Nuclear.
    In Stock ( ) Yes ( ) No.
    ( ) a. Dosimeters.
    ( ) b. Ionization Chambers.
    ( ) c. Scalers.
    ( ) d. Scintillation Counters.

    In Stock ( ) Yes ( ) No.
    ( ) a. "Q" Meters.
    ( ) b. Signal Generators, AM.
    ( ) c. Signal Generators, FM.
    ( ) d. Signal Generators, TV.
    ( ) e. Standard Frequency Generators & Multi-Vibrators.
    ( ) f. Sweep Generators & Calibrators.

70. Transformers.
    In Stock ( ) Yes ( ) No.
    ( ) a. Audio Frequency.
    ( ) b. Hermetically Sealed.
    ( ) c. High Fidelity Audio.
    ( ) d. Power Components.
    ( ) e. Pulse Generating.
    ( ) f. Radio Frequency.
    ( ) g. Voltage Regulating.

71. Transmitters.
    In Stock ( ) Yes ( ) No.
    ( ) a. AM Broadcast.
    ( ) b. Communications.
    ( ) c. FM Broadcast.
    ( ) d. Radar.
    ( ) e. Special Types.
    ( ) f. TV Broadcast.
    ( ) g. UHF-VHF.

72. Vacuum Tubes.
    In Stock ( ) Yes ( ) No.
    ( ) a. Cathode Ray.
    ( ) b. Geiger-Mueller.
    ( ) c. Iconsopes.
    ( ) d. Image Orthicon.
    ( ) e. Industrial Types.
    ( ) f. Kinescopes, Black & White.
    ( ) g. Kinescopes, Color.
    ( ) h. Klystrons & Magnetrons.
    ( ) i. Phototubes.
    ( ) j. Pirani Tubes.
    ( ) k. Receiving Types.
    ( ) l. Rectifiers.
    ( ) m. Special Purpose.
    ( ) n. Thyatrons.
    ( ) o. Transmitting Types.
    ( ) p. Voltage Regulators.

73. Vacuum Tube Component Parts.
    In Stock ( ) Yes ( ) No.
    ( ) a. Anodes.
    ( ) b. Envelopes, Glass.
    ( ) c. Envelopes, Metal.
    ( ) d. Grids.
    ( ) e. Guns—Gun Parts.
    ( ) f. Pins—Probes.

74. Voltage Regulators.
    In Stock ( ) Yes ( ) No.
    ( ) a. Automatic.
    ( ) b. Manually Controlled.

75. Waveguides.
    In Stock ( ) Yes ( ) No.
    ( ) a. Couplings.
    ( ) b. Flexible Types.
    ( ) c. Rigid Types.

76. Waxes, Potting & Sealing Compounds.
    In Stock ( ) Yes ( ) No.

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Rm. 707, 303 West 42nd St., New York 18, N.Y.

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To whom in your organization should we direct correspondence concerning:
Product Data __________________ Advertising __________________

IRE Yearly Convention ___________________________
HF and UHF power leakage positively and economically controlled by new gasket material

The unique combination of controlled resilience, stability and conductivity found in Metex “Electronic Weather Stripping” makes it particularly effective as a shielding material for such electronic applications as radar equipment, high frequency heating, television broadcasting and high frequency communication.

It is available in strips or in die-formed gaskets of various shape, size and volume required by the particular application. Economical in cost, the use of this material permits further savings in assembly time and eliminates much costly machining of closure surfaces that would normally be required.

**Metex “Electronic Weather Stripping”**

The base material is a knitted—not woven—wire mesh which is made from any metal that can be drawn into wire. Knitting produces a mesh consisting of a multiplicity of interlaced loops which increase the residual resilience of the wire and, by their hinge-like action, permit freedom of motion without loss of stability.

These characteristics are retained even when multiple layers of this mesh are compressed to form gaskets or strips. The result is a compressible, resilient, cohesive, conducting material with a large internal surface area. Where hermetic sealing is also required, these gaskets are made in combination with neoprene or similar materials.

**Applications**

Among the varied applications where Metex “Electronic Weather Stripping” has already proved its effectiveness and economy are: Air craft pulse modulator shields, wave-guide choke-flange gaskets, shielding metal housings, replacing beryllium-copper bungs and springs on TR or ATR tubes, and ignition shielding to prevent radio noise interference.

The facilities of our engineering department are available at any time to assist you in determining the possible adaptability of “Electronic Weather Stripping” to your specific requirements. A letter, addressed to Mr. R. L. Hartwell, Executive Vice President, and outlining briefly your particular problem, will receive immediate attention. No obligation, of course.

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