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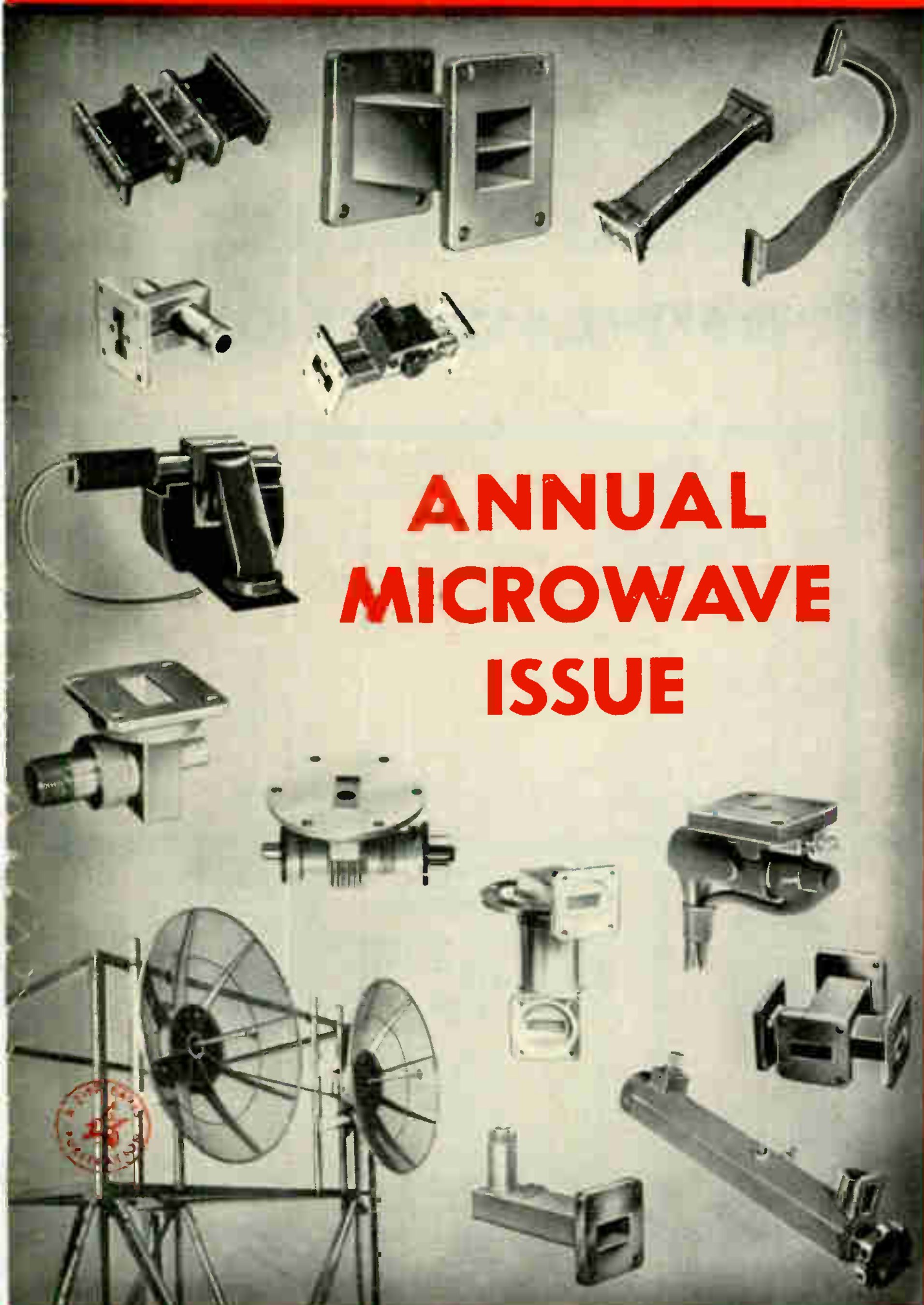
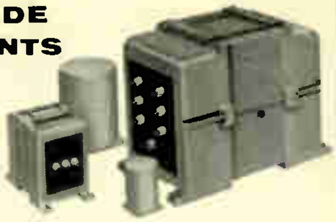


APRIL, 1955

DEPARTMENTS

TELEVISION • ELECTRONICS • COMMUNICATIONS • AUDIO • MICROWAVES • RADAR • RESEARCH

COMMERCIAL GRADE POWER COMPONENTS



CG power components are conservatively designed for long, continuous duty, life. Their rugged mechanical structure is matched by high insulation safety factors permitting 250% applied voltage tests.

Type No.	Application	High Volt.	DC Volt.	DC ma.	Filaments
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CG-302	Plate	950-750-0-750-950	760/610	360	
CG-308	Plate	3500-3000-2400-0 -2400-3000-3500	3000/2500 2000	500	
CG-315	Bias	Tapped for any DC voltage from 15 to 100 volts within 6%-250ma			
CG-422	Power & Bias	435-365-0 -365-435 125-0-125		125 25	5V-3A, 5V-2A, 6.3VCT-3A 2.5VCT-5A
CG-33	Filament	2000V Test	500V working		6.3VCT-4A

Type No.	Application	Induct. Henries at rated DC ma.	DC Resist. Ohms	DC ma.	Test Voltage
CG-40	Filter Choke	10	110	200	1750
CG-44	Filter Choke	30	400	100	1750
CG-48C	Filter Choke	50	2200	50	1750

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CG-134	Input, line to 1 grid humbucking	50, 200, 500	80.000
CG-137	Mixing	50, 200, 500	50, 200, 500
CG-140	Low Level Output, Triode plate to line	15,000	50, 200, 500
CG-19	Output, 6V6, Triode:6L6, 5881 20 watts max.	6,000/10,000	500, 200, 16, 8, 5, 3, 1.5
CG-2L6	Output, 6L6's, AB1, 5881 30 watts max.	9,000	500, 200, 16, 8 5, 3, 1.5
CVP-1	Varimatch outputs for P.A. 12 watts	3000, 5000, 6000, 7000, 8000, 10,000, 14.000	500, 200, 16, 8 5, 3, 1.5
CVP-2	Varimatch output for P. A 30 watts	3000, 5000, 6000, 7000, 8000, 10,000, 14 000	500, 200, 16, 8 5, 3, 1.5
CVM-0	Varimatch modulator, 12 watts	500 to 20,000	30 000 to 300

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R-42	125 watt capacity	3	3	3½	5
R-43	175 watt capacity	3¼	3¼	3⅞	5½
R-44	250 watt capacity	3⅞	3¼	3⅞	6½
R-45	500 watt capacity	4⅛	3⅞	4⅝	12
R-46	1200 watt capacity	6⅜	3⅞	4⅝	18
R-64	2500 watts, no cord	10½	4¾	6¾	30

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R-79	60, 70, 80, 90, 100, 110, 120, 130, 140	115	300	7	4	4¾	9
R-80	60, 70, 80, 90, 100, 110, 120, 130, 140	115	600	10¼	4	4¾	13
R-81	60, 70, 80, 90, 100, 110, 120, 130, 140	115	1200	10¼	4	4¾	21
R-83	160, 170, 180, 190, 200, 210, 220, 230, 240	230	150	7	4	4¾	6
R-84	160, 170, 180, 190, 200, 210, 220, 230, 240	230	300	7	4	4¾	9
R-85	160, 170, 180, 190, 200, 210, 220, 230, 240	230	600	10¼	4	4¾	13
R-86	160, 170, 180, 190, 200, 210, 220, 230, 240	230	1200	10¼	4	4¾	21

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Type No.	Rating		L	W	H	Wgt. Lbs.
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R-88	18A.	2 KW.	3⅞	4⅛	4⅝	12

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R-72	40 watts	2¾	2⅝	3⅛	4
R-73	100 watts	3⅜	3¼	3⅞	6
R-74	250 watts	4⅜	3⅞	4⅝	12
R-75	600 watts	6⅞	3⅞	4⅝	20
R-76	1200 watts	8⅜	4½	5⅞	30
R-77	2500 watts (no-cord)	12	7	9	70

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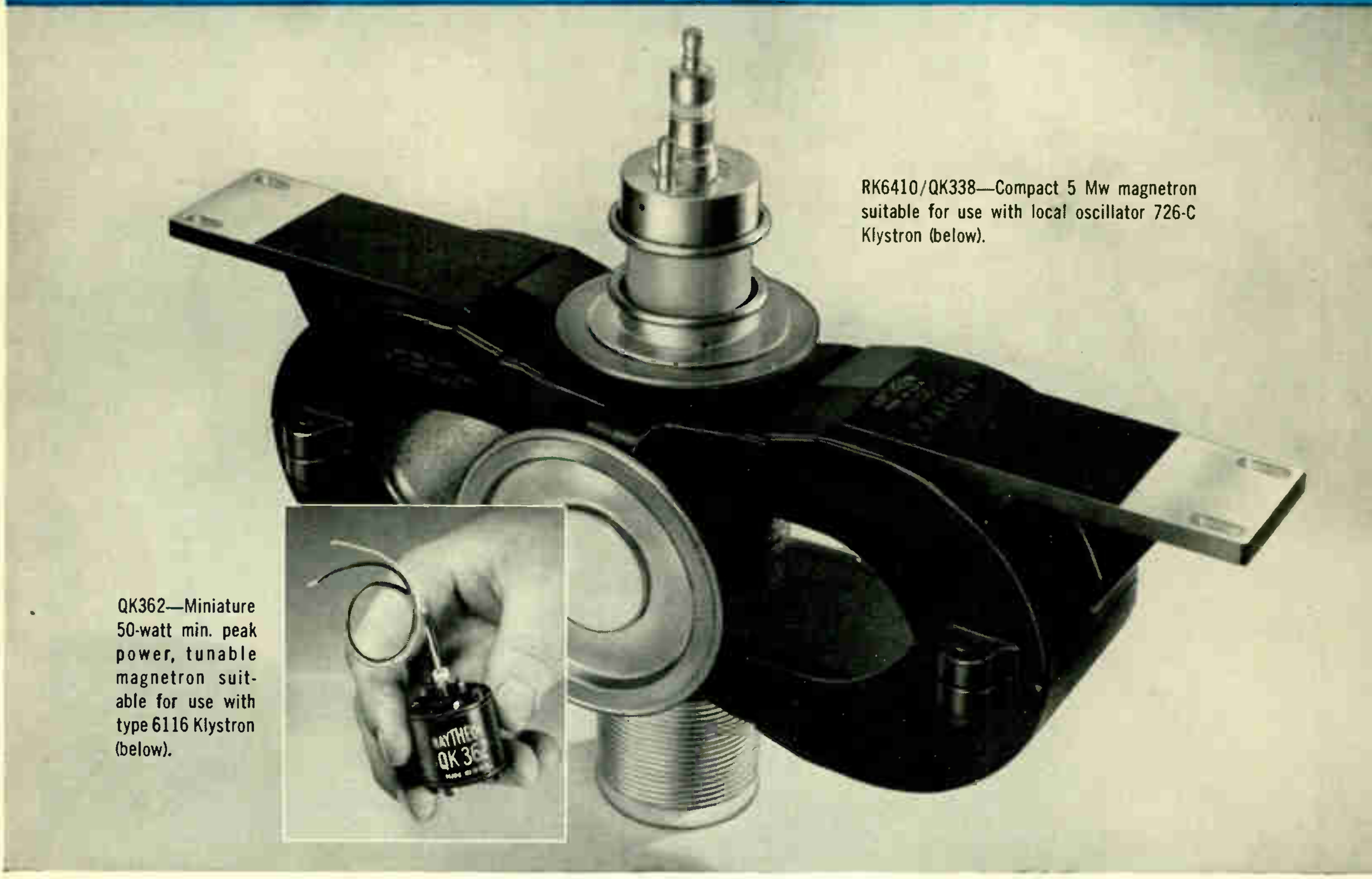

RK6410/QK338—Compact 5 Mw magnetron suitable for use with local oscillator 726-C Klystron (below).

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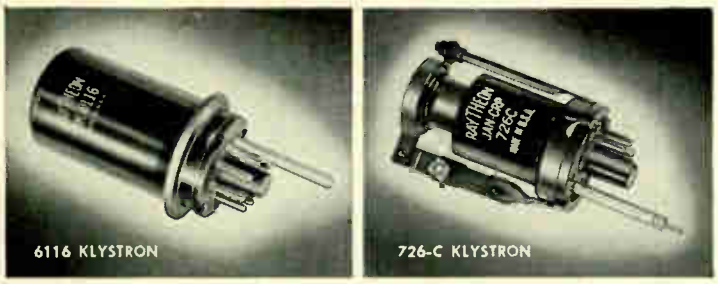

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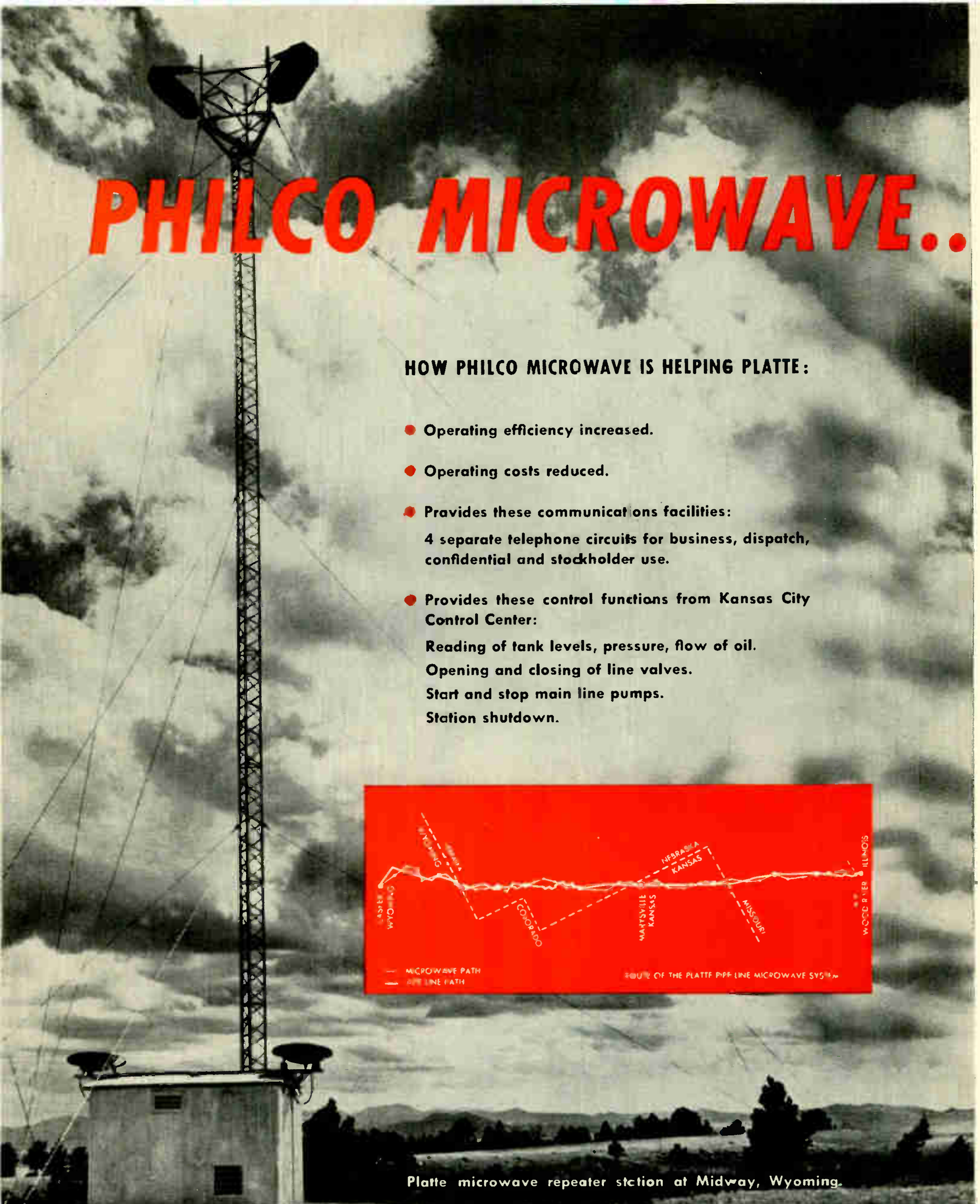

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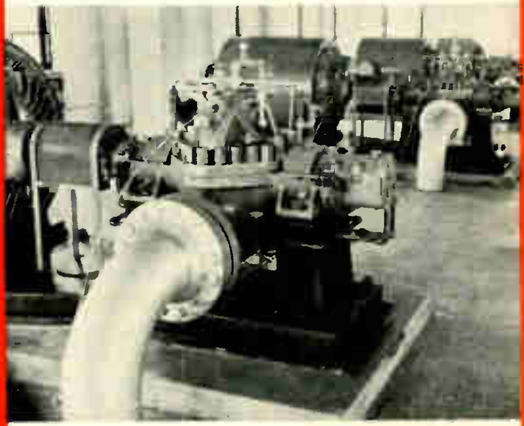
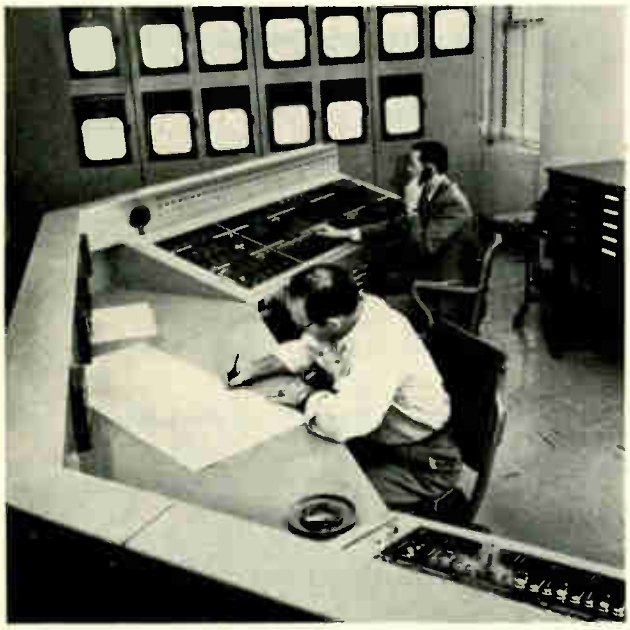


Pipe line pump station operated by microwave.



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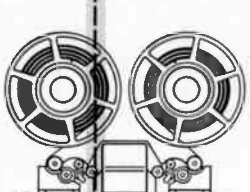

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Jan. 20, 1955

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KEEPING UP WITH MICROWAVES

A GUEST EDITORIAL

By W. W. MUMFORD,* Chairman

IRE Professional Group on Microwave Theory and Techniques

MICROWAVES are playing an ever-increasing role in the communications field. Over 30,000 route miles are already being used in the United States by communication companies, industrial and transportation concerns, and the military agencies. *Bell System* microwave facilities alone provide more than 6,500,000 miles of telephone circuits and 48,000 miles of television channels. Thousands of miles of additional microwave facilities are either under construction or in the planning stage. In addition to voice and television transmission, microwave systems are being used for services such as teletype, telemetering and remote control. The military agencies are installing an increasing amount of microwave equipment for national defense. With such expansion in the uses of microwave, those of us who are responsible for the design and installation of these systems must keep abreast of the art in order that new systems may contain the latest advances, resulting in improved quality, greater dependability and lower cost.

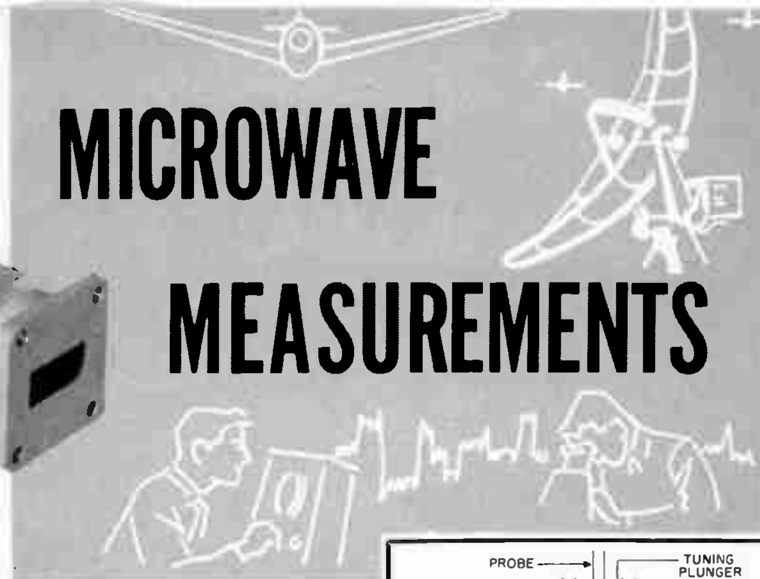
There are many ways of keeping abreast of the art, the chief of which is to absorb the information appearing in all of the available publications dealing with the subject as soon as they appear. One example of such a publication is this annual Special Microwave Issue of RADIO-ELECTRONIC ENGINEERING which contains so many pertinent papers. Another example of a publication which deals entirely with microwaves is the IRE Transactions of the Professional Group on Microwave Theory and Techniques (PGMTT). During 1954, these Transactions contained a total of 228 pages devoted to highly specialized microwave papers, and in 1955 the number of pages is expected to be at least double that amount.

Another way of keeping abreast of the art is to attend conventions, symposia and other technical meetings. For example, there is the annual IRE National Convention held in March; in 1954, one whole day was devoted to microwaves and ten fine papers were presented. Last October, there was a three-day Symposium on Microwave Strip Circuits at Tufts College. In November, the Polytechnic Institute of Brooklyn held a three-day Symposium on Modern Advances in Microwave Techniques.

In addition to these large symposia, there are local meetings sponsored by Chapters of PGMTT under the guidance of local IRE Sections. Specialized meetings and inspection tours have proven to be very popular with those interested in microwaves who are located in the eight IRE Sections where Chapters now thrive. In general, the objectives of PGMTT are scientific, literary and educational in character. It strives for the advancement of the theory and practice of radio engineering and of the allied arts and sciences, and the maintenance of a high professional standing among its members. The chief objective of the Group is to disseminate up-to-date information to "microwave men" by means of sponsored meetings and published papers.

It is hoped that by means of the continued dissemination of such up-to-date information through the various media available the microwave art will advance even more rapidly in the future than it has in the past, and that our capacity for communication will become ever greater.

*Bell Telephone Laboratories, Whippany, New Jersey



MICROWAVE MEASUREMENTS

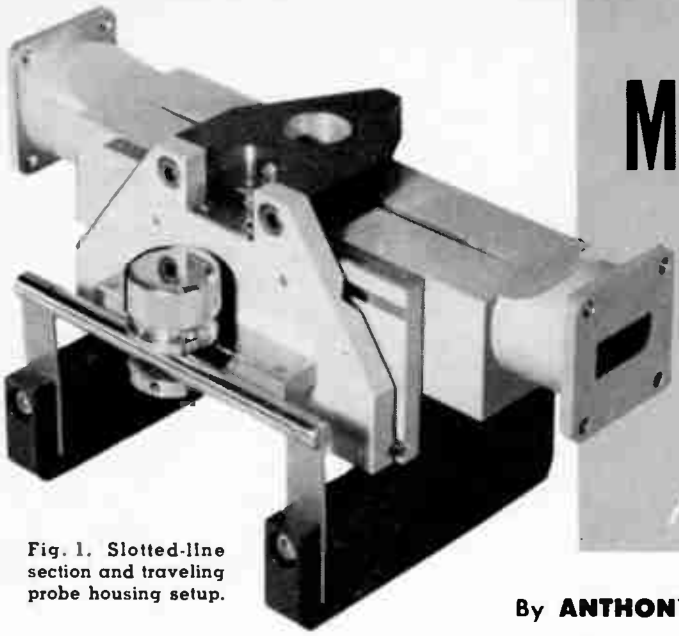


Fig. 1. Slotted-line section and traveling probe housing setup.

By **ANTHONY B. GIORDANO**

Microwave Research Institute
Polytechnic Institute of Brooklyn

Measurement of standing-wave patterns, frequency, power and attenuation is discussed, together with devices used.

THE spectacular trend toward the utilization of higher and higher frequencies has resulted in broader analytic concepts and novel experimental and measuring techniques[1,2,3,4,5]. No longer can one speak of unique currents and voltages, but rather of wave intensities and current streamlines. In fact, it becomes convenient to regard electrical transmission as residing in the space bounded by conductors and not within the conductors themselves. Moreover, this concept is most general and applies equally well to either a single conductor or a double conductor transmission system. Both are guide systems and the supported phenomena are guided electromagnetic waves completely predicted by Maxwell's wave theory.

As an analytic description of guided waves is available in published literature, it will not be given here. Instead, this article will be concerned with the devices used in the microwave field to measure standing-wave patterns, wavelength (or frequency), power and attenuation, together with the methods which are best employed in making these measurements.

Standing-Wave Patterns

A device known as a standing-wave detector enables one to measure standing-wave patterns[6]. It consists of a slotted-line section, a traveling probe, and a detector. The slotted-line section possesses a narrow longitudinal slot milled in one face of the guide. Location of the slot is such that the disruption of the surface current streamlines is a minimum and its presence does not appreciably modify the original field pattern. Its length usually corresponds to a few wavelengths so that several maxima and minima can be observed. The traveling probe is generally a short metallic rod which samples the intensity of the electric field through the slot while riding on a movable carriage. A typical rectangular guide combination of slotted-line section and traveling probe housing is shown in Fig. 1.

As the probe couples to the electric field, a voltage is induced proportional to the insertion depth of the probe within the guide. A variety of devices is available for detecting this effect, such as thermistors, bolometers, crystals, thermocouples, etc. However, the crystal diode is preferred since it is simplest in construction and most sensitive.

Figure 2 shows a typical arrangement of a standing-wave detector. The probe is connected to a screw mechanism which provides the motion for controlling its depth. Tuning is accomplished by a sliding short-circuit plunger which introduces a reactance to match the probe and crystal for maximum power transfer. The crystal diode is mounted in a short length of coaxial line (or wave guide line). A path for the rectified r.f. current of the crystal is established by introducing a bypass capacitor as a mica ring. As indicated in Fig. 2, this current appears across terminals a-b.

Construction of such an instrument requires considerable skill. This is especially true for the shorter wavelengths. As the probe moves along the slot, its insertion length within the guide must not vary; otherwise irregularities are superimposed on the standing-wave pattern. Likewise, the guide used must possess an inner surface which is uniform to a high degree. The position of the probe must be accurately controlled to achieve repeatable results.

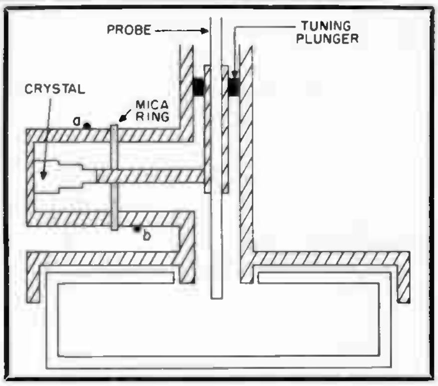


Fig. 2. Standing-wave crystal detector.

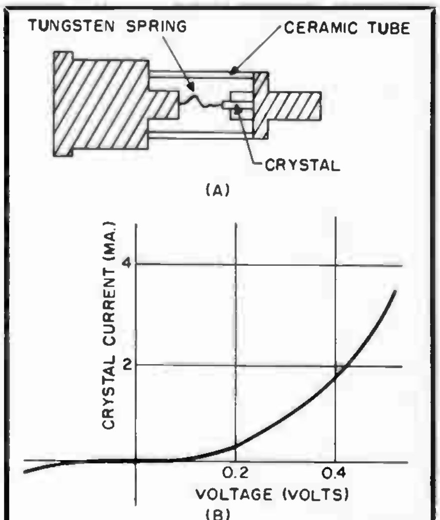
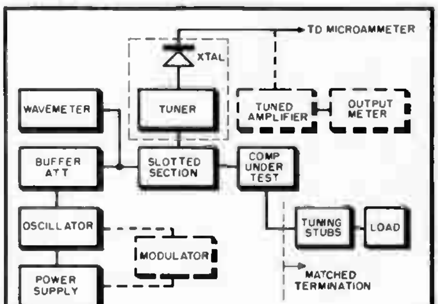


Fig. 3. Structure (A) and current-voltage characteristic (B) of typical crystal diode.

Fig. 4. Unmodulated (solid line) and modulated (dotted line) arrangements for measuring VSWR with slotted-line detector.



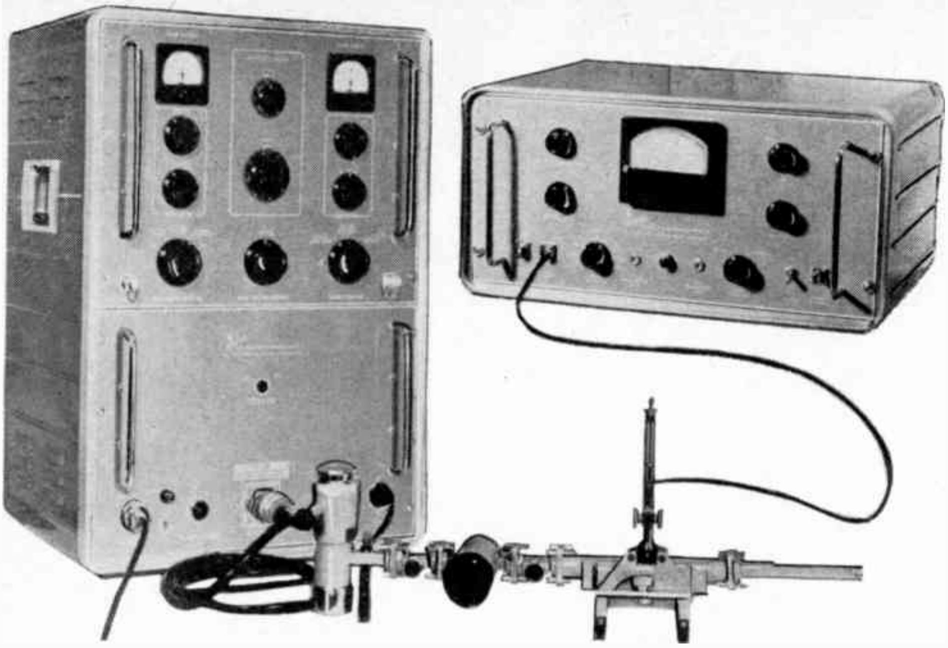


Fig. 5. Setup for measuring VSWR with modulated signal generator system.

Voltage induced in the probe is proportional to its exposed length in the electric field. By increasing this length, a greater sensitivity is realized. However, if inserted too far, the probe may set up an appreciable reflection which will distort the standing-wave pattern[7].

The crystal diode consists of a semiconducting material, usually silicon or germanium. The structure of a typical unit is shown in Fig. 3A, and its current-voltage characteristic is illustrated in Fig. 3B. As noted, the current response of the crystal is nearly square-law with voltage. Thus, the current indication is proportional to the voltage squared or power. This property usually holds true for currents of less than 15 ma., which corresponds to an r.f. power input of approximately 20 μw. Most crystals in use are made of type N silicon, which conducts more readily when the whisker is negative.

Unmodulated Signal

Figure 4 shows a measuring arrangement which utilizes an unmodulated signal generator. A reflex-type cavity klystron is usually employed as an r.f. reference. Frequency pulling is minimized by the buffer attenuator. A transmission cavity-type wavemeter is used for measuring wavelength, and the indicating meter takes the form of a suspension-type galvanometer with an Ayrton-Mather shunt. The matched termination is usually tuned to yield a VSWR of better than 1.02.

In performing measurements, the line setup is tuned for a desired frequency with the component under test removed. The procedure involves matching the signal source to the line, adjusting and matching the probe of the standing-wave indicator for minimum depth and maximum usable output, and matching the load for minimum VSWR. The next step is to insert the element under test. Maximum (G_M) and minimum (G_m) values of the galvanometer deflection corresponding to the standing-wave pattern should be noted as the probe carriage is moved along the slotted-section. Then, the position of the first minimum (z_m) should be noted from the matched termination and the distance between minima (z_D) measured. These measurements yield the following information:

$$\text{VSWR} = \sqrt{G_M/G_m} = \rho \quad . \quad . \quad . \quad (1)$$

Γ = magnitude of reflection coefficient

$$= \frac{\rho - 1}{\rho + 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Φ = phase angle of reflection coefficient

$$= \frac{4\pi}{\lambda_g} z_m - \pi \text{ radians} \quad . \quad . \quad . \quad (3)$$

Z_L = normalized input wave impedance of element under test[8]

$$= \frac{1 + \Gamma \varepsilon^{+j\Phi}}{1 - \Gamma \varepsilon^{-j\Phi}} \text{ ohms} \quad . \quad . \quad . \quad . \quad (4)$$

$$\lambda_g = \text{guide wavelength} = 2\, z_D. \quad . \quad (5)$$

Modulated Signal

If a greater sensitivity of the crystal output is desired, the source can be audio-modulated and the crystal output amplified by a tuned a.f. amplifier such as the TAA-16, H-P 415A, PRD Type 275, etc. These units employ three stages of amplification with a maximum full-scale sensitivity of approximately 5 μv. from 500 to 5000 cps on selective operation.

Fig. 6. Coaxial cavity frequency meter.

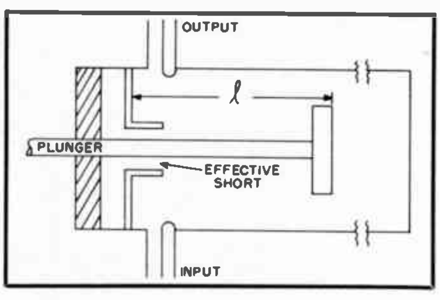


Fig. 7. Cross-sectional view of a TE_{011} mode cavity resonator frequency meter.

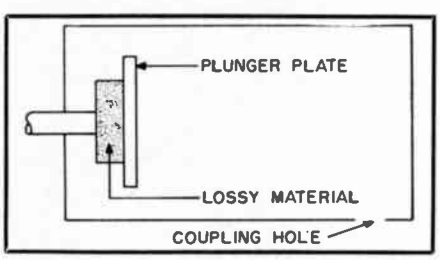
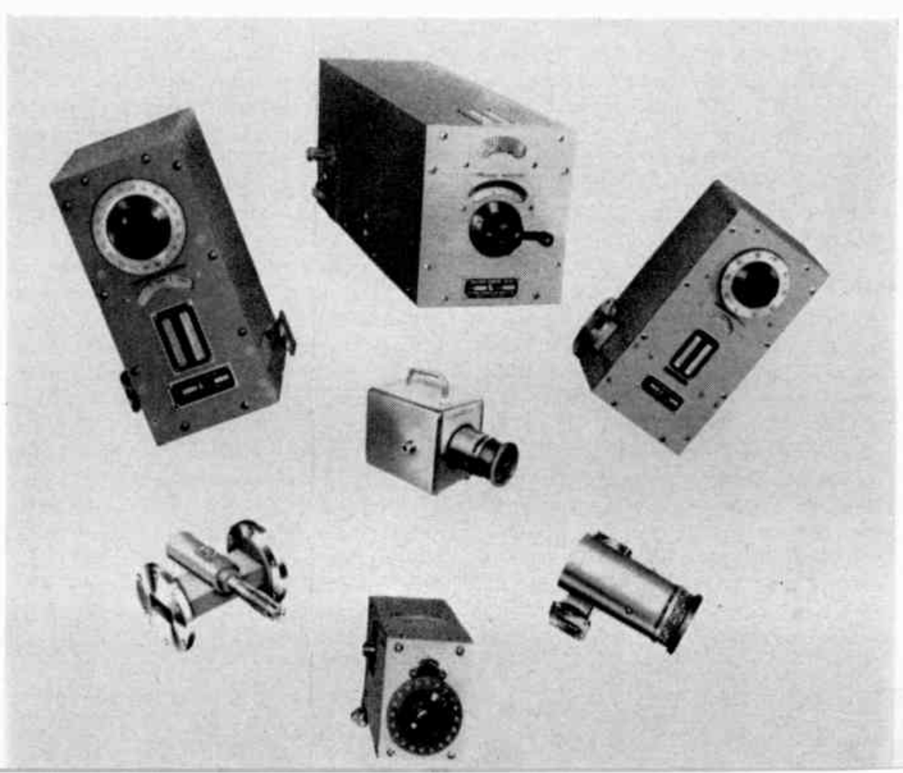


Fig. 8. Array of cavity frequency meters with accuracies from 0.01% to 0.1%.



They can be operated either wide-band or selective. Selective operation is most sensitive and allows the exclusion of noise interference. The amplifier output meter scale is calibrated to read directly in VSWR when the amplifier is fed by a square-law detector such as a crystal diode.

Modulation is provided by a square wave, usually 1000 cps, to prevent frequency modulation of the klystron output. The envelope frequency of the pulsed output power corresponds to the modulation frequency. Crystal output is applied to the amplifier which is sharply tuned to pass only the modulation frequency, eliminating interference which might otherwise be present in a high-gain amplifier of this type. Since the amplifier is linear, the meter response is thus linear in power. The scale is so calibrated that if the pointer is set to full scale when the probe rests on a voltage maximum the scale reads VSWR directly when the probe is moved to a voltage minimum.

Since the crystal square-law characteristic holds true only for small powers, the amplifier should be run at almost full gain so that full-scale reading corresponds to very low probe power. The dashed portions of Fig. 4 indicate the additions necessary to set up a modulated signal generator measurement system and Fig. 5 shows the actual components used.

Normal precautions in performing slotted-line measurements include an accurate knowledge of the detector response law and stability of the signal source. However, major inherent errors are related to the probe insertion, the slot distortions, and structural irregularities.

Wavelength

The most convenient method of measuring wavelength[8] is by means of selectively tuned cavity resonators. Tunable cavity resonators may be used either as transmission-type or reaction-type meters. The technique involves measuring the distance between two adjacent resonance positions of the plunger. This distance corresponds to half a wavelength. In the transmission-type meter, energy is coupled into the cavity by a loop and energy is extracted from the cavity by a detector. When the cavity is tuned to resonance, maximum energy is detected. In the reaction-type meter, the cavity impedance is in series with the detector. As the cavity is tuned through resonance, a dip occurs in the detected energy since the cavity absorbs maximum energy at resonance.

Cavities for the measurement of wavelength should have a geometrical shape that can be economically fabricated, a single-mode broadband response over the required frequency range, and a high Q. These requirements are fulfilled by open-circuited coaxial and circularly cylindrical cavities.

Frequency Meter

For the lower microwave frequency range starting at about 450 mc., coaxial cavity resonators are preferred since they are small in physical size. The cross-section details of such a meter are shown in Fig. 6. A noncontacting short circuit is used to eliminate variations in contact resistance of shorting fingers. Capacitive end loading is often used to linearize the plunger movement. Above 10,000 mc., these cavities are limited by low Q and greatly decreased plunger travel.

The circularly cylindrical cavity resonators are designed for frequencies that start at about 1000 mc. and extend upward to 40,000 mc. The mode most frequently used is the TE_{011} type, and the resulting Q is extremely high. Construction of such a cavity is shown in Fig. 7. A simple noncontacting end plate is utilized to vary the cylinder length since the conduction currents of the TE_{011} mode do not exist across the end walls of the cavity. The lossy material behind the plunger attenuates unwanted modes which may couple into this area through the plunger gap.

Figure 8 contains an array of cavity frequency meters with accuracies ranging between 0.01 and 0.1%. Factors which influence the accuracy are mainly temperature, humidity, and external reactive loading.

Power

Accurate detectors of microwave power[9] are basically thermal devices which compare the heating generated by microwave power to that generated by a low frequency power source. These devices are specifically known as thermocouples, calorimeters, and bolometers. Of the three varieties, bolometers are the most popular.

Bolometers are temperature-sensitive resistance elements. As a bolometric element absorbs power, its resistance changes. This change can be either measured and calibrated in terms of power or an equal resistance change can be effected by d.c. or low frequency power. Various types of elements are used. The corresponding units are known as *barretters*, *thermistors*, and *film-type bolometers*.

A *barretter*[10, 11] is composed of a short piece of fine metal wire whose resistance increases with temperature. More sensitive types of barretters utilize Wollaston wire, very thin platinum coated with silver. The barretter element is prepared by stretching the Wollaston wire to reduce the cross section of the platinum core to the desired value and then etching off the silver. Final diameter is in the range of 40 microinches, and average sensitivity is approximately

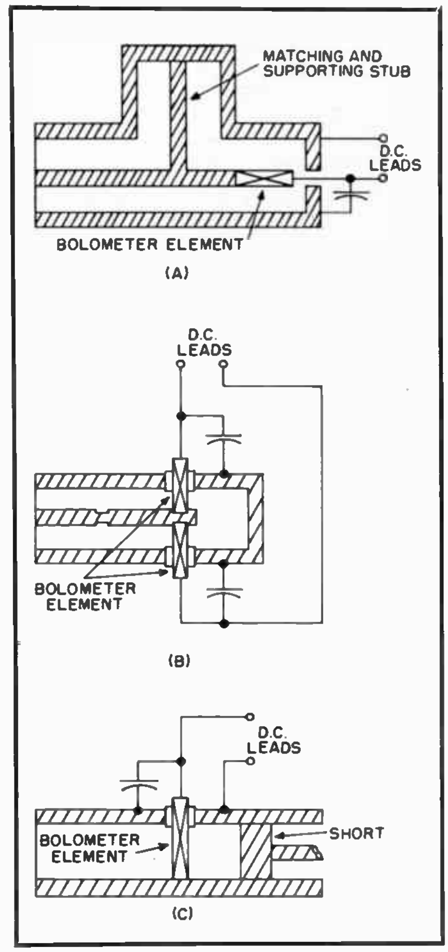


Fig. 9. Basic bolometer mounts. (A) Fixed-tuned, coaxial narrow-band series mount. (B) Fixed-tuned, coaxial broadband parallel mount. (C) A tunable wave guide mount.

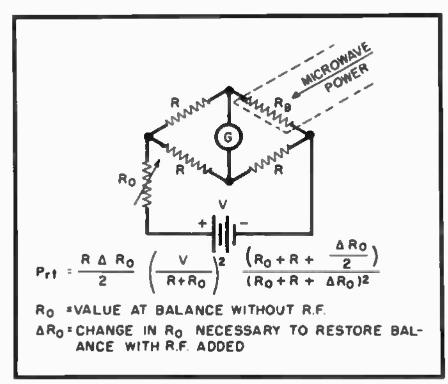
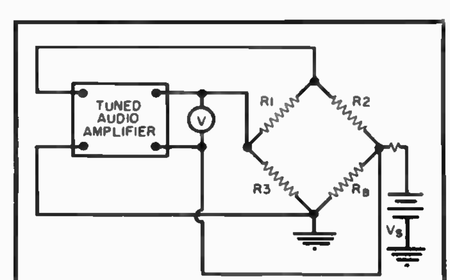


Fig. 10. Wheatstone bridge circuit for measuring microwave power in a bolometer.

Fig. 11. Self-balancing circuit for measuring microwave power in a bolometer (R_B).



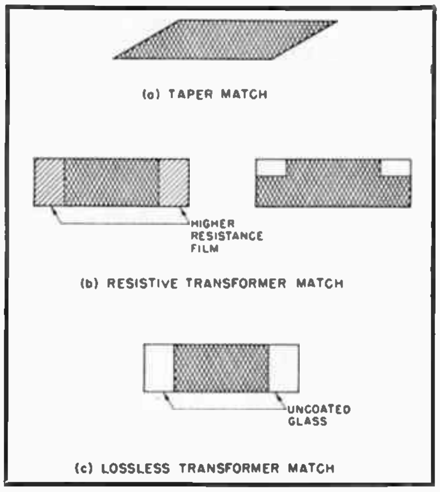


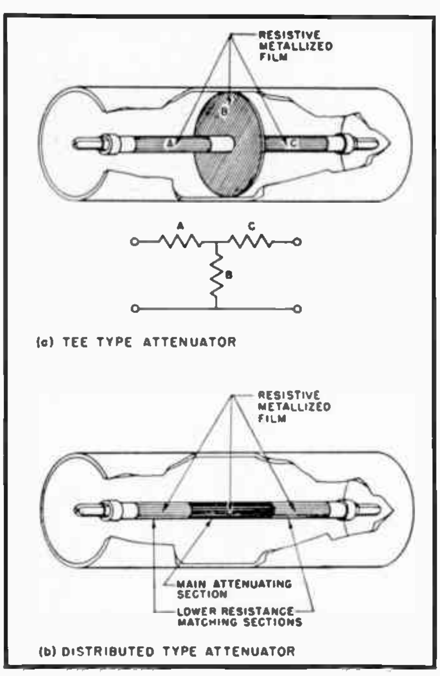
Fig. 12. Methods of matching resistive elements in wave guide attenuators.

5 ohms/mw. Though barretters are limited to low powers, the range is easily extended by means of broadband attenuators.

Careful studies have been made to evaluate the assumption that equal amounts of r.f. and d.c. power produce the same resistance change in barretters. It has been shown that the discrepancy between these heating effects is negligible if the heat lost by the wire to its surroundings is primarily in the form of convection loss. If the ratio of wire length to wavelength of the microwave power is kept below 0.1, this error can be kept to less than 2%.

A *thermistor* consists of a resistance element made up of a semiconducting mixture of metallic oxides combined with finely divided copper particles to control its resistivity. It is usually in the form of a bead having a diameter of about 0.02"; two fine wires are embedded in the bead which is then sintered. Thermistors have a high negative temperature coefficient of resistance resulting in average sensitivities of the order of 50 ohms/mw.

Fig. 13. (A) Tee and (B) distributed type resistive film coaxial attenuators.



Thermistors may be operated over a wide resistance range. Near burnout, the resistance is very low and the resulting mismatch in a guide system prevents absorption of excessive power. This self-protecting property is highly desirable. However, thermistors cannot be uniformly manufactured. Sensitivity and normal resistance vary from unit to unit. Furthermore, the resistance vs. power curves are quite nonlinear as compared to those of barretters.

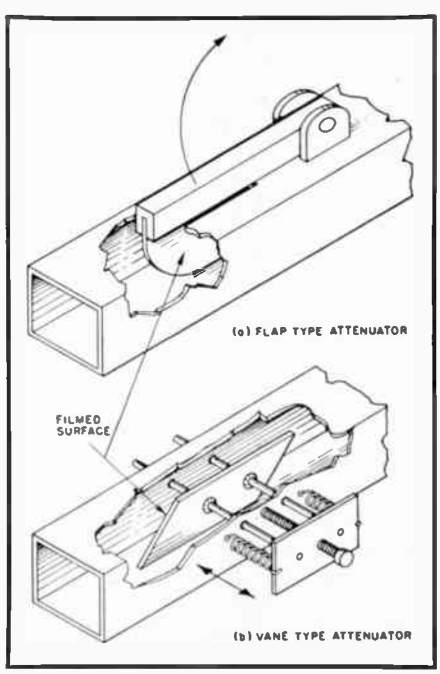
The supporting wires of a thermistor tend to reduce the incident power absorbed and introduce an appreciable error. However, the power-handling capacity of a thermistor is somewhat greater than that of a barretter.

Film bolometers are constructed of molecularly thin platinum-silver or carbon film baked onto a thin strip of glass or mica. These elements have a higher burnout power rating than either barretters or thermistors. They are well suited for a power range from 1 to 100 mw. and their average sensitivity is around 50 ohms/mw. However, film bolometers have sluggish response time.

Bolometer Bridge

When using a bolometer element, it is connected as a termination for the microwave transmission system in order to absorb the power flowing in the system. To make best use of their characteristics, bolometers are operated at resistance values which do not normally provide a matched load to the system. Therefore, an impedance-matching arrangement is usually required as part of the mount since a VSWR will result in a reflection loss. For example, a VSWR of 1.2 will result in a reflection error of about 1%. For greatest usefulness, the mount[9] should maintain a low VSWR over as broad a frequency range as possible. Basic mounts are shown in Fig. 9.

Fig. 14. (A) Flap and (B) vane type resistive film wave guide attenuators.



A method of measuring the change in bolometer resistance as it is heated by microwave power is to insert the thermal element as one arm of a Wheatstone bridge[12] as shown in Fig. 10. As illustrated, three arms contain equal resistances. Currents in these arms are kept low so as not to cause any temperature effects. The bolometer element comprises the fourth arm of the bridge.

In this method, the bridge is adjusted to exact balance by means of the external resistance R_0 which controls the d.c. bias power in the element. Without applied microwave power, the bolometer resistance is equal in value to the other arms at balance. When microwave power is applied, the bolometer resistance changes. The bridge is then restored to balance by increasing resistance R_0 by an increment ΔR_0. This increment reduces the original bias power in the element and the element is brought back to its former state. In essence a substitution process, this procedure is limited in its industrial usefulness because it is not a direct-reading method.

The self-balancing bridge shown in Fig. 11 illustrates a second method of measuring the change in bolometer resistance. In this circuit, the bridge couples the output and input of a high gain audio amplifier. The result is an audio oscillator whose output voltage automatically adjusts itself to maintain the bridge at a near-balanced condition. Thus, as the bolometer resistance increases with applied microwave power, the audio voltage is reduced until an equal amount of audio power is removed from the thermal element. The voltmeter which measures the audio voltage is then calibrated in terms of microwave power.

Attenuation

Microwave attenuators are of two types, reflective[13] and dissipative. The first type employs a wave guide which is operated below its cutoff frequency. Attenuation is achieved through mismatch which reduces the power output by reflecting a portion of the incident power, and the amount of mismatch is dependent upon the length and size of the wave guide. Such attenuators are used as primary standards. The second

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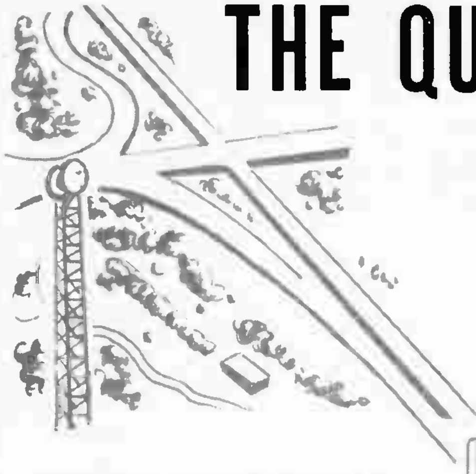
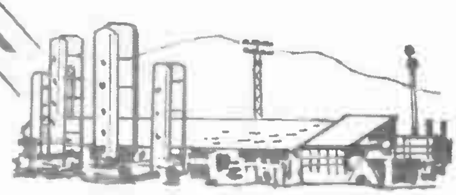


THE QUADRIPHASE MICROWAVE SYSTEM



By **SAM McCONOUGHEY**

General Electric Company

MICROWAVE radio relay, in a few short years, has become one of the most valuable "instruments" in the communication engineer's "kit of tools." The multichannel microwave system provides a communication medium comparable to other point-to-point facilities such as open-wire, cable, carrier, etc., while offering many advantages over these media. Some of these advantages lie in the lower initial investment, greater reliability and lower operating expense which microwave affords. Systems already installed throughout the United States represent an investment approximating one-hundred million dollars, thus attesting to industry's faith in the new "tool."

In order to meet the needs of this rapidly expanding market, the *General Electric Company* has developed a new and greatly improved microwave system, the UA-1-D, which is a long-haul, multichannel radio relay system designed to operate in the 1850-1990 mc. band. It is capable of providing up to 25 full duplex, voice-band (300-3000 cps) channels with a signal-to-noise-ratio of 60 db for a single hop, F1A weighting, and 45 db or better for a 32-hop system. The equivalent of a d.c. path is available with each voice channel for signaling purposes.

Design objectives of the UA-1-D system were: (1) increased reliability; (2) improved performance; (3) reduced operating expense; and (4) simplification of maintenance. The resulting features of the design are pointed out in the following paragraphs.

R.F. Equipment

Equipment comprising the r.f. portion of the new microwave system is known as the UM-3-A. Designed to operate on a full duplex (simultaneous transmission and reception) basis in the 1850-1990 mc. band, this equipment provides the basic communication medium for the UB-4-A "Quadriphase" multiplex equipment.

The UM-3-A system is comprised of certain basic units: a transmitter (UT-2-C); receiver (UR-3-C); duplexer (UE-3-A); coaxial switches (UC-3-C and UC-3-D); r.f. switching unit (UC-10-C); power supply (UP-5-A); and a blanking and switching unit (UC-4-A). This equipment is usually applied in the form of assemblies to provide terminal or repeater functions, or some combination thereof. It has been designed, as has the rest of the system, for unattended operation and infrequent maintenance.

Figure 3A illustrates the usual arrangement of the assemblies at a repeater station. At a terminal station, equipment for only one direction of transmission and reception is required. At a repeater, one set of standby equipment will suffice for a failure of either E-W or W-E equipment. Since only one pair of frequencies is used at a repeater, one for transmitting and one for receiving, only one standby transmitter and receiver is necessary. Automatic sensing and switching equipment determines the direction of operation of the standby equipment upon main station equipment failure.

Transmitter

The UT-2-C transmitter is crystal-controlled with a stability and accuracy of 0.01% of carrier frequency. It delivers a peak power output of 20 watts under pulsed carrier modulation. Figure 3B shows the tube line-up and functions of the various transmitter stages. Video input passes through amplifier-reshaper stages and then to the modulator which keys the final stage. Fault-sensing circuits are an optional item.

Many advantages over previous designs are offered by the new transmitter. Power output has been doubled, thus providing higher system gain. This gain can be used either to provide better fading margins or lower cost installations through the use of lower gain antennas and transmission line of higher loss.

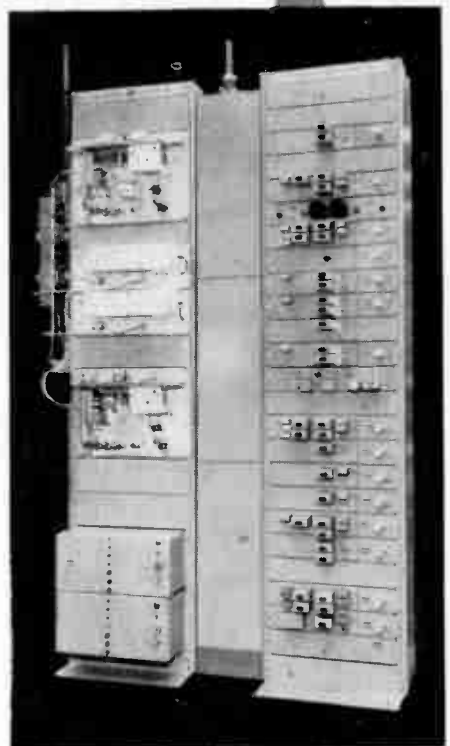


Fig. 1. Front view of UA-1-D terminal.

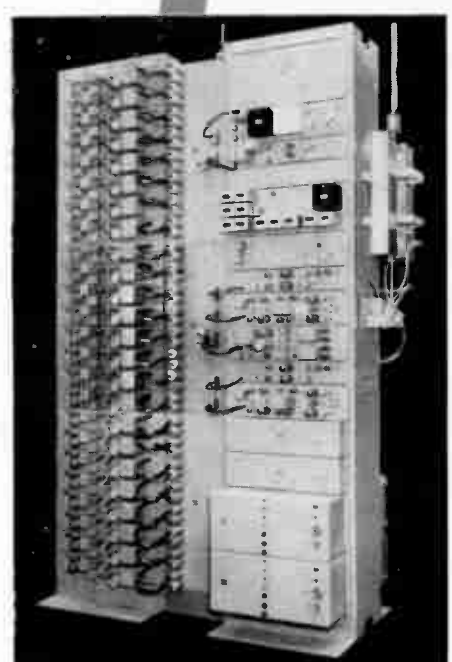


Fig. 2. Rear of microwave terminal shown in Fig. 1.

★ *Design details on a multichannel system employing a new type of PPM multiplexing.*

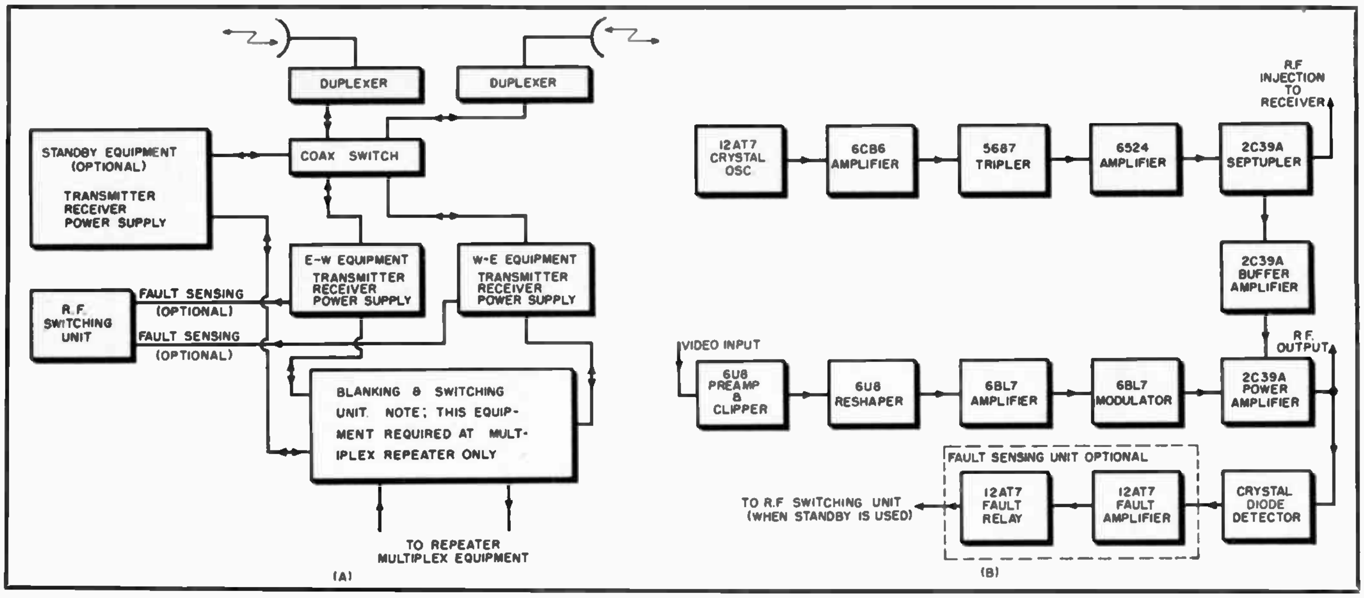


Fig. 3. Block diagrams of (A) the multiplexed repeater assemblies and (B) the various transmitter stages.

The 2C39A tube, which has a record of good performance, has been retained. This tube has a low replacement cost, high reliability and long life. System reliability is enhanced by operating all 2C39A stages at less than one-third rated plate dissipation.

Vastly improved clipping and reshaping circuits in the transmitter modulator stages insure noise-free transmitter output. These circuits use baseline and peak clipping to remove noise.

Crystal control of the transmitting frequency offers several advantages. With crystal-controlled transmitting equipment, a statement of frequency measurement need be made only once every six months in order to comply with FCC requirements. In addition, switching to standby can be immediate because no "drift-on" time is required for the system to become stabilized.

Gold-flashed, re-entrant cavities are used in the buffer and final stages in order to insure high *Q* and resistance to corrosion.

Receiver

The UR-3-C receiver is one of the outstanding accomplishments in the UA-1-D microwave system. A heterodyne receiver designed to operate in the 1850-1990 mc. band, it has a sensitivity of — 108 dbw at the multiplex threshold and a noise figure of 11 db. It derives its local oscillator energy from the transmitter just described to heterodyne down to 60 mc. for i.f. amplification.

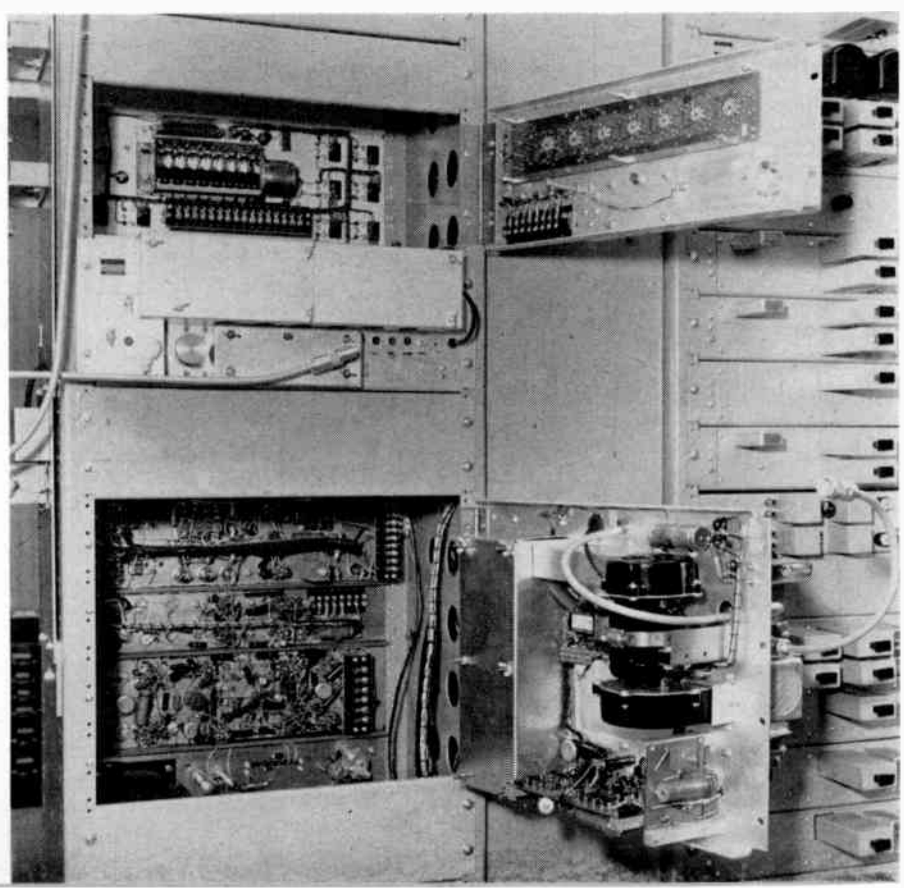
Shown in Fig. 4, the receiver employs in its input circuit a line-above-ground construction and a built-in attenuator which is continuously variable from 0 to 30 db or better. This permits an immediate check of fading margins and path performance without interruption of the system to insert lossy line or other form of attenuation.

The i.f. amplifier consists of two staggered triples preceded by a cascode input circuit. (See Fig. 5.) A double-tuned input transformer matches the r.f. mixer to the input tube of the i.f. amplifier, and a 60-db range a.g.c. is applied to all i.f. stages with the exception of the cascode amplifier. Video detection is accomplished by a diode which is then followed by a video amplifier and cathode-follower output tube. Uniformity of construction and long-term stability of the i.f. amplifier are achieved through the use of printed wiring. Typical receiver bandwidth is shown in Fig. 5.

Normally, the i.f. amplifier will not require tune-up following factory alignment. However, if field tuning need be undertaken, such line-up can be performed without a sweep generator or an oscilloscope. A calibrated signal generator and a v.o.m. similar to a *Simpson* 260 will suffice. Figure 4 (top), showing the rear of the receiver, illustrates its simplicity.

Since the crystal-controlled transmitter serves as the local oscillator for the receiver, both have the same frequency stability (0.01% of carrier frequency). The total number of tubes for a trans-

Fig. 4. Hinged panels permit access to receiver (top) and transmitter (bottom).



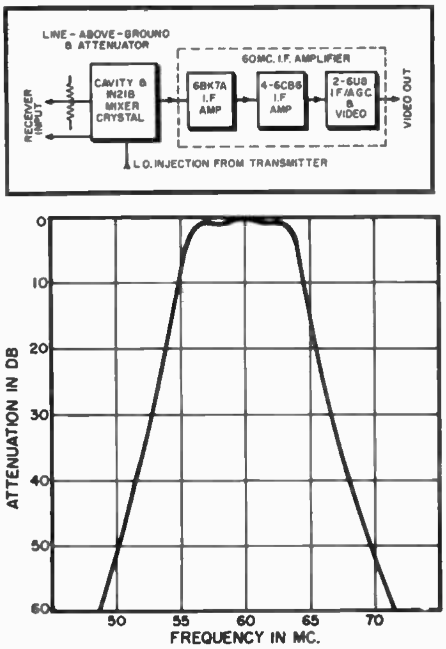


Fig. 5. Block diagram (top) and selectivity curve (bottom) of receiver.

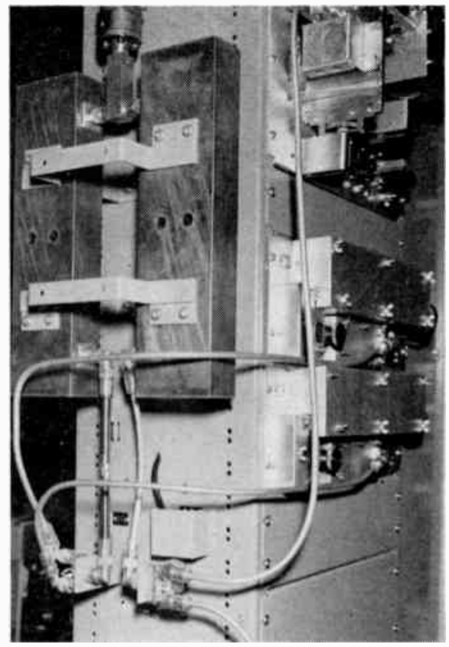


Fig. 6. Close-up of duplexer-coaxial switch assembly on the end of the rack.

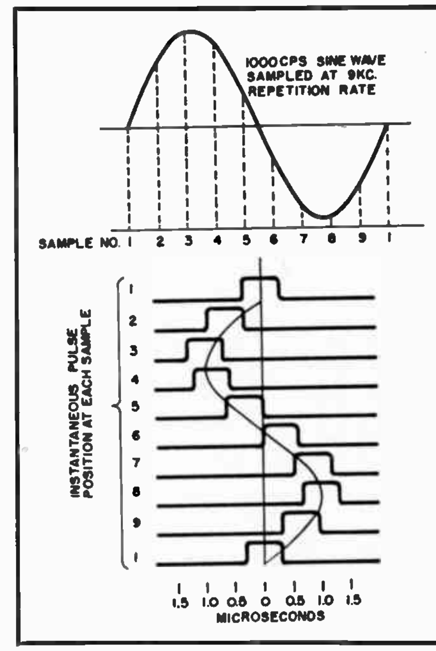


Fig. 7. A simplified drawing of the waveforms as used in PPM modulation.

mitter-receiver combination has also been greatly reduced and system reliability improved proportionately by this arrangement.

Other Units

Shown mounted on the end of the rack in Fig. 6 is the UE-3-A duplexer, which permits simultaneous operation of a transmitter and receiver on a single antenna and transmission line. Its insertion loss over the operating passband is less than 1 db. VSWR over the same passband is less than 1.5:1, and attenuation at the rejection point (60 mc.) is greater than 80 db. This unit is factory-tuned to operating frequency and does not require field adjustment.

Shorting-type coaxial switches provide an r.f. crosstalk figure of better than 45 db from 1850 to 1990 mc. Contacts of these switches are gold-plated to prevent corrosion. Aluminum-jacketed coaxial transmission line is used for all r.f. connections and prevents any r.f. spray usually encountered with even the best braided outer conductor coaxial cables. This construction serves to minimize any crosstalk at the r.f. level.

Representing another advance in microwave design, the UP-5-A power supply uses selenium rectifiers in high efficiency bridge circuits. Electronically regulated supplies are not required because all equipment has been designed to work with unregulated supplies when primary power of 115 volts, ± 5%, is furnished. The same power supply is used for both the r.f. and the multiplex systems.

Quadriphase Multiplexing

The UB-4-A multiplex system performs its multiplexing function of applying 25 voice channels to the r.f. system by the time-division (TD) method more specifically described as pulse position modulation (PPM).

In a TD multiplexing system, each channel is allocated a small portion of time in which to present or accept intelligence to or from the main carrier. In order to provide the transmission quality required by present-day standards, it is necessary that the individual channels be sampled at least twice per cycle for the highest frequency to be transmitted over each channel. The UB-4-A system uses a repetition rate of approximately 9 kc., which means that a sample is taken every 112 μsec. or nearly 2½ times per cycle in the case of the highest channel frequency (3500 cps).

With *G-E* PPM, the rate at which the channel sample crosses its normal (centered) position in the pulse train is determined by the frequency of the modulating wave, and the amount of swing about the normal position is determined by the amplitude of the modulating signal. (See Fig. 7.) D.C. and low frequency a.c. signaling are transmitted by the insertion and removal of the channel sample (pulse) at the signaling rate. Depending upon application, the channel pulse may be absent from the pulse train when not in use.

Because all channel selection and detection of intelligence is based upon the time and position relationships of the channel pulses, it is necessary to transmit a time reference. This reference, called the sync pulse, consists of three closely spaced pulses. A typical video wavetrain is shown in (1) of Fig. 8. It will be noted that the sync pulse consists of three 0.5-μsec. pulses spaced 1 μsec. apart. Channel pulses are 0.5 μsec. in duration, spaced 4 μsec. apart (centered position), and are modulated ± 1 μsec. for 100% modulation.

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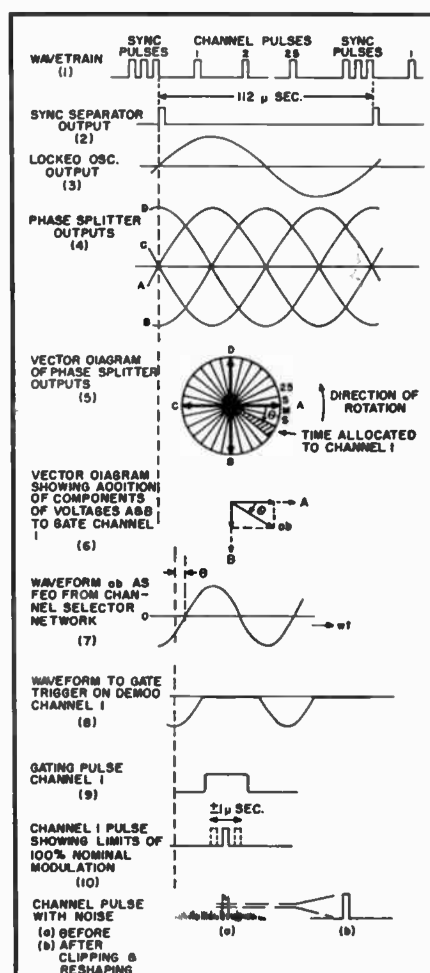
Fig. 8. Various quadriphase waveforms.



DOUBLE RIDGE WAVE GUIDE FOR WEATHER RADAR

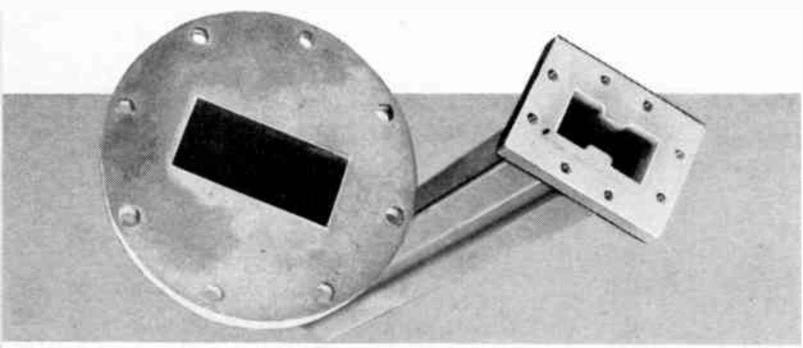


Fig. 1. Comparison of double ridge guide with standard 1" x 2" guide.

Fig. 2. Assembly of double ridge guide sections ready for installation in nose of airplane.

THE TWO most important features of double ridge wave guide are its small size and its extremely broad frequency band. These features have been combined with very good peak power performance and relatively low attenuation in a double ridge wave guide that has opened a new field in the design of wave guide installations, particularly for airborne applications where space is at a premium, light weight is a necessity, and broader frequency band coverage is important.

One of the most interesting applications of this ridge wave guide is its recent adoption by *Aeronautical Radio, Inc.* as standard wave guide plumbing for commercial airlines. Since this double ridge wave guide is for commercial airlines use, it is completely unclassified. Its use in airborne weather penetration radar systems is its first commercial application.

Design

Commercial weather penetration systems are currently in production by several manufacturers in both *X*-band (3.2 cm.) and *C*-band (5.7 cm.) frequency ranges. The problem of coordinating the installation of electrical systems in aircraft is one of the prime functions of *ARINC*; therefore, at the start of the airlines weather radar program, one of the design goals was a common medium of wave guide transmission by which a single installation of plumbing could be made in an aircraft regardless of the type of radar the airlines might wish to install. To reach this goal, a double ridge wave guide was designed which is capable of propagating over the frequency range from 5200 to 9600 mc. with a single mode operation, remarkably low losses, and good peak power-handling capabilities.

Design of this guide and its adoption by *ARINC* has made it possible for an aircraft manufacturer to install a plumbing system during the fabrication of the airplane that will function with either *X*-band or *C*-band equipment, whichever the airline that purchases the airplane prefers. The only change necessary to convert from *X*-band equipment to that of *C* band is to replace the compact step transitions connecting antenna and RT (receiver-transmitter) units to the ridge guide transmission line.

Table 1. Characteristics of double ridge guide for commercial airlines weather radar.

Desired Characteristics	Design Values
Operating Bandwidth: 5260-9415 mc.	*Theoretical Bandwidth:* 4200-10,000 mc.
Attenuation: 2.0 db max. for 30' typical aircraft run (0.067 db/ft.)	*Theoretical Attenuation, Aluminum:* 0.043 db/ft. at 5400 mc.; 0.029 db/ft. at 9300 mc.
Peak Power-Handling Capability: 100 kw. at 16,000', VSWR 1.5 (Equivalent to 510 kw. at atmospheric pressure. VSWR 1.0)	*Theoretical Power-Handling Capacity:* 1840 kw.

Figure 2 shows an installation currently in production which is composed of three rigid sections and three flexible sections. All the components of this installation, including the RT unit, are mounted in the nose of the airplane. The flexible sections serve a twofold purpose: they permit freedom of motion in order to allow for (1) tolerance build-up in mating equipment and (2) excursion of shock-mounted equipment (RT unit) under vibration.

Possibly a more representative installation would be one designed to connect the RT unit mounted in the standard radio equipment rack with the antenna in the nose of the airplane. Such an installation would be composed of two flexible sections, one mating with the RT unit and the other with the antenna, with a rigid run between the two flexible sections; the length of this run is dictated by the type of airplane. These rigid sections may have bends or twists so that the wave guide routing follows the most direct path possible. Pressurized bulkhead fittings (Fig. 2) may be used to make air seals when it is necessary for the wave guide installation to go through a pressure bulkhead. Quick disconnect clamps also have been designed for use with this wave guide where space limitations make it either impossible or impractical to use screws, or where it is necessary to have an easily opened joint for servicing or testing a unit of the installation such as the antenna.

By **T. N. ANDERSON** and **J. VEGA**
Airtron, Inc.

Reduced size and increased bandwidth make ridge guide useful for airborne radar.

Fig. 3. R.F. and pressure contact flange with associated gasket.

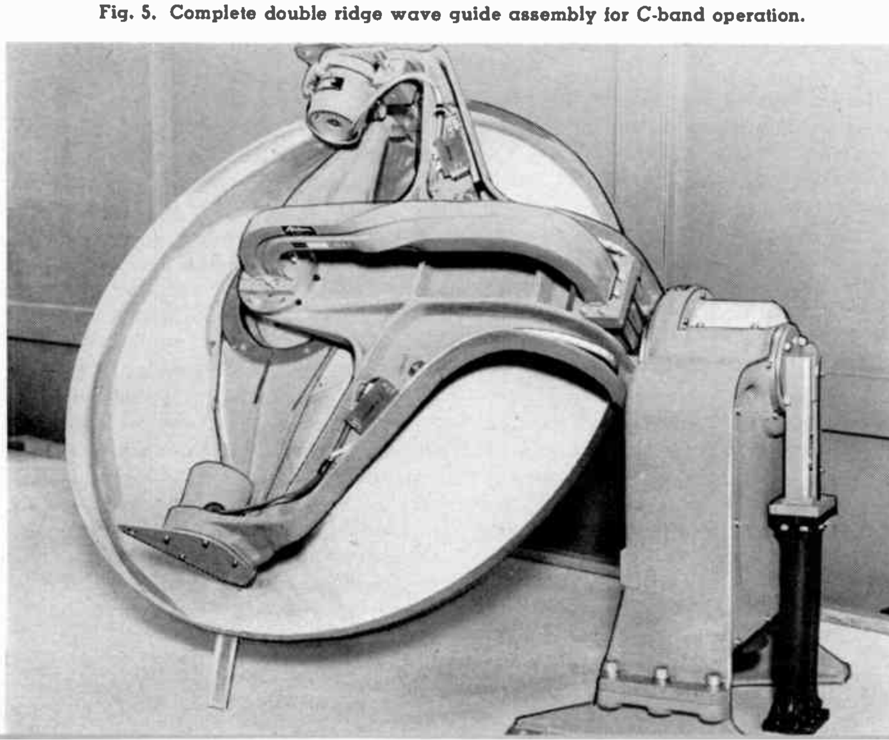
Fig. 4. A section of unjacketed double ridge flexible wave guide.

There are a number of cross-sectional shapes which can be made to propagate electromagnetic energy similar to the familiar rectangular wave guide. Since the very inception of these units, considerable theoretical investigation has been done on various cross sections. The most familiar of these are circular, square and rectangular. For practical systems, especially operating at high powers, it is essential to use the lowest single fundamental mode that can be propagated. This is typical of both circular and rectangular guides. Since the geometry of the cross section limits the bandwidth for a particular fundamental mode, there have been several types of cross-sectional geometries proposed in the past for increasing single mode bandwidth. In analyzing all of the various types, the ridge wave guide furnishes the best compromise between minimum dimensions and peak power-handling capabilities. Both single ridge and double ridge wave guide can be designed to operate in very nearly the same manner. The double ridge guide, however, has a considerable mechanical advantage due to its symmetry, and it is this construction that has been chosen for the majority of military and commercial ridge wave guide applications.

One of the actions of a ridge wave guide is to reduce the TE_{10} mode cutoff frequency. The propagating mode is exactly the same as for the normal rectangular wave guide with the exception that the concentration of the electric field in the region of the ridge gap has a nonsinusoidal distribution across the broad dimension of the electric field. There is also some increase in the TE_{20} mode cutoff frequency through the use of these ridges, although this effect is slight and for moderate ridges can be neglected in initial design calculations. The most advantageous ratios of width-height and the widths of the ridges have been well worked out by Cohn, Hopfner and others.

For optimum design, the broad dimension is twice the narrow dimension and the ridge occupies approximately one-third of the broad dimension. Depth of the ridge then determines the TE_{10} mode cutoff frequency and is generally rounded slightly for better peak power-handling properties. The size reduction as compared to *C*-band (2.000" x 1.000" O.D.) wave guide is shown in Fig. 1.

Fig. 5. Complete double ridge wave guide assembly for C-band operation.



Operating Characteristics

Desired operating characteristics for a double ridge wave guide for airborne weather radar are given in Table 1. The peak power-handling capability of this design was calculated by assuming that the electric field fringing at the ridge is negligible due to the generous radius. Power at breakdown is then equivalent to a section of rectangular guide whose narrow dimension is the ridge gap and whose broad dimension is the same as that which will yield the same TE_{10} mode cutoff.

To evaluate the design for this application, a standard section was milled from two L-shaped blocks contrary to the normal practice of splitting a wave guide down the middle of the broad wall. Using this section, the TE_{10} mode cutoff and the guide wavelength which was required for computation purposes, design of components, etc., were measured using the sliding short-circuit technique. From this reference standard of guide, only approximate numbers could be obtained for attenuation and peak power-handling capabilities. Tests were run to ascertain that these characteristics were well within the theoretical limits and drawn tubing was procured.

Drawn samples of guide were then checked for peak power-operating capabilities using quarter-wave block transitions of *X* band with a 4J50 magnetron. From these tests, an equivalent peak power-handling capability at *X* band was determined, and a similar test was run at 5400 mc. using a 200-kw. tunable magnetron, *Raytheon* QK-235. Measured performance with 2.5-μsec. pulses at 400 pps revealed peak power-handling capabilities of 1500 kw. at 5400 mc. and 1280 kw. at 9375 mc.

Attenuation measurements were then made on short sections of drawn tubing by the standing wave method as de-

(*Continued on page* 50)

MICROWAVE ECONOMICS

By

LEO G. SANDS

Sands Associates

Comparison of initial cost and maintenance of microwave systems with wire and leased lines.

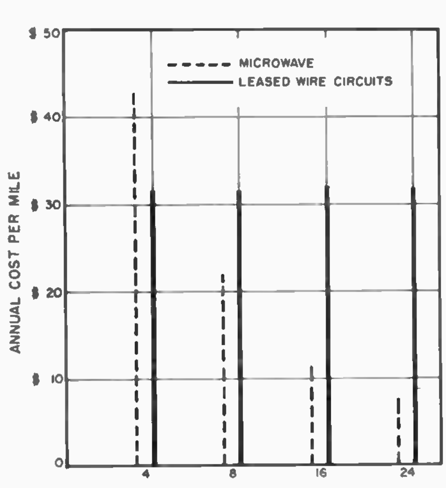
IT HAS been stated many times by representatives of microwave equipment makers as well as by consulting engineers that microwave radio relay systems cost less to own and operate than comparable open-wire line facilities and are also less expensive than leased wire service. This statement can be verified by simple arithmetic and is equally true when reference is made to microwave systems vs. new wire line construction. There is seldom any argument when referring to microwave systems vs. leased wire service since the cost of leased service is not a variable except in cases of rate increases.

To arrive at a basis for comparison, it is necessary to consider initial outlay, taxes, maintenance, and depreciation for the different systems. The most variable factor is maintenance expense, and accurate information on this point is difficult to obtain.

Initial Cost

The initial cost of a microwave system can be easily determined. In short systems, a dollars-per-mile rule-of-thumb figure doesn't work readily because of widely varying tower costs. However, in long systems, tower costs generally balance each other out so that a rough dollars-per-mile figure can be computed. This works out to about $1000 to $2000 per mile in most instances and is determined by the complexity of the system. The cost per mile of a microwave system generally decreases with length.

Fig. 1. Estimated cost per channel mile of leased wire and microwave facilities.



Required outlay for new open-wire line construction is also hard to nail down due to variable labor and material costs. However, for comparison purposes, the figure quoted by a major railroad will be used. The expense of building a new 100-mile open-wire line was estimated at $500,000, which amounts to $5000 per mile and roughly 250% more than the cost of an equivalent microwave system. In this instance, the wire line was to handle 15 voice channels, eight of them on carrier. The per-mile-cost of an open-wire line remains approximately the same regardless of distance.

Leased service is governed by established tariff structures and is charged for at so much per channel mile. For very short systems, the cost of leased wire service could be lowest and for medium-haul and long systems generally is highest. There is no initial expense —only a monthly charge which does not diminish with time and may increase if rates are raised.

If the initial cost of installing a microwave system is amortized over a 12½-year period, wire lines amortized over a 25-year period might still sound attractive. However, the microwave system is expected to last much longer than 12½ years. In the event of equipment obsolescence due to tightening of FCC regulations or great improvements in the art which would make new equipment very desirable, the towers, shelters and many other appurtenances need not necessarily be replaced. Therefore, the charges involved in replacing the electronic equipment only may represent but a fraction of the over-all initial cost.

Most microwave systems, when installed, are seldom loaded to capacity. More channels can generally be added at very low cost per channel mile. When a system is fully loaded, it is also possible in some installations to add a second microwave system at the same terminal and repeater sites. This means that the capacity of the system can be doubled for much less than would be necessary to install two separate independent systems.

Wire lines, too, can be expanded to accommodate additional channels by adding more wire or carrier equipment. More expensive carrier equipment is required for wire line applications than for microwave use. Generally, it is necessary to transpose the wire lines to accommodate multichannel carrier systems, and often it is desirable to install new wire. At prevailing rates, these costs are considerable.

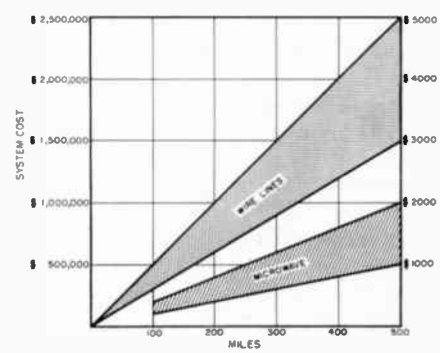


Fig. 2. The estimated initial cost of microwave and wire line installations.

Leased service can be expanded by the leasing of more channels. The charge for each additional channel is usually the same as for the initial channels. However, there is no capital outlay.

Maintenance

When inquiring about the cost of maintaining private microwave systems, one generally receives as coherent an answer as when asking "which came first, the chicken or the egg?"

The typical operator of a private microwave system is reluctant to release figures on the cost of maintaining a microwave system, for various reasons. Often, the figures would not be accurate because personnel engaged in maintaining microwave systems may also be responsible for taking care of mobile radio, wire line equipment and other apparatus in addition to microwave. In instances where microwave maintenance personnel are engaged in microwave work ex-

(*Continued on page* 63)

FIRST MICROWAVE SYSTEM FOR 2450-2700 MC.

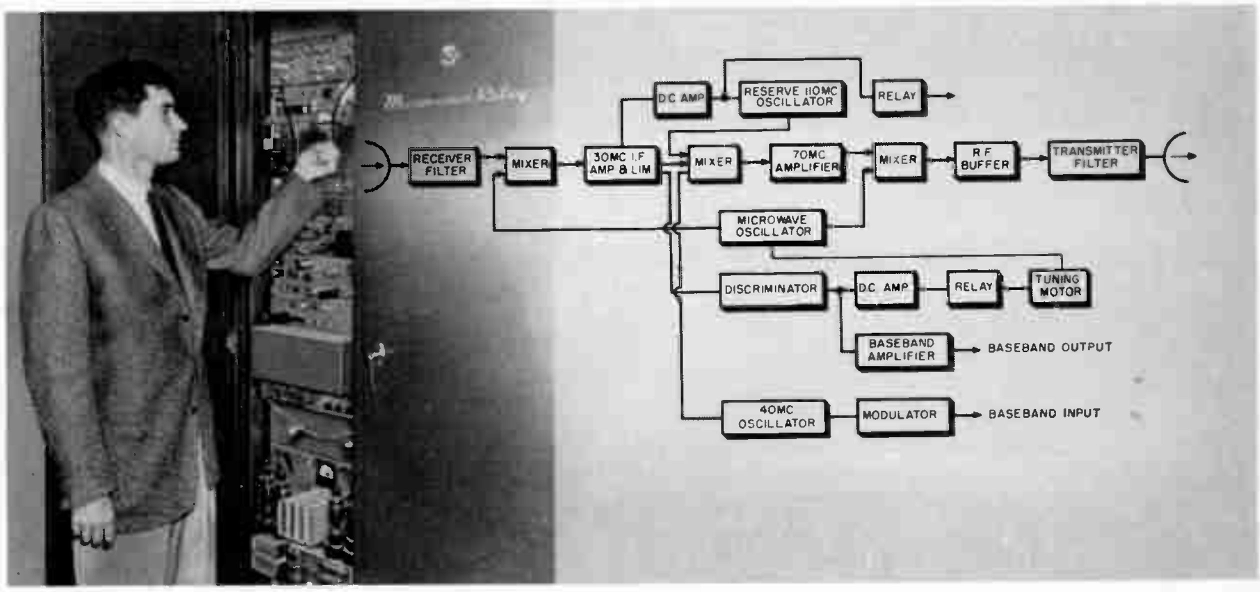


Fig. 1. View of the over-all equipment (left) and a block diagram of a typical branch through a repeater station. Stages shown are in the transmitter and receiver units.

By **PAUL A. GREENMEYER** and **S. LAPENSON**

Engineering Products Division, Radio Corporation of America

Specially designed equipment for operational fixed 2450-2700 mc. band opens up an additional 250 mc. of channel space in the microwave spectrum.

TEN SHORT YEARS ago, the use of microwave radio relay systems for private communications was considered an interesting possibility. Today, microwave towers are mushrooming across the countryside as many industries find microwave the answer to their communications needs. The widespread use of microwave has already created frequency crowding in some areas and it is now difficult to establish new systems because of limited channel space. This is especially true for the desirable 2000-mc. bands.

Of the operational fixed microwave bands made available to industrial users (such as power utilities, pipelines and turnpikes), one band which has until now remained unused because suitable commercial equipment was not available is the 2450-2700 mc. band. Because of the many operational advantages which are to be found in this portion of the spectrum, *Radio Corporation of America* recently developed its latest microwave system, Type MM-26, which is especially designed to operate at 2450 to 2700 mc. It represents the first commercially available system to operate in this band, and will open up 250 mc. of presently unused channel space.

The first installation of a system in the 2450-2700 mc. band using the *RCA* Type MM-26 equipment will be along the Pennsylvania Turnpike. This system will stretch some 400 miles across the length of the state, from New Jersey on one side to Ohio on the other, and will provide administrative voice channels, teletype circuits, and v.h.f. mobile radio control circuits. Numerous interchanges, administrative offices, and maintenance offices will be interconnected. The new system constitutes an expansion of the presently existing 960-mc. Type CW-5 system, and provides communication in a new and entirely uncongested band. It was system-engineered, and is being installed and maintained by the *Raymond Rosen Engineering Products Company* of Philadelphia, Pa.

Basic Units

Type MM-26 systems are composed of eleven standard unit panels which can be easily assembled

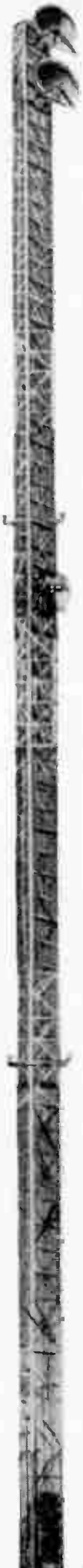
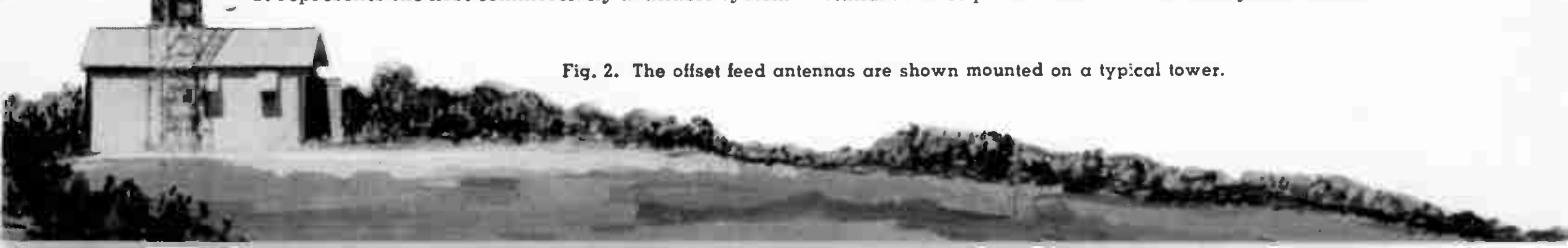



Fig. 2. The offset feed antennas are shown mounted on a typical tower.

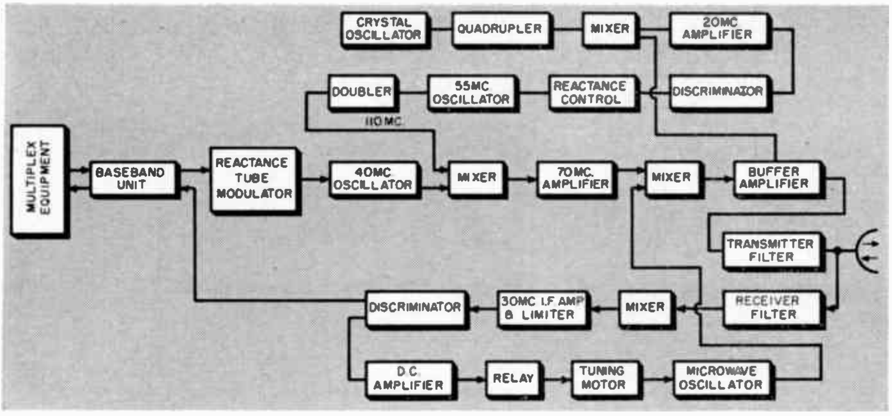


Fig. 3. Diagram of terminal station, including receiver, transmitter and a.f.c. unit.

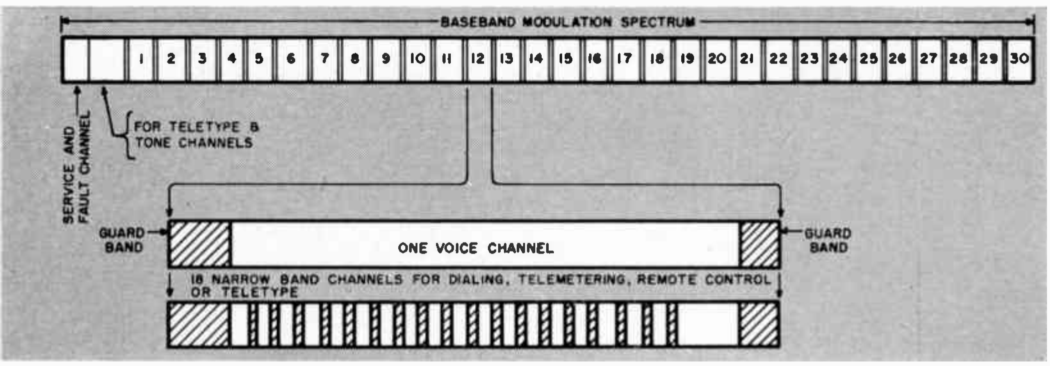


Fig. 4. The MM-26 system provides 30 voice channels, 20 tone channels and a service channel. Each voice channel can be further subdivided into 18 narrow-band channels.

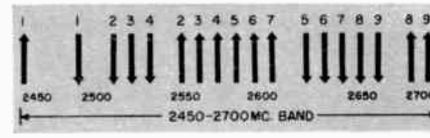


Fig. 5. Chart showing how up to nine parallel duplex systems can be fitted into the 2450-2700 mc. band in a given locality. More can be utilized when they intersect from various angles.

into all the different types of stations needed to meet specific user requirements. It is only necessary, for example, to assemble these basic panels in the proper combinations to obtain any one of six types of terminal stations, ten different types of repeater stations, and up to 24 different types of junction stations. Thus, in laying out a microwave system, the basic station types which are required at various points in the system can be easily assembled using these standard building block units.

Basic units designed for the MM-26 system include: (1) microwave transmitter, (2) receiver, (3) automatic frequency control, (4) base-band unit, and (5) power supply. Three units required in all stations are: transmitter, receiver, and power supply. The base-band unit serves to connect the microwave radio equipment with the multiplex equipment at stations in which channels are added or dropped from the system. Due to the heterodyne repeater type of operation around which MM-26 systems are designed, the automatic frequency control unit is required only at terminal stations of the system to establish and maintain the transmitter frequencies for an entire chain of stations.

Transmitter

In the transmitter unit, which generates the highly stable carrier, the carrier is derived from a wave guide cavity-type self-oscillating circuit. Tuning is easily accomplished by means of thumb-screw adjustments. The oscillator stage makes use of a 2C39A planar electrode (lighthouse) type triode, which is also used as a mixer and r.f. amplifier.

The transmitter unit includes a number of characteristics that are normally found only in equipment operating at the more conventional lower frequencies. The r.f. output stage includes a 2C39A tube which operates as an amplifier. Use of this stage to feed the antenna is highly desirable, since it acts as a buffer which isolates the oscillator and mixer stages from the r.f. transmission and radiating system. Impedance mismatches with the resultant "frequency pulling" effects are thereby avoided.

Use of an r.f. buffer amplifier enables the radio equipment to be physically separated from the antenna. The radio equipment can, in most systems, be safely housed within a building, while the antennas can be mounted some distance away at the top of a tower or on the roof of a tall building.

Receiver

Designed to perform two functions in the system, the receiver unit demodulates an incoming carrier and—at the same time—modulates the outgoing signal which is applied to the transmitter in the same station. Although transmitter and receiver are designed as separate assemblies, in actual operation both units share common stages, while control signals between both units provide for an integrated operation and greater reliability.

The receiver unit uses six i.f. amplifiers to provide an unusually flat band-pass with sharp cutoffs. Adjacent channel attenuation is in excess of 60 db and permits received carriers to be spaced as closely as 10 mc. in the majority of systems without interference. Two limiter stages are provided which contribute to the achievement of practically ideal FM performance. The receiver bandwidth is 6 mc. (Fig. 10) and the noise figure is 12 db.

Automatic Frequency Control

When the transmitter and receiver operate in conjunction with a third unit —a terminal a.f.c. unit—a frequency control loop is established which maintains the transmitter carrier within ± 0.05% of its assigned operating frequency. Incorporated in the frequency control loop is a low-temperature coefficient, hermetically-sealed quartz crystal oscillator which is contained in the a.f.c. unit. This unit establishes the frequency reference and maintains transmitter frequency within the desired limits. Ovens, temperature - controlled cavities, and other complex control apparatus for maintaining a constant temperature are not required.

When the a.f.c. unit is in operation, a sample of the carrier signal heterodynes with a harmonic of the crystal oscillator in a mixer cavity to produce a difference frequency of 20 mc. Any tendency of the transmitter to drift will vary this signal above or below 20 mc. Any deviation which is present will produce a d.c. control signal, which varies the frequency of a reactance-tube-controlled 55-mc. oscillator. This frequency is then doubled to provide a 110-mc. signal which is mixed with a 40-mc. signal to produce the 70-mc. i.f. signal required by the transmitter. Any variation in the frequency of this oscillator, therefore, produces a corrective change in transmitter frequency. In normal operation, the reactance tube oscillator shifts in frequency as necessary in order to maintain the correct carrier signal frequency.

Base-Band Unit

In the base-band unit, channels which

are to be applied to the radio system receive the proper amount of pre-emphasis, are combined with service channel signals, and are applied at the proper levels to the modulator input of the receiver. Transmitting level of — 26 dbm per channel is required at the 600-ohm input to the base-band amplifier. An excess gain of 9.5 db is available.

In the receiving branch of this unit, incoming channels which are to be demodulated are applied at a level of — 10 dbm per voice channel to the multiplex equipment. Excess gain available is 9.0 db.

Tone channel signals which are applied directly to the base-band will normally be operated about 10 db below the values indicated.

Power Supply

A sturdy nonregulated power supply meets all power requirements of any single rack or cabinet assembly. Operating from conventional commercial power sources, selectable taps provide for operation on inputs of from 95 to 125 volts r.m.s., 50/60 cycles. The permissible voltage variation on a selected tap is ±0.5%. Operating power for the microwave equipment units is provided at 250 volts d.c., 500 volts d.c., and 115 volts a.c.

Conservatively rated 3B28 rectifier tubes accommodate current drains of 600 ma. on the 500-volt d.c. supply and 500 ma. on the 250-volt supply. Double choke filtering is used to attain low ripple content. It is important to note that the design of the radio equipment is such that voltage regulation need not be incorporated in the power supply.

Design Features

Essentially, MM-26 microwave systems are composed of an integrated arrangement of terminal stations, repeater stations, and junction stations which operate on a heterodyne principle. This method of operation effectively ties together all stations in a system by enabling transmitting and receiving branches at each station to share common frequency components. The new MM-26 system was designed along the same lines as the CW-20 system—in the neighboring 1800-1990 mc. band—in order to make use of design features which have been proved successful by many years of actual operation by public utilities, oil product pipelines, turnpike authorities, and many other users around the world.

Heterodyne repeater operation permits through channels to be relayed at microwave frequencies from one station to the next without demodulating the carrier. It results in a minimum of audio distortion and eliminates variation in audio levels along the system. Such operation also makes it possible to insert or drop channels conveniently at any station without degrading the channels passing through.

Only two r.f. channels are normally required for this type of system. The transmitted frequencies are alternated at successive stations in order to prevent overshoot interference. A duplex filter (see Fig. 9) permits a single antenna to transmit and to receive the microwave signals. In order to reduce interference between back-to-back antennas on a tower, one antenna normally is horizontally polarized while the other is vertically polarized. A frequency separation of 40 mc. is maintained between transmitted and received frequencies at each station. Antennas which were specifically designed for high gain and directivity in the 2450-2700 mc. band provide beamwidths of the order of 4 to 7° and gains of the order of 27 to 30 db. Polarization can be easily adjusted to either horizontal or vertical planes. For both types of polarization, radiation patterns are very nearly identical.

Channels Provided

FM-type carrier modulation is used with a peak carrier deviation of ±1.5 mc. The base-band modulation range is from 300 cycles to 160 kc., which is divided into individual bands of 5 kc. The bandwidth of individual channels is approximately 300 to 3000 cycles, allowing room for guard bands between channels.

A service channel is provided from 300 cycles to 3 kc. This channel interconnects all stations of a system for maintenance purposes, and includes a signaling or calling circuit. A handset is supplied at each station for full party-line operation.

Tone channels can be inserted directly on the base-band above 4 kc. for telemetering, supervisory control, and similar functions. Normally, these channels are allocated to the frequencies between 4 kc. and 9.5 kc. Signals can be applied directly to the base-band without the

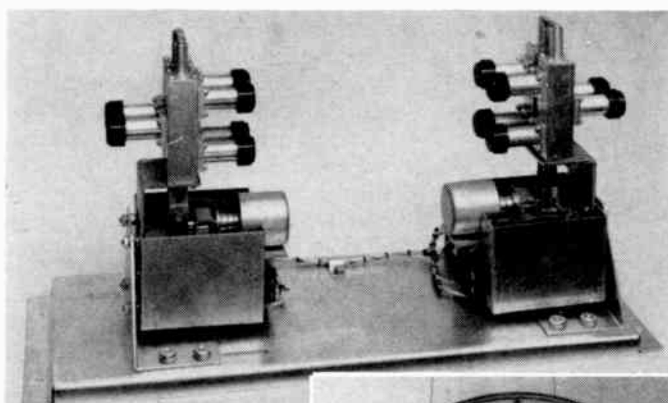


Fig. 6. Repeater antenna switching unit used at stations with standby in order to switch antennas to active radio equipment.

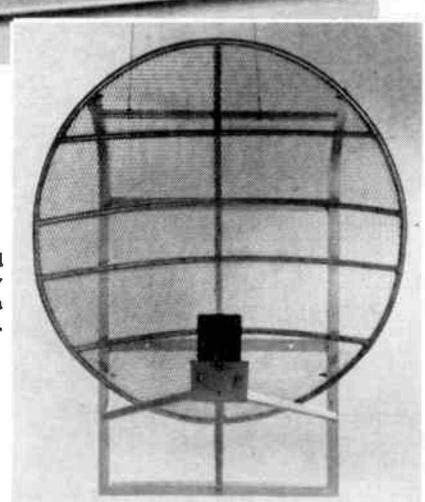


Fig. 7. This offset feed antenna is especially designed for high gain in 2450-2700 mc. band.

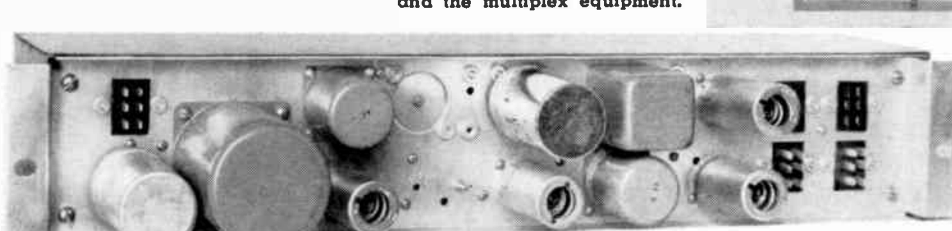


Fig. 8. The base-band unit raises amplitude level of multichannel signals passing between receiver-modulator and the multiplex equipment.

Fig. 9. Typical drop repeater station is 92½" high (including filter), 21" wide, and 18" deep. Power drain is about 800 watts.

use of voice channel equipment, and are accessible at all access points of the microwave system.

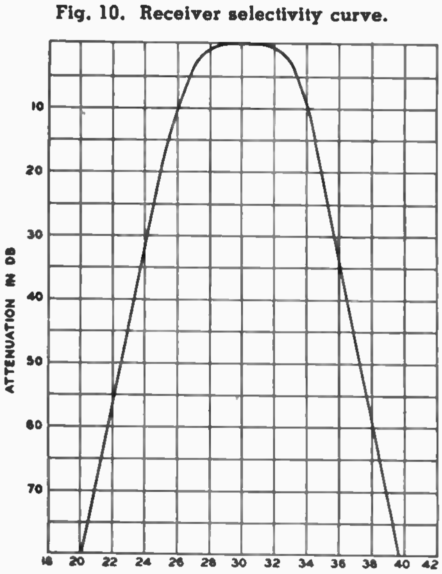
The extended base-band range of this system can provide up to 30 voice channels—plus a service channel for maintenance purposes—and space for 20 tone channels. Most users may not require this large number of channels, but they are available in all systems, and can be conveniently added at a future time to meet increased communications requirements. (The loading varies somewhat according to the type of single-sideband equipment required for the particular application.)

A moderate amount of pre-emphasis, on the order of 5 db at 135 kc., is used at the higher modulating frequencies. This provides an over-all system frequency response which is flat +1, —2 db, relative to the 5-kc. response from 3 kc. to 160 kc.

Multiplexing

In anticipation of the present widespread use of microwave, as well as its continued growth in the communications services, the MM-26 system is designed specifically to provide maximum use of available spectrum. It uses only the barest minimum of spectrum space for the facilities provided, primarily because of the fact that only two frequencies are employed. In addition, single-sideband multiplexing enables channels to occupy a narrower portion of the available spectrum. In any given locality, up to nine parallel duplex systems can be fitted into the 2450-2700 mc. band (Fig. 5). Many more systems can be utilized when they intersect from various angles. Narrow spectrum operation enables more users to benefit from the available frequency space in any locality, and also has the advantage of presenting a lighter load on the media used for transmitting the signal.

Fig. 10. Receiver selectivity curve.



The MM-26 system makes use of the same type of multiplexing equipment which is standard in the commercial telephone and telegraph services around the world. Therefore, it can be readily interconnected with standard telephone and telegraph equipment. The familiarity of this type of multiplexing equipment constitutes an important maintenance advantage. In addition, because the MM-26 uses the same type of multiplexing equipment used for wire lines, it is possible to separate physically the multiplexing equipment from the radio equipment and to connect them by wire lines. For example, radio equipment at a repeater station at the top of a mountain can interconnect with multiplex equipment at a pump station in a valley by means of conventional wire line circuits, permitting a number of voice channels to be carried to some important location before they are broken down into individual channels.

Single-sideband suppressed-carrier frequency-division multiplexing enables individual channels to be added to a system at any time, as they are required. It is not necessary to add an entire bank of channels or to demodulate for party-line operation. Also, each channel can be adjusted and maintained on an individual basis.

In this multiplexing process, each signal channel modulates a separate subcarrier from which one sideband is selected. Subcarriers are spaced in frequency to avoid overlapping of subcarrier sidebands. Selection and demodulation of each signal channel are on an individual basis, according to its frequency. For example, a telephone conversation on any channel of the microwave system would make use of a single duplex voice channel terminal provided by the multiplexing equipment. Voice frequencies of from 300 to 3000 cps from a handset are applied to the multiplex equipment, where they are shifted in frequency and transmitted as a single-sideband signal. All the individual sideband signals are then combined on the base-band and applied to the microwave radio equipment. At the receiving point, a reversal of this process would make the intelligence available to the person on the other handset.

Since the MM-26 utilizes single-sideband frequency-division multiplexing, it can be connected to standard wire line and telegraph equipment at any terminals. The MM-26 can also be interconnected with *RCA* systems designed for other frequency bands—with Type MM-9 pole-mount or conventional 960-mc. systems, or with the Type CW-20 1700-1990 mc. systems. It does not obsolete existing equipment but is compatible therewith. By this principle of design, an existing system of any type can always be integrated with newer equipment, without expensive or time-consuming modifications.

Specifications for MM-26 System

Frequency range	2450-2700 mc.
Type of modulation	frequency modulation
Type of associated multiplex equipment	single-sideband suppressed-carrier frequency division
Total peak deviation	±1.5 mc.
Transmitter power output	3 watts
Frequency stability	±0.05%
Base-band modulation frequency range	3-160 kc.
Service channel frequency range	300 cycles to 3 kc.
Receiver bandwidth	6 mc.
Number of channels	30 voice, 20 tone, and 1 service
Nominal transmitter modulation sensitivity per voice channel	—26 dbm
Nominal receiver output level per voice channel	—10 dbm
Temperature range	—20° to +50°C
Receiver noise figure	12 db

Table 1. Specifications for *RCA* 2450-2700 mc. microwave system.

Optional Equipment

Optional equipment for the system includes new fault transmitter and fault indicator panels, which enable one or more stations to keep constant check on the performance of an entire microwave system. In effect, these units provide "long-distance eyes" for the serviceman. The fault transmitter unit acts as a monitor when installed in a remotely situated unattended location; it can be adjusted to report back irregularities such as power line failure, low transmitter output, loss of signal, operation on emergency power, illegal entry, or any similar condition which might occur at an unattended station. The fault indicator panels can be installed at a centrally located station or stations to provide an indication of over-all system condition. They are designed to provide a visual display—in coded form—of an incoming fault signal, so that the maintenance personnel will immediately know which station originated the transmission and the nature of the fault. The fault units operate over the service channel of the microwave system.

In some systems, or at specific station locations where an unusually high degree of reliability is required, it is often desirable to provide standby equipment which duplicates the equipment in operation. In this case, a switching unit can be installed which will automatically switch out a faulty equipment group and substitute the corresponding standby group. Such units distinguish between power supply and radio equipment faults, and at a repeater station can determine whether the east-west or west-east radio equipment is at fault. Switch-

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CHARACTERISTICS OF RIDGE WAVE GUIDE

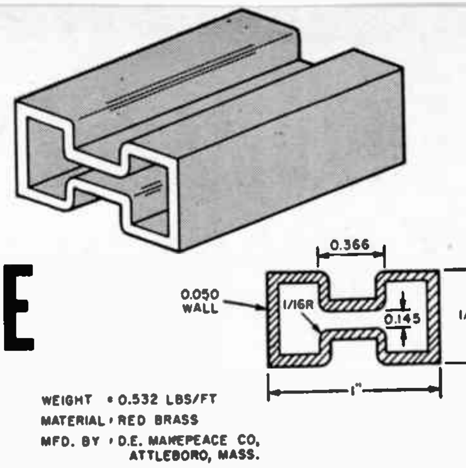


Fig. 2. Construction details and dimensions of typical double ridge wave guide.

By **SAMUEL FREEDMAN**

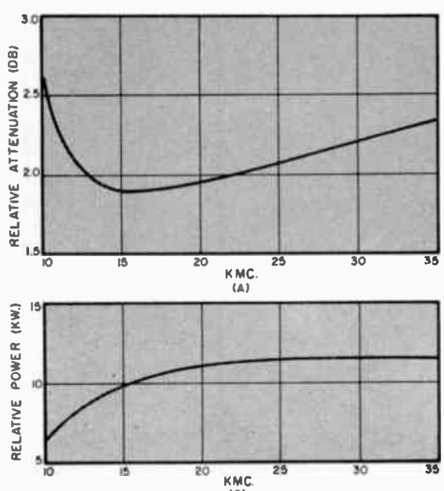
Chemalloy-Electronics Inc.

Bandwidth is greater and cutoff frequency lower than for comparable nonridge guide.

CONVENTIONAL (nonridge) wave guides present the most efficient means of conveying microwave power known. Their use, however, is restricted by three inherent drawbacks: (1) inconveniently large dimensions for lower microwave frequencies, (2) inconveniently small dimensions for the higher microwave frequencies, and (3) exponential electrical efficiency and narrow-band characteristics, necessitating many wave guide sizes to cover the spectrum. Often, separate transmitters, antennas, receivers, test equipment, etc., are required.

When a rectangular guide is fitted internally with a ridge, the effect is to increase greatly the frequency range between TE_{10} and TE_{20} modes. Also, the attenuation, power-handling capacity and impedance are much more uniform for many times greater frequency spread. Uniformity is particularly important in receiving signals over a wide frequency monitoring range or in using primary standard test equipment where the efficiency needs to be constant over the tunable range. The penalty for accomplishing such performance is greater attenuation and reduced power-handling capacity. Either single or dual ridges may be employed, although it appears that double ridge guide will be used most extensively. Figure 2 shows the construction of typical double ridge wave guide.

Fig. 1. Plot of relative attenuation (A) and power-handling capacity (B) of ridge wave guide. Specific values of each characteristic will depend on many factors.



Ridge guide is not new. In seeking references to literature, one may search back to World War II and immediately thereafter for much of it. An exception is the limited government-sponsored research and development projects, the findings of which are not generally available outside the Department of Defense. There has been inadequate attention directed to use of this guide until very recently.

Generally considered to be a quarter-wavelength guide terminated in a capacitor, a ridge guide is critical in the ridge or throat section. It is similar to a standard-type rectangular wave guide except that it is capacitively loaded by the introduction of the ridge section in the center of the E plane (a dimension or width).

This type of guide may be described as representing a capacitive load so that increase in electrical dimensions can result without increase in physical dimensions. Because of the increase in electrical dimensions, the mode separation increases (notably the frequency distance between TE_{10} and TE_{20}), so that the operable frequency range of a given guide is greatly increased. This gain in frequency width of the modes is achieved at a cost of increase in attenuation, due to increase in current density in the center of the guide, and lower power-handling capacity. The flashover distance is reduced by the presence of the ridge so that a ridge guide cannot handle as much power as can a properly dimensioned nonridge guide.

Ridge wave guide may be said to have the following advantages over conventional guide:

1. Bandwidth is greater without change of wave guide operating mode. In the common dominant mode operation used in most microwave applications utilizing the region between TE_{10} and TE_{20}, this bandwidth or frequency range can be four or more times greater than that of nonridge guide for feasibility of operation.
2. Cutoff frequency is lower. A ridge wave guide can be about a third of the size of nonridge guide both in width and height for a comparable low frequency cutoff.
3. Impedance is lower and more constant. Although the attenuation is greater and the power-handling capacity less than for nonridge guide ideally dimensioned for a particular frequency, the power-handling capacity is still of a magnitude that suffices for virtually all medium and lower power installations.

In short, the advantages are greater operational bandwidth and reduced physical dimensions.

It should be emphasized that the power-handling capability and attenuation characteristics depend on many factors, such as internal dimensions, material, curvature at edges of ridge, and whether single or double ridge guide is used. The curves of Fig. 1 are included to give a general idea of the uniformity of the attenuation and power-handling capacity over a very wide frequency band rather than to present specific design values. Ridge wave guide is now in production which has a power-handling capacity of above a megawatt and attenuation of less than .06 db/ft. (See the article on page 18 of this issue.)

A possible method of manufacturing ridge guide which holds promise would be to cast the wave guide directly complete with ridge, ridge tapering, flange terminations, etc., as required, by means of the shell molding technique perfected by *Chemalloy-Electronics Inc.* Efforts are now being made to adapt this process to ridge wave guide.

FERROMAGNETISM AT MICROWAVE FREQUENCIES

By **JOHN H. ROWEN**
Bell Telephone Laboratories

Ferrites are advantageous in a number of devices at microwave frequencies, including isolators and circulators.

Measuring the performance of a microwave isolator.

ONE OF THE most rapidly growing areas in the field of microwave technology is that concerned with the application of ferrites to microwave techniques. A large number of novel circuit elements such as isolators, modulators, electrically controlled phase shifters and attenuators are for the most part developments of the last four years, and probably represent only the beginning of a list of new devices made possible through the use of ferrites. All of these devices take advantage of the fact that the effective microwave permeability of a ferrite can be varied by means of a static magnetic field, and can even be made to produce nonreciprocal effects. This article will serve to familiarize the reader with the fundamental theory of microwave ferrite circuitry, and will review some of the outstanding developments to date.

Ferromagnetic Theory

By way of analogy, assume that a magnetic field H is produced by an electric current or a movement of charge. In empty space, the flux density arising from this magnetic field is simply μ_0 H, where μ_0 is the permeability of free space. If this region in space is filled with a large number of bar magnets or magnetic dipoles which are free to turn, it will be found that they can be aligned by the field, *H*. Each of these dipoles contributes an additional small magnetic field so that the total flux density is now $\mu_0\ (H+M)$, where M is used to designate the sum of the magnetic dipole moments.

Suppose further that there are thermal forces causing the dipoles to oscillate about. Then a very large field is required to overcome these forces and line up the dipoles. Finally, suppose that a large number of the bar magnets are paired up as shown in Fig. 1A. Their moments will then cancel each other. Both of these effects will reduce the number of dipoles which can be aligned by an applied magnetic field.

All of the unpaired bar magnets can be joined rigidly together so that their axes are always parallel, as shown in Fig. 1B. With this arrangement, it will be seen that there is a large cooperative effect and that random thermal forces acting on any one bar magnet cannot do very much to the over-all structure. However, the coupling between the bar magnets does not keep the whole structure from turning if it is subjected to an external force. In fact, if the structure were placed in a magnetic field, it would be found that a relatively small field would turn the structure so that the magnetic dipoles would be lined up with the field.

The foregoing analogy can be reduced to actual theory simply by replacing the bar magnets with spinning electrons. If an electron is a small charged sphere

Fig. 1. Bar magnets joined so that their moments (A) cancel and (B) add.

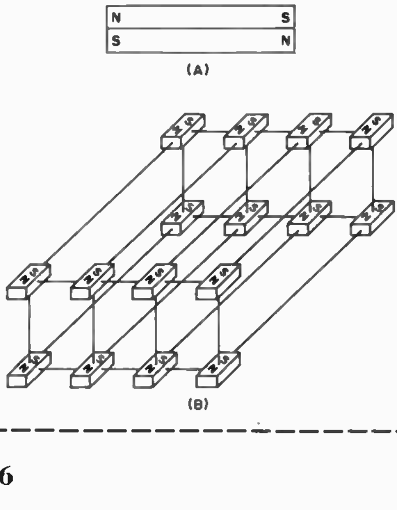


Fig. 2. (A) Each domain is completely magnetized but bounded in such a way as to produce no external field. (B) Domain structure found in silicon iron.

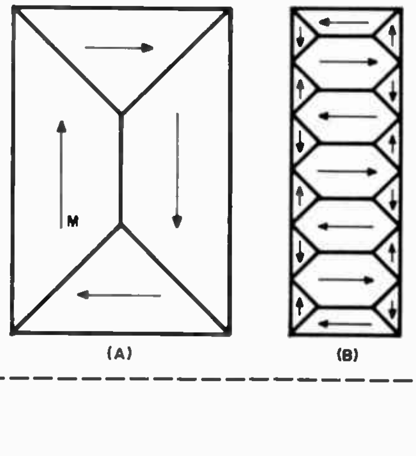
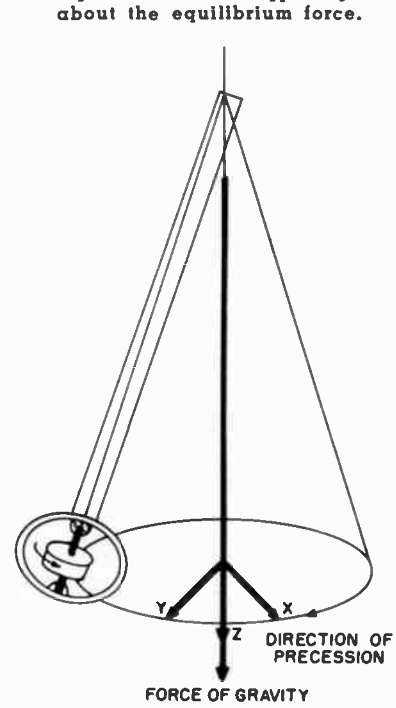


Fig. 3. Precession of gyroscope about the equilibrium force.



of mass m, then the fact that it is spinning will result in a magnetic moment. It appears to be a law of nature that all electrons are spinning at the same rate—the spin being one of the fundamental properties of electrons. So the bar magnets become electron magnetic moments and the rigid connection is replaced by the so-called "exchange interaction," which causes a large number of electron spins to act in concert instead of pairing up antiparallel or acting independently as they do in nonmagnetic materials. If the sum of the magnetic moments is M, the magnetization, it will be seen that the relation:

$$B = \mu_0 (H + M) \quad . \quad . \quad . \quad . \quad . \quad (1)$$

gives much more insight into the nature of ferromagnetism than can be obtained from the equivalent expression:

$$B = \mu_0 \mu H \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where μ is the relative permeability of the material. A material is said to have a high permeability when it has a large magnetization which is easily aligned by a magnetic field.

One might ask, "Why are magnetic materials not always magnetized?" The answer is that they are, at least in small regions called domains. A body of magnetic material might have a domain structure such as that shown in Fig. 2A, where each domain is completely magnetized but oriented and bounded in such a way that the flux is completely contained in the body. A more complicated domain structure actually observed in a single crystal sample of silicon iron is shown in Fig. 2B for comparison. The body breaks up into domains so as to reduce the energy stored in external fields resulting from the magnetization of the material. It might be pointed out that "soft" magnetic materials are under discussion, not permanent magnets. In the latter case, there is still another internal force of great consequence which causes the magnetization to stay in a particular direction even if it means the existence of external field energy.

An insight into the reason for the existence of domains may be obtained by imagining a chain consisting of small links each joined to the next by a flexible spring. By holding up one end of the chain, it can be made to stand up with all links in a straight line. However, unless the springs are very stiff, the chain will collapse when it is let go. In the same way, all of the domains can be aligned by applying a magnetic field; but unless the internal forces are very great, the magnetization will "collapse" into domains when the field is removed.

Gyroscopic Effect

There is one other property of ferromagnetism which is of fundamental importance in the behavior of ferromagnetic materials: the spinning electron also has a mass and therefore must act as a top or gyroscope. This behavior is not evident at low frequencies but is of paramount importance at microwave frequencies, as will be shown by an experiment with a gyroscope model.

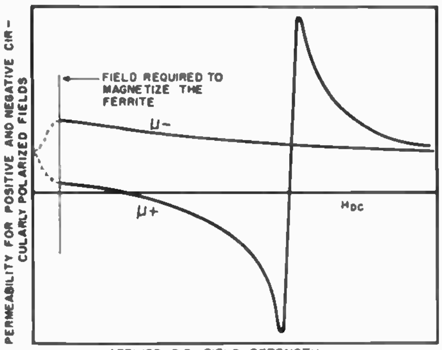
A gyroscope is fastened to the end of a stick so that the axis of the spinning gyroscope must stay in line with the stick. In equilibrium, the stick and gyroscope will hang straight down because of the force of gravity. If the observer now applies a horizontal force ever so slowly, he will find that the stick can be made to move back and forth like a pendulum. However, let him try to make the stick move back and forth rapidly and he will find that the gyroscope causes the stick to move in a precessional motion, i.e., it will describe a conical surface as shown in Fig. 3. Here, it is evident that a linear force in, say, the X-direction produces a motion not only in the X-direction but in the Y-direction as well.

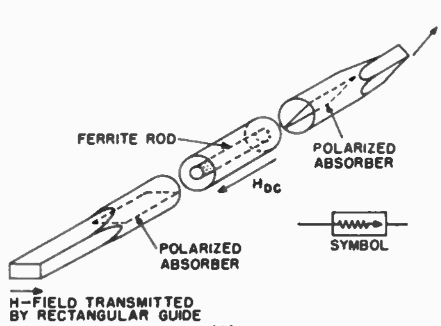
The magnetization produced by the spinning electrons behaves in much the same way. At low frequencies, it can be made to move back and forth in a single plane; but at high frequencies it will precess, with the result that there are components of M at right angles to the applied r.f. field. In most microwave applications, there is an applied d.c. magnetic field whose effect on the magnetization corresponds to the force of gravity in the gyroscope experiment, and an r.f. field applied in the plane at right angles to the d.c. field.

Going back again to the gyroscope model, it will be seen that if the stick is pulled away from the equilibrium position and released, the stick and gyroscope will precess at a frequency determined by the momentum of the gyroscope and the gravitational field. If the force of gravity could be increased, it would be found that the precessional frequency would increase proportionally. Anyone familiar with resonance phenomena will realize that if the observer should apply his forces to the stick at just this natural frequency of precession very large amplitudes of motion will result, while forces applied at other frequencies will produce smaller responses. Furthermore, if the observer tries to make the stick move in a circular motion in the natural direction, he will succeed; but if he tries to force the stick to precess in the opposite sense, he will have difficulty.

In the model, forces applied in a horizontal plane, perpendicular to the gravitational field, have been discussed. Correspondingly, the discussion of magnetized materials will principally concern r.f. magnetic fields in a plane perpendicular to the d.c. magnetizing field. When polarization is mentioned, reference is being made to the form of the magnetic field in this plane. For example, a linearly polarized magnetic field is one which simply varies sinusoidally along a single line. Circular polarization refers to an H-field which is constant in magnitude but rotates through all directions in the plane, completing one revolution per cycle of the r.f. frequency. Two equal circular polarizations of opposite sense combine to give a linear polarization in a direction determined by the relative phase of the circular polarizations. Intermediately,

Fig. 4. Effective permeability is shown for circularly polarized fields.





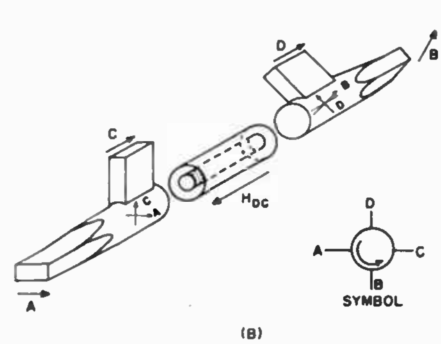


Fig. 5. (A) Faraday-rotation isolator. (B) Faraday-rotation circulator.

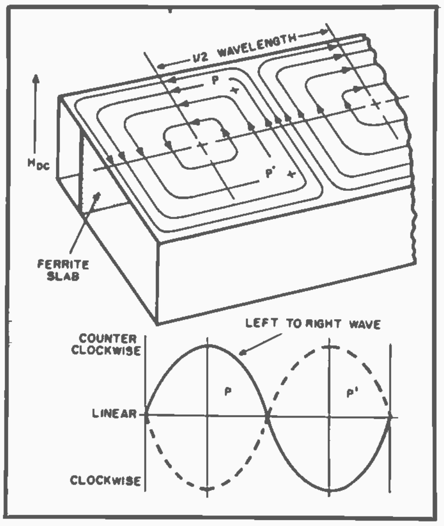


Fig. 6. Magnetic field contours in planes parallel to broad face of wave guide and resultant polarizations.

there is elliptical polarization, which can be broken down into two opposite circular polarizations of different size.

Bearing in mind that the permeability of a given medium expresses the behavior of the magnetization relative to the applied field, H, it will be seen from the gyroscope discussion that the effective permeability at microwave frequencies can be varied by changing the d.c. magnetic field, and that the permeabilities for the two opposite senses of circular polarization are different.

In brief, the permeability is not a simple constant but depends both upon the strength of the d.c. field and upon the particular field distribution of the r.f. wave. In a wave guide, the r.f. magnetic field varies from point to point both in direction and in amplitude. However, the field at any point may always be represented as the sum of two circular polarizations of opposite sense. Therefore, if the behavior of the permeability for these two circular polarizations is known for all values of d.c. magnetic field, the behavior of any wave guide structure containing a magnetized ferrite can be predicted roughly. Curves showing these permeabilities are given in Fig. 4. A resonance can be seen for the positive circular polarization but none for the negative. It will also be noted that there is a large difference between the two permeabilities, $\mu+$ and $\mu-$, at rather low fields. In fact, by the time the d.c. field is large enough to line up all of the magnetization, the separation has become quite large. The dotted portions of the curves show the behavior of $\mu+$ and $\mu-$ during the magnetizing process. Now, observe how these permeabilities predict the behavior of wave guide devices.

Applications

The simplest microwave devices to illustrate the foregoing theory are those which depend upon Faraday rotation. Faraday rotation in optics has been known for some time to be a non-reciprocal effect. However, because no optically transparent materials are ferromagnetic, the rotations observed have always been small. The development of ferrites, which are almost perfect insulators and are therefore "transparent" to microwaves, led to experiments in Faraday rotation in wave guide structures. Large rotations of the plane of polarization were observed and were immediately put to use in microwave devices. One of the most useful of these is the "isolator" which will be described in the following paragraphs.

For the reader who is not familiar with microwave techniques, it may be sufficient to observe that visible light and radio waves are both electromagnetic waves and that radio waves of very high frequency behave very much like light waves. They can be "guided" by hollow tubes having reflecting walls, they can be "polarized" by passing through the proper type of wave guide in much the same way as light waves are polarized by passing through a piece of polaroid, and, in general, they behave very much like light waves. The primary difference between the two types of energy is that optical wavelengths are less than ten-millionths as long as microwave wavelengths.

Figure 5A shows a linearly polarized wave coupled into a circular pipe containing a piece of ferrite magnetized along the axis of the pipe. The entire wave can be broken down into two equal circular components traveling together. Since these two components "see" different permeabilities, one travels faster than the other; and therefore, when the circular components are recombined at the other end, they produce a linear polarization which has been rotated. The sense of circular polarization depends only upon the direction of the field, so that the rotation is in the same direction regardless of whether the wave travels from left to right or vice versa.

The rectangular wave guides at either end can carry only a polarization whose magnetic field is parallel to the broad face, and therefore they act as polarization filters. It will be seen that the wave traveling from left to right is rotated 45° (through a suitable choice of ferrite dimensions and applied field) and the rectangular wave guide at that end is so oriented as to receive the rotated wave. Therefore, the wave travels freely from left to right. However, a wave entering at the right end will be rotated an additional 45° and will arrive at the left end polarized at 90° to the rectangular wave guide so that it cannot be received. A polarized absorbing vane is placed at the end of the circular section to absorb this polarization selectively. Therefore, a wave entering the structure at the right and traveling from right to left is totally absorbed by the polarized absorber and is not transmitted. Here is a passive, linear element which is truly a one-way transmission device.

By a slight variation, a second type of circuit element is achieved which has been named the "circulator*." By coupling additional rectangular wave guides to the circular section, as shown in Fig. 5B, the polarization previously absorbed by the resistive vane can be taken out. Now it will be seen that a wave entering at A is rotated through 45° so as to emerge at B. A wave entering at B is further rotated and emerges at C. Likewise, C couples to D, and D to A. One can place a transmitter at A, an antenna at B, a load at D, and a receiver at C, and simultaneously receive and transmit on the same antenna with crosstalk limited only by the degree to which the antenna is reflectionless. The load at D serves the purpose of absorbing any power which may be reflected from the receiver at terminal C.

Modulators and Attenuators

It has been seen that Faraday rotation depends upon the difference between $\mu+$ and $\mu-$; in fact, the rotation per unit length is directly proportional to this difference. Referring to Fig. 4, it is clear that Faraday rotation should vary almost linearly with applied field during the magnetizing process (dotted portion of Fig. 4). By taking the isolator structure of Fig. 5A and varying the field from the value shown, through zero, to an equal value in the opposite direction, the rotation will vary from +45° to −45° and the transmitted power will vary from 100% to 0. In actual practice, the minimum transmitted power is down about 50 db (0.001%). Here, then, is an electrically controlled attenuator which becomes a modulator if the field is varied at the modulation rate. Heretofore, it has not been possible to modulate a klystron or magnetron signal except by electrical control of the oscillator tube, and such control usually leads to undesired frequency modulation. A great many other devices depending upon Faraday rotation have been developed and many more are no doubt yet to come.

There is another type of structure which operates on a somewhat more subtle principle, employing rectangular wave guides and a magnetizing field across the narrow dimension of the guide rather than along the axis of the guide. Some very excellent performance has been obtained from such structures.

(*Continued on page* 40)

**The names "isolator" and "circulator" as well as the symbols used to represent them were suggested by A. G. Fox and have been almost universally adopted.*

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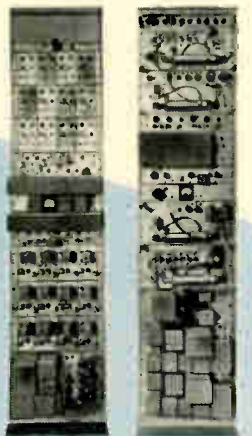

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NEW PRODUCTS

BALANCED MIXER

Suitable for use in either laboratory or radar system, the new *Airtron* balanced "magic tee" mixer has a low noise

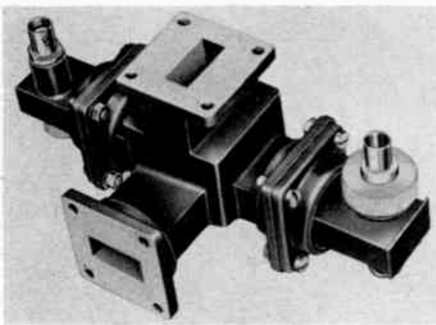


figure over its entire 12% bandwidth. In the 1" x ½" O.D. wave guide size, it is assembled from one precision-cast magic tee and two crystal holders.

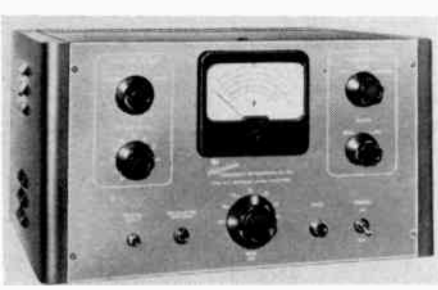
Through the use of both direct and reversed crystal mounts, two in-phase i.f. signals are produced in the mixer from the received signal and the local oscillator signal with resultant cancellation of local oscillator noise. Isolation between local oscillator and signal input arms is greater than 30 db, and the VSWR of each signal input is less than 1.25 from 8500 to 9600 mc.

Further information on this mixer may be obtained from *Airtron, Inc.*, Department A 1103, Linden, N. J.

Circle No. 56 on Reader Service Card

VSWR AMPLIFIER

The *PRD* Type 277 VSWR amplifier is an inexpensive, low noise, high gain audio amplifier with a sensitivity of 0.3 μv. for full scale deflection on the meter —which is calibrated both in VSWR and



db. This amplifier is well suited for use with slotted sections in measuring VSWR over the wide range of 1.0 to more than 100. With a 15-cps bandwidth, the noise level is only 0.03 μv.

A selector switch permits either high input impedance for such applications as low-level crystal operation and null indication in bridges, or low input impedance for use with crystals operating at higher level and bolometers requiring either 4.5-ma. or 8.75-ma. bias. Further information is available from Raymond E. Jacobson, *Polytechnic Research & Development Co., Inc.*, 202 Tillary St., Brooklyn 1, N. Y.

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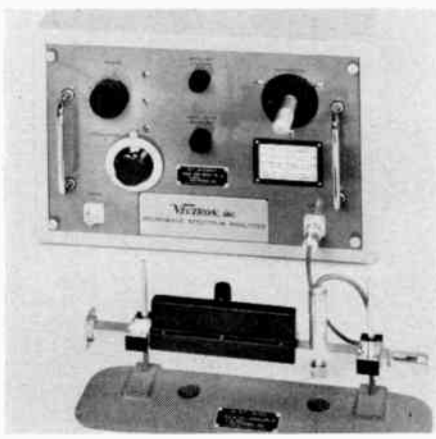
K-BAND R.F. HEADS

Covering the microwave spectrum from 12,400 to 40,000 mc., the new *Vectron* *K*-band r.f. heads are complete



microwave tuning units including r.f. assembly and *K*-band mixer. They were specifically designed for use with the SA25 microwave spectrum analyzer, but other analyzers can be modified or adapted to use these assemblies.

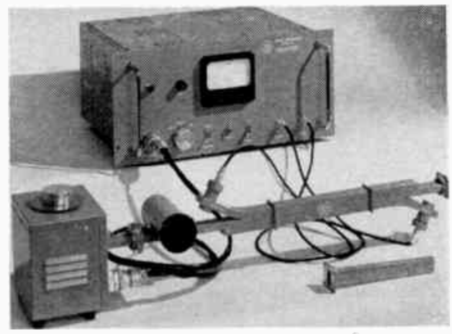
Standard *K*-band r.f. heads permit economical coverage of the most actively used portions of the spectrum; the 25K1 tunes from 15,300 to 17,700 mc., the 25K2 from 22,800 to 26,400 mc., and the 25KQ1 from 34,000 to 38,600 mc. Other portions of the band are covered by special combinations as required.

Detailed specifications and operating data are contained in Bulletin *K*-Band, available from *Vectron, Inc.*, 406 Main St., Waltham 54, Mass.

Circle No. 58 on Reader Service Card

X-BAND VSWR MEASURING SYSTEM

In addition to retaining the speed and high accuracy of earlier models, the *CTI* Model 110B *X*-band VSWR measuring system also has an attenuation scale and new VSWR scales reading from 1.02 to 1.20 and 1.1 to 2.50. Announced by *Color Television Incorporated*, 983 E. San Carlos Ave., San Carlos, Calif., the system possesses an over-all accuracy of better than 2%. Simplicity of opera-



tion facilitates its use by unskilled personnel.

The *CTI* system includes a tunable oscillator permitting complete and continuous coverage from 8500 to 9600 mc., an accurate wavemeter to supplement the direct-reading dial of the oscillator, a bidirectional coupler with bolometer detectors for incident or reflected power, and a direct-reading VSWR indicator. No adjusting or zero-setting is necessary when the oscillator is tuned through the *X* band or the load is changed.

Circle No. 59 on Reader Service Card

ELECTRONIC ABSORPTION ATTENUATORS

Roger White Electron Devices, Inc., Route 17 & Erie RR., Ramsey, N. J., has announced the GAW Series of tubes—broadband electronic microwave attenuators which are available in all wave guide bands from 2.6 to 26.5 kmc. They may be used successfully over wide ambient temperature ranges, and are well matched to the line under all conditions of operation.

Each attenuator consists of a gaseous discharge tube mounted in an appro-

priate section of rectangular wave guide. When the discharge tube is off, the insertion loss is essentially that of the wave guide. When the discharge tube is switched on, the attenuation may be varied from less than 1 db to greater than 40 db.

Circle No. 60 on Reader Service Card

DIAGRAPH

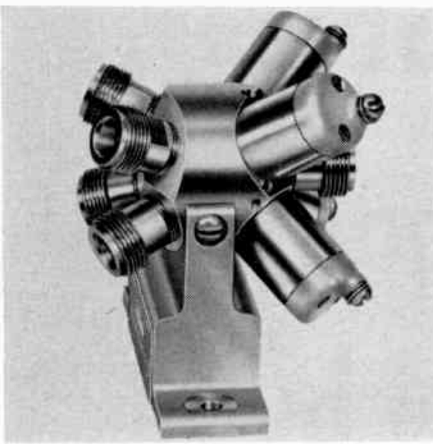
Complex impedances and admittances can be instantaneously and accurately plotted on a Smith or similar chart with the Z-g diagraph by means of a light spot. Introduced by the Instrument Division of *Federal Telephone and Radio Company*, 100 Kingsland Rd., Clifton, N.J., the Z-g diagraph eliminates tedious measurements and involved calculations usually associated with other measuring methods.

Requiring no special accessories, this instrument uses as a signal source any oscillator capable of supplying between 1 and 3 volts at the measuring frequency. It is available in two models: Type ZDU, covering the frequency range from 30 to 300 mc.; and Type ZDD, for the 300—2400 mc. range. Both have a characteristic impedance of 50 ohms and are supplied with type N connectors. Overall accuracy is better than 3% for amplitude and 1.5° for phase measurements.

Circle No. 61 on Reader Service Card

MINIATURE SP4T SWITCH

Remote control switching of four circuits is possible with the miniature SP4T broadband r.f. coaxial switch which has been added to the *Transco* line. Weighing but 12 ounces, the unit occupies only 3" x 3½" x 2½", thus providing unusual latitude in designing



with coaxial switches. Performance is said to be excellent for frequencies up through *X* band.

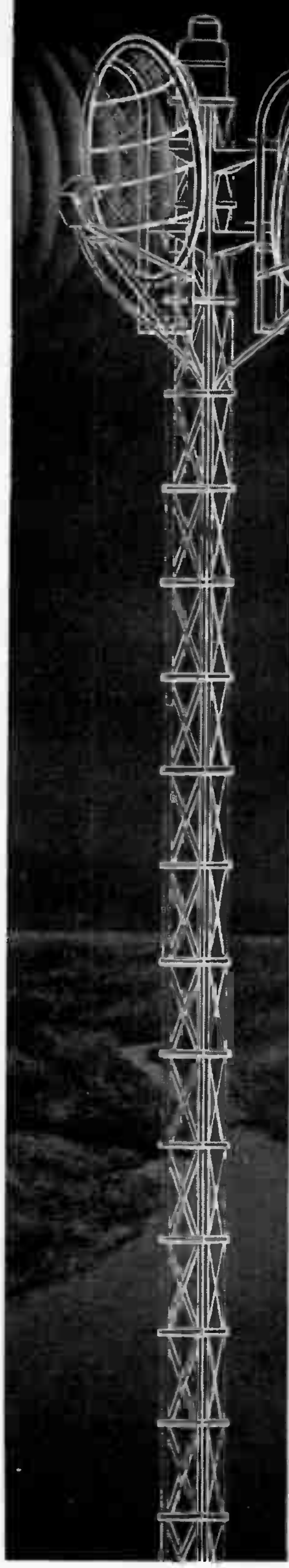
Announced by *Transco Products, Inc.*, 12210 Nebraska Ave., Los Angeles 25, Calif., the new SP4T has an actuator power rating of 18-30 volts d.c. at 0.18 amp. maximum per coil. Ambient operating temperature is −65° F to +225° F, actuating time 10 milliseconds, and life duration 500,000 operations minimum. Models are available with two r.f. circuit combinations.

Circle No. 62 on Reader Service Card

MICROWAVE ENVELOPE DETECTOR

Direct viewing of high-level r.f. pulse envelopes is possible with the Model 433 microwave envelope detector announced by *Commercial Products*, division of *Aircraft Armaments, Inc.*, 4003 Seven Mile Lane, Pikesville 8, Md. Distortions

(*Continued on page 62*)



New CONGESTION-FREE MICROWAVE SYSTEM

Now offered You by RCA for the Uncrowded 2450-2700 mc Band

If you've hesitated about Microwave because of any concern about spectrum congestion in certain areas, you'll welcome news about RCA's revolutionary MM-26. First to operate in the uncrowded 2450-2700 megacycle portion of the microwave spectrum, this new system, *offered only by RCA* means:

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No perplexing engineering problems to solve in getting your system oriented. And your system won't be subject to interference from systems now in operation, thus providing all-time reliability. Single side band suppressed carrier frequency division multiplex is used exclusively to meet highest standards of dependability.

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Available frequency space is utilized most efficiently, offering more systems in one band, thus giving added protection against obsolescence—a major economic advantage. The new system can feed into existing RCA systems and so be added to your present equipment.

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RCA's 12 basic units are readily interchangeable, which means you can put together a wide variety of stations, each designed to provide a specific combination of facilities. You get equipment exactly to your specifications, each combination being clearly explained on catalog sheets. Integrated operation of all units assures convenience and versatility in system planning, uniformly high performance.

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Conventional triode tubes, unregulated power supply, familiar circuits, obviate the need for specially trained personnel. Tuning is simplified because the frequency is controlled from the terminal through the entire system.

Microwave is today's most modern form of radio for private communications systems. A radio beam carries communications and control signals from one place to another, following a narrow line-of-sight path. RCA was one of the first to pioneer in Microwave. Today its installations cover the nation and the globe. Only RCA systems provide so many advanced engineering features. Microwave specialists will be glad to answer any questions and plan your installation. Mail Coupon below for further particulars.

New stylized racks with doors feature modern functionalized design and open back for ease of servicing. Open cabinet shows complete Microwave Terminal. Closed rack shows stand-by equipment.

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Communications Equipment
Department P-157, Building 15-1, Camden, N. J.

Please send me new booklet on RCA MM-26 Microwave—a system for the uncrowded 2450-2700 mc band, designed for pipelines, utilities, railroads, turnpike, common carrier.

NAME__________ TITLE__________

COMPANY__________

ADDRESS__________

CITY__________ ZONE____ STATE__________

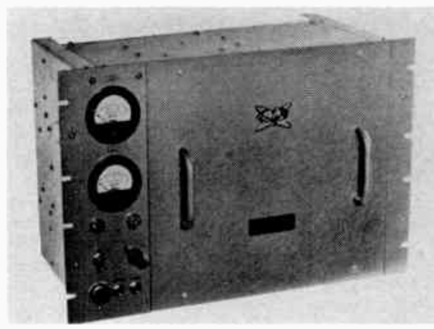
☐ Have an RCA Representative get in touch with me.

For more information, circle No. 11 on Reader Service Card

COMMUNICATION REVIEW

BASE STATION TRANSMITTER

The *COMCO* Model 450 v.h.f.-FM base station transmitter was designed to meet a demand for a moderately priced transmitter with an output greater than



the usual 30 to 60 watts but less than the more expensive 250-watt transmitter. Units are now available for the 25-54, the 72-76 and the 154-174 mc. bands. Power output for the low band is 100-125 watts; for the 72-76 mc. band, 80-100 watts; and for the high band, 60-80 watts.

Announced by *Communications Company, Inc.*, 300 Greco Ave., Coral Gables, Florida, the Model 450 has provisions for dual audio input, full simplex operation over single-pair metallic line, and "slave" or relay station operation. Use of selenium rectifiers minimizes the chance of sudden failure of the transmitter caused by rectifier tube failure and also reduces the power requirement by elimination of rectifier filament.

Circle No. 63 on Reader Service Card

MICROWAVE RADIO SYSTEMS

Contracts for four microwave radio system installations have been announced by the Engineering Products Division of *Radio Corporation of America*, Camden, N. J.—two for the Department of Highways in the State of Washington, one for the *Colorado Central Power Company*, Englewood, Colo., and one for the *Southern California Edison Company* in Los Angeles, Calif. All systems will utilize standard RCA CW-5B microwave equipment.

Circle No. 64 on Reader Service Card

SHIP-TO-SHORE SERVICE

Ship-to-shore telephone service has been made available to the S. S. Homeric, the *Home Lines'* new 26,000-ton flagship. According to the Long Lines Department of the *American Telephone and Telegraph Company*, 32 Avenue of the Americas, New York 13, N. Y., the S. S. Homeric is the 34th ship to which high seas telephone service is now being provided.

Circle No. 65 on Reader Service Card

TWO-WAY PORTABLE RADIO

Having a three-way power supply, the Model A "Pak-Fone" may be operated as a central control station when powered by 115 volts a.c., as a mobile unit when powered by a 6-volt auto battery, or as a completely portable station using its own self-contained batteries. Announced by *Industrial Radio Corp.*, 428 N. Parkside Ave., Chicago 44, Ill., it is designed for use in civil defense, fire and police departments, forestry services, and other applications where radio-telephone communications are required.

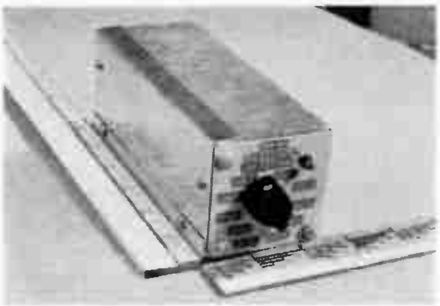
The "Pak-Fone" consists of an eight-tube crystal-controlled FM transmitter which operates in either the 50- or 140-mc. bands, and a 15-tube crystal-controlled dual-conversion superheterodyne receiver, with a special relay circuit that

automatically switches off the power-consuming radio tubes if no incoming signal is present. Clear FM voice signals are reproduced on the built-in loudspeaker.

Circle No. 66 on Reader Service Card

"SELECTO-TUNER"

Max-Sig Communications, P. O. Box 522, Medford, Oregon, has announced the development of a "Selecto-Tuner" for aircraft radio equipment. A tuning adapter for v.h.f. receivers, it permits selective tuning of any receiver and eliminates the necessity of count-calls



to find a frequency. Simple to install, the "Selecto-Tuner" operates on all frequencies between 118 and 130 mc. It is 2⅜" square by 6" long, and weighs seven ounces.

Circle No. 67 on Reader Service Card

CALENDAR of Coming Events

MARCH 21-24—Radio Engineering Show and IRE National Convention, Kingsbridge Armory and Waldorf-Astoria Hotel, New York, N. Y.

MAR. 30-APR. 1—Seventeenth Annual American Power Conference, Sherman Hotel, Chicago, Ill.

APRIL 13-15—Symposium on Modern Network Synthesis, Engineering Societies Building, New York, N. Y.

APRIL 15-16—Cincinnati IRE Annual Spring Technical Conference, Engineering Societies Bldg., Cincinnati, Ohio.

APRIL 21-23—AIEE Conference on Feed-back Control, Claridge Hotel, Atlantic City, N. J.

APRIL 27-29—Seventh Region IRE Technical Conference, Hotel Westward Ho, Phoenix, Arizona.

APRIL 29-30—New England Radio-Electronics Meeting, Sheraton Plaza Hotel, Boston, Mass.

MAY 2-5—Joint URSI-IRE Spring Meeting, National Bureau of Standards, Washington, D. C.

MAY 4-6—Electronic Components Conference, U. S. Department of the Interior, Washington, D. C.

MAY 9-11—National Conference on Aeronautical Electronics, Biltmore Hotel, Dayton, Ohio.

MAY 18-20—IRE-AIEE-IAS-ISA National Telemetering Conference, Hotel Morrison, Chicago, Ill.

MAY 26-27—IRE-AIEE-RETMA-WCEMA Electronic Components Conference, Los Angeles, Calif.

JUNE 20-25—URSI-University of Michigan International Symposium on Electromagnetic Wave Theory, University of Michigan, Ann Arbor, Mich.

JUNE 21-25—AIEE Summer and Pacific General Meeting, Biltmore Hotel, Los Angeles, Calif.

For more information, circle No. 13 on Reader Service Card

NEWS BRIEFS

"BRAIN" FOR ELECTRICAL SYSTEM

Solution of complex electrical system generating, transmission, and distribution problems will be speeded by the use of a new electronic "brain" now in operation at the *General Electric Company*, Schenectady, N. Y. Capable of remembering up to 2000 ten-digit numbers and locating any one of them in three-thousandths of a second, it fills the gap between superspeed electronic computers and standard punch-card type equipment.

This is the first time that the Type 650 magnetic drum data-processing machine, manufactured at the Endicott, N. Y., plant of *International Business Machines Corporation*, has been applied to nongovernment, scientific work.

Circle No. 68 on Reader Service Card

THERMOSTATIC CONTROLS PLANT

Robertshaw-Fulton Controls Company expects to be able to double its production of thermostatic controls and ignition devices for gas heating appliances at its new *Grayson Controls Division* plant in Long Beach, Calif. Formally opened on February 2, the three-million-dollar plant has 237,000 sq. ft. of floor space, almost twice that at the division's former location in Lynwood, Calif.

Circle No. 69 on Reader Service Card

MICROWAVE LINEAR ACCELERATOR

A radiation-producing machine designed especially for operation in the 4 to 7 million volt range has been undergoing an exhaustive test program for several months at the *High Voltage Engineering Corporation*, 7 University Rd., Cambridge 38, Mass. It is the first microwave linear accelerator to be offered commercially in the United States.

In the linear accelerator, a magnetron sends pulsed r.f. waves down an evacuated tube or wave guide. The powerful beam of electrons thus produced can be used directly in the treatment of biological or chemical systems, or it can be fired onto a gold target with x-rays being produced in the collision. Such x-rays have far greater penetrating power than x-rays normally used in medical therapy and industrial radiography.

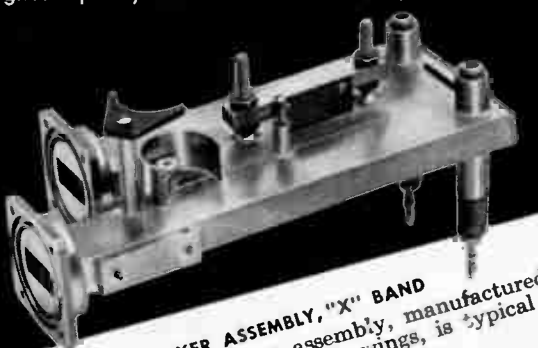
Circle No. 70 on Reader Service Card

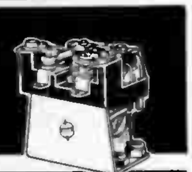
ULTRASONIC ATTENUATION ANALYZER

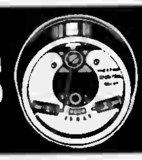
At *Vibro-Ceramics Corporation*, a *Gulton Industries* affiliate in Metuchen, N. J., an instrument has been developed that exposes the inner secrets of many materials, comprising mostly solids and some liquids, with precise accuracy. Called an ultrasonic attenuation analyzer, it enables one to determine internal changes of structure where no apparent changes show on the surface, or detect flaws and irregularities inside that can make the difference between

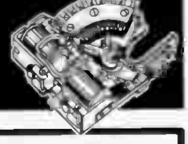
(*Continued on page* 49)

For more information, circle No. 16 on Reader Service Card









Ferromagnetism

(Continued from page 28)

Since the d.c. field is perpendicular to the broad face of the guide, the r.f. magnetic fields of the wave are considered in planes parallel to this face. Although the wave as a whole is linearly polarized, by analyzing the field pattern in these planes definite circular and elliptical polarization can be detected at various points in the planes. Figure 6 shows a rectangular wave guide with the contours of the magnetic field as they appear in such a wave guide. As the wave travels from left to right, the entire contour moves just as the crest of a wave moves along the surface of a body of water.

Now assume that there is a small stationary observer at the point P. As far as the observer can tell, he detects a magnetic field which is rotating counterclockwise if he is looking down as the wave moves by. If he moves to the center line of the broad face, he will detect only variations in the amplitude of the field, for everywhere on the centerline the field is in the same direction. If he moves to the point P′ on the other side of the guide, he finds that here the magnetic field is rotating clockwise, and at the edges of the guide he sees that the field is always longitudinal. The curves in Fig. 6 show how the polarization varies across the width of the wave guide. For a wave traveling from right to left, the sense of polarization is everywhere completely reversed as shown by the dotted curve, which is 180° out of phase with the solid curve.

A small piece of ferrite placed below the point P, and magnetized as shown by the arrow, $H_{d.c.}$, "sees" a magnetic field which is positive* circularly polarized when the wave moves from left to right and negative circularly polarized when the wave moves from right to left. The ferrite may be in the form of a thin slab, as is also shown in Fig. 6, because all points in the slab will "see" the same polarization. It will be recalled that there is a resonance in the permeability, $\mu+$, when the d.c. magnetic field is adjusted so as to make the "natural" precessional frequency coincide with the frequency of the microwave signal. There is an absorption of power associated with the resonance because as the magnetization precesses more and more violently, it interacts more and more strongly with the atoms of the material, and by exerting forces on them gives up some of its energy. An electron-atom

**Clockwise and counter-clockwise circular polarizations are defined relative to the direction along which the rotation is observed. Positive and negative are defined relative to the direction of the d.c. magnetic field. If the thumb of the right hand points in the direction of the d.c. field, the fingers point in the "positive direction," which is also the direction in which the magnetization naturally tends to precess.*

system that did not absorb power would be equivalent to an ideal *LC* circuit with absolutely no resistance. Such situations do not often occur in nature.

If the d.c. field is adjusted to produce such a resonance, it will be found that the wave traveling from left to right is largely absorbed, but a wave traveling the other way would not be absorbed because there is no resonance for negative circulary polarized fields. Again, the result is an isolator but without any circular wave guide or polarized absorber.

A variation of the above structure takes advantage of the difference between $\mu+$ and $\mu-$ at low fields. High permeability acts like a high dielectric constant in that it causes more of the wave energy to be crowded into the material. Low permeability has the opposite effect, and it will be seen, therefore, that more energy of the wave is contained in the ferrites for one direction of propagation than for the other. A film of carbon placed on the inward face of the ferrite slab will absorb a lot of energy when the fields are crowded into the ferrite region but will absorb much less when the energy is forced out of the ferrite. In actual practice, it was found that a complete null in electric field can be created on the face of the ferrite slab by the proper value of $\mu+$, and virtually no energy is absorbed from the left-to-right wave, so that an isolator with almost no loss in the forward direction and over 20-db loss in the reverse direction can be realized. The name "field displacement" isolator has been used to describe such a structure.

Summary

In the preceding paragraphs, a representative selection of devices has been discussed. A great many more have appeared in the literature, but the structures mentioned here are basic types and give a fair picture of the present state of the art. The discussion of ferromagnetic theory, while very qualitative and simplified, is basically accurate according to current physical theory. An extensive bibliography is provided for the benefit of those readers interested in more detailed information.

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Personals

ADAM E. ABEL is the new director of engineering and research for the *Bendix Radio Communications Division* of *Bendix Aviation Corporation*, Baltimore, Md. Mr. Abel, who has served as assistant director since 1952, first joined *Bendix* in 1937. At one time director of transmitter design, he was also chief engineer in charge of radar for eight years and one of the mainstays in the pioneering and development of ground-controlled approach radar.

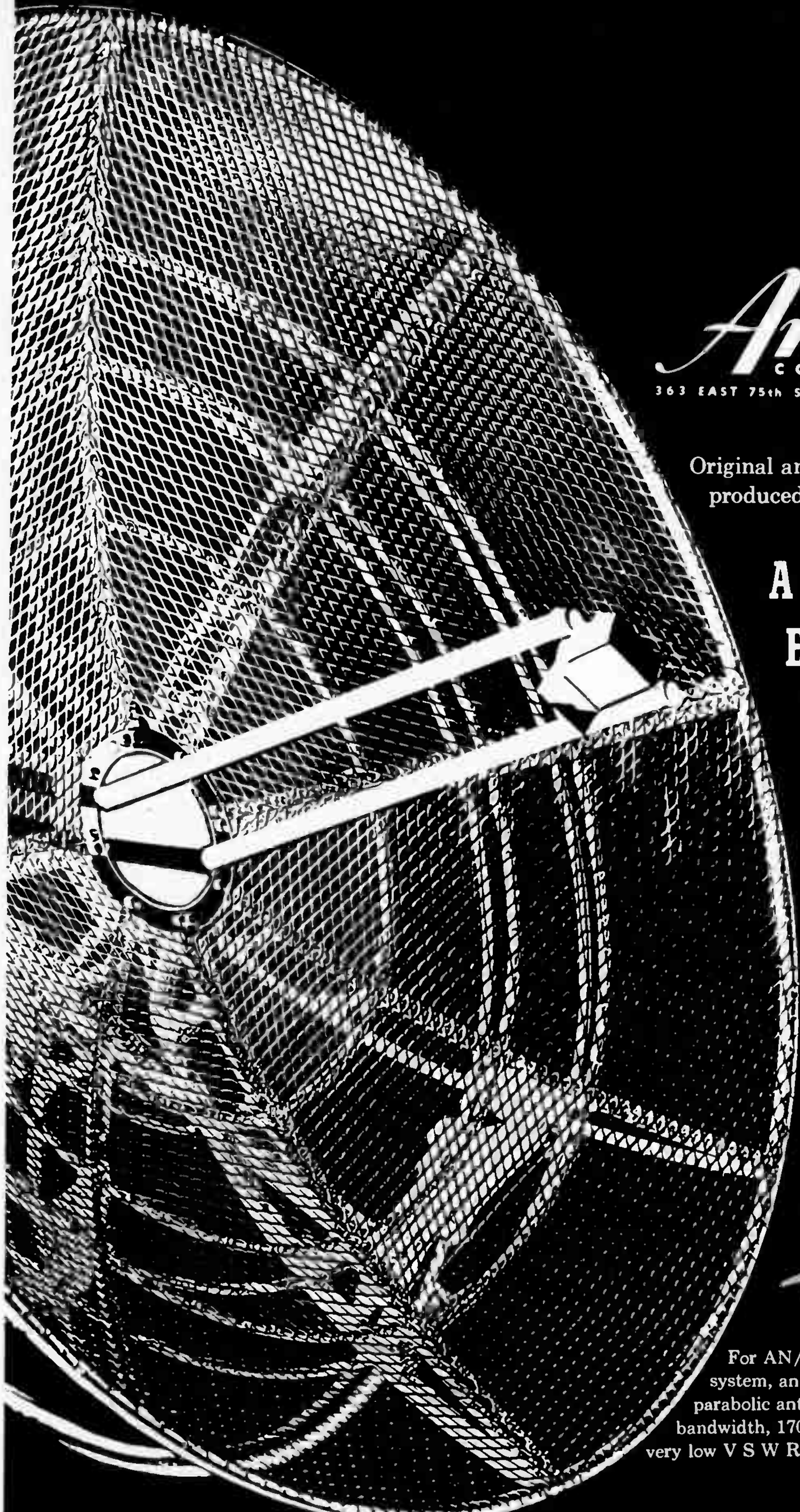
EDWARD ALPERT has been appointed an applications engineer for *Raytheon Manufacturing Company's* line of communications equipment; he will handle application problems for TV microwave relay equipment. With the Waltham, Mass., firm for almost six years, Mr. Alpert has had assignments in radar receiver design, production engineering and project engineering. He is a graduate of Syracuse University and a member of the Institute of Radio Engineers.

THEODORE C. GAMS, as director of research for the *N. J. Electronics Corp.*, Kenilworth, N. J., will direct the company's new development program in the field of electronic instruments. A lecturer in applied electronics at Polytechnic Institute of Brooklyn from 1945 to 1952, Mr. Gams has been a consultant in industrial electronics, instrumentation, and radar equipment design for the past eight years. He holds a B.S. degree in electrical engineering.

RAYMOND F. GUY, formerly manager of radio and allocations engineering for the *National Broadcasting Company, Inc.*, New York, N. Y., has now been appointed director of radio frequency engineering. Mr. Guy has been an active figure in broadcasting, television and short-wave service since their beginnings. He was for many years a director, officer and worker for the Institute of Radio Engineers, and in 1950 served as its president.

DR. HAROLD LYONS was named assistant chief for research of the Radio Standards Division of the National Bureau of Standards' Boulder (Colorado) Laboratories. In addition to directing research phases of the standards program, he will continue his work on atomic clocks and microwave frequency standards for which he received the Arthur S. Flemming Award in 1948. Dr. Lyons has been chief of the Microwave Standards Laboratory at NBS since 1946.

DR. GORDON K. TEAL, who has played a major role in research and development of semiconductor devices, will head the Research Division of *Texas Instruments Incorporated*, Dallas, Texas. Dr. Teal was associated with *Bell Telephone Laboratories* for 22 years before joining *Texas Instruments* in 1953. As assistant vice-president, research, he will have charge of all *TI* research, involving work in many phases of electronics and geophysics.



Quadriphase System

(*Continued from page* 17)

The manner in which the UB-4-A system accomplishes PPM multiplexing has been named "Quadriphase" by its inventors, and it performs the multiplexing functions for the PPM system through the use of resistance-capacitance networks and sine wave voltages in time quadrature. Some of the advantages offered by this advanced design are: (1) greater reliability; (2) lower initial cost; (3) fewer vacuum tubes; (4) improved stability; (5) fewer adjustments; (6) simplified maintenance; and (7) more compact design.

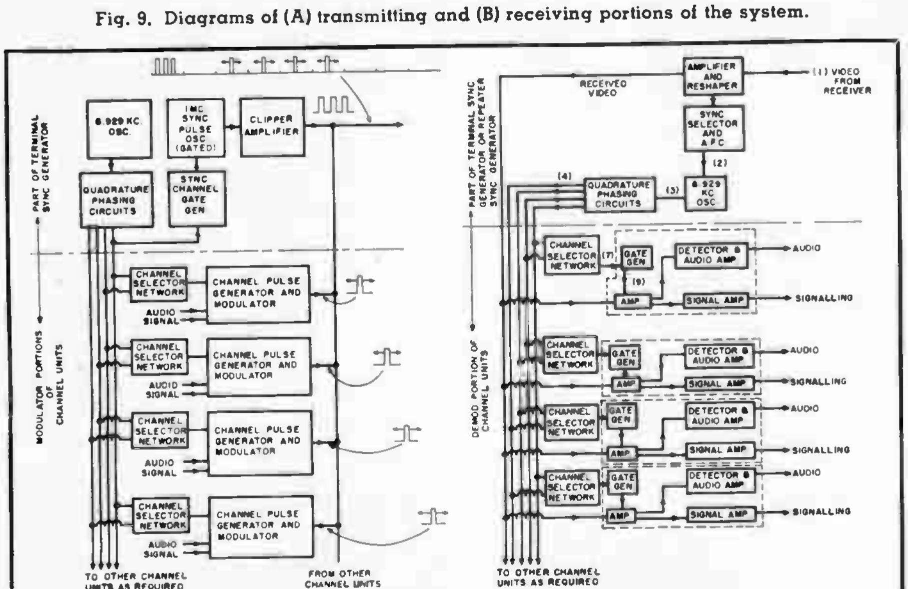
Waveforms

Quadriphase embodies a new approach to time-division multiplexing. It does not make use of video pulses, delay lines or bias voltages plus composite waveforms to achieve timing. Instead, it uses low frequency sine-wave voltages in conjunction with *RC* networks to accomplish synchronization. These networks remain stable over the lifetime of the equipment, thus minimizing maintenance and improving over-all system reliability and transmission quality. The manner in which channel commutation is accomplished is best described by reference to Fig. 8, which shows the Quadriphase waveforms present at various points in the receiving portion of the Quadriphase multiplex system. (See the block diagram in Fig. 9B.)

In Fig. 8, waveform (1) illustrates the synchronizing pulse followed by channel pulses. The sync selector circuit detects the presence of the synchronizing pulse and delivers one pulse for each sync pulse. Then, the sync separator output keys a highly stable toroid oscillator and serves to lock the frequency and phase of this oscillator to the synchronizing pulse. The sine-wave output of this oscillator is shown in waveform (3). This sine wave is fed to a simple amplifier and resistance - capacitance network which then provides the four waveforms designated as phase-splitter outputs. The four sine waves represent the original waveform shown in (3) and its reversal plus the quadrature components of these two waves. All four sine waves are shown in (4). A conventional vector diagram is used in (5) to represent the same four voltages. These four quadrature voltages are then carried by rack wiring to the channel selector sockets located along the edge of the duct covers. Completion of selection of any particular channel in the pulse train is accomplished in the channel selector plug-in unit. The manner in which this is accomplished is shown in (5) and (6).

For example, presume that it is desired to select pulse No. 1 from the pulse train. Selection of the synchronizing pulse from the sync separator circuits establishes zero time reference for all other voltages and waveforms. Channel 1 is allocated to a 4-μsec. time interval following the synchronizing pulse and its guard band. In order that the mods or demods will be able to present their information to—or accept information from—the pulse train at this interval, it is necessary that they receive a gating impulse at the proper time. Examination of (5) will show that Channel 1 occurs in time relation somewhere between quadrature voltages A and B. In order to derive a voltage component which follows voltage A by an angle Θ, it is necessary to add components of voltages A and B. This is done by the channel selection network. The vector addition is shown in (6). The addition of these two sine waves produces a third sine wave which is shown in (7) as waveform a-b.

Fig. 9. Diagrams of (A) transmitting and (B) receiving portions of the system.



Waveforms (7) and (8) illustrate successive steps whereby the point at which waveform a-b reverses polarity is used to start a gating pulse shown in waveform (9). The duration of this gating pulse is controlled in such a manner as to open the gate for Channel 1 only during that interval of time which is allocated to Channel 1. The Channel 1 pulse is then either presented to the composite waveform or accepted from the composite waveform at this time only. Thus, Channel 1 equipment does not "see" the presence of the other channels.

Numerals in parentheses in Fig. 9B indicate where the similarly numbered waveforms of Fig. 8 appear in the block diagram of the circuits. The same methods of commutation of channel units are used in both the transmitting and receiving portions of the multiplex system. With this arrangement, it is possible to provide a fixed impedance termination for the Quadriphase voltages regardless of the number of channel units installed or in operation. Because channel selection is performed entirely external to the channel unit, channel units are completely interchangeable, i.e., a channel unit may be switched from Channel No. 1 to Channel No. 5, etc., or from one location to another. The use of sine waves instead of pulses permits simple rack wiring instead of video cables.

Precision resistive and capacitive networks used for timing functions provide circuits with extreme reliability and stability. No delay line integration or base-band balancing techniques are required when equipping additional channels.

At a repeater, the multiplexing equipment performs essentially the same function as at a terminal, except that the modulators and demodulators are duplicated for each direction of transmission in the case of a party line circuit, and blanking and switching units are required. The blanking and switching units permit the station (when off-the-hook) on a party line circuit to be heard, and also permit hearing from both directions simultaneously without push - to - talk; and if the station is not in use (on-the-hook), it is completely bypassed, thereby avoiding any distortion to through transmissions by virtue of demodulation-remodulation of the signal.

UB-4-A Equipment

Type UB-4-A multiplex consists of the following units: a transmitting sync generator (UX-3-A); receiving sync generator (UX-4-A); auxiliary sync generator (UX-5-A); channel unit (UX-2-A); blanking and switching unit (UC-4-A); auxiliary channel unit (UD-2-A); service channel unit (UD-1-C); termination units (UH-2-B, C, D, E, etc.); multiplex switching unit (UC-5-A);

power supply (UP-5-A); and a power control unit (UP-7-A). The basic function of some of these units will be described briefly.

1. *Transmitting sync generator*—originates the synchronizing pulse and the quadrature waveforms used in initiating the gating of channel modulators.
2. *Receiving sync generator*—detects and separates the synchronizing pulse from the received pulse train; and from this as a reference, generates the quadrature waveforms used in the initiation of the gating channel demodulators.
3. *Auxiliary sync generator*—used at multiplex repeater stations, where its function is to generate an auxiliary synchronizing pulse in the event of failure or introduction of noise on the video train being received.
4. *Blanking and switching unit*—used at multiplexed repeaters, where it serves to perform video bridging by the removal and insertion of channel pulses in the pulse train.
5. *Channel unit*—accomplishes the modulation and demodulation of the channel pulse; it is synchronized to the 9-kc. quadrature sine waves from the sync generator in order that the intelligence being presented to it is passed only at the time allocated to the particular channel.
6. *Termination units*—perform the function of translating the intelligence delivered by the channel units into a form usable by the terminal apparatus.

The UX-2-A channel unit performs an almost universal function in this microwave system. Because all channel synchronization is done in the phasing network, all units are identical and interchangeable. As previously mentioned, in addition to providing a voice band channel, this unit provides a d.c. signaling path for dialing, telemetering or other telegraphic functions. A special test arrangement permits the input and output levels of the individual channel unit to be set without the necessity of a two-man or far-end loop arrangement. Individual channel unit power supplies eliminate the need for a supply common to more than one unit, and therefore over-all system reliability is greatly improved.

Termination units provide a wide variety of applications for the channels available on the UA-1-D system. In general, any type of communication facility which can be transmitted on a voice band can be provided. Alarm transmission and recording for use with the microwave system as an aid to system maintenance is also available as an optional item.

Mounting Arrangement

Physical space occupied by a microwave system is no small item when one considers that it has been the customary practice to use buildings of 9′ x 12′ size in most cases, and that such buildings or an equivalent amount of floor space must be provided at each equipment location. Admittedly, in simpler systems, outdoor-weatherproof cabinets are used. In systems offering 25 channels, such has not been the practice.

The UA-1-D system offers a rack-up arrangement long used by the communication industry. Figures 1 and 2 show such an arrangement which consists of a double rack, or bay, equipped on both sides (baysides) with units comprising the assembly. An integral part of the bay is the wiring duct and duct covers. All interbay and interunit cabling and customer connections are contained within this duct. The power wiring is contained within a second duct.

Normally, bayside mounting restricts access to the rear of panels. Designers of the UA-1-D system have overcome this problem by either hinging the units from one edge or putting the units on pivotal slide-outs where rear panel access is desirable. This arrangement permits a maintenance man to check a unit while in operation without "walking around" or "reaching through" a rack. Bayside racking reduces floor space by approximately 50% over an equivalent amount of conventional racking.

NEW LITERATURE

WAVE GUIDE COMPONENTS

Complete data on wave guide components for 3 to 75 kmc. are given in Catalog 55W which has been announced by *Microwave Associates, Inc.*, 22 Cummington St., Boston, Mass. Containing over 60 pages and including outline drawings, this two-color brochure is a useful reference manual for design, standards, production and purchasing personnel in the microwave field.

Circle No. 71 on Reader Service Card

FERRAMIC MAGNETIC CORES

In a four-page brochure entitled "Ferramic Magnetic Cores," *General Ceramics Corporation*, Keasbey, N. J., offers data and specifications on standard grades of Ferramic "Q." Magnetic properties are presented in graph form, and advantages are demonstrated by means of comparative characteristics.

Circle No. 72 on Reader Service Card

MICROWAVE INSTRUMENTS

Airborne Instruments Laboratory Incorporated, 160 Old Country Rd., Mineola, L. I., N. Y., has literature available on the following instruments in the microwave field: wide-range power oscillator, microwave crystal test set, precision 30-mc. attenuator, instantaneous SWR indicator, polar pattern recording system, nonresonant pressure window, rectangular coordinate recording system, and stripline low-pass filter.

Circle No. 73 on Reader Service Card

PRECISION POTENTIOMETERS

Models 162, 200 and 300 precision potentiometers are featured in a four-page bulletin available from *George Rattray & Co., Inc.*, 116-08 Myrtle Ave., Richmond Hill 18, N. Y., with complete electrical and mechanical specifications listed. The production of both linear and nonlinear potentiometers is discussed in this bulletin, and basic information is included on six production models.

Circle No. 74 on Reader Service Card

PARABOLIC REFLECTOR ANTENNAS

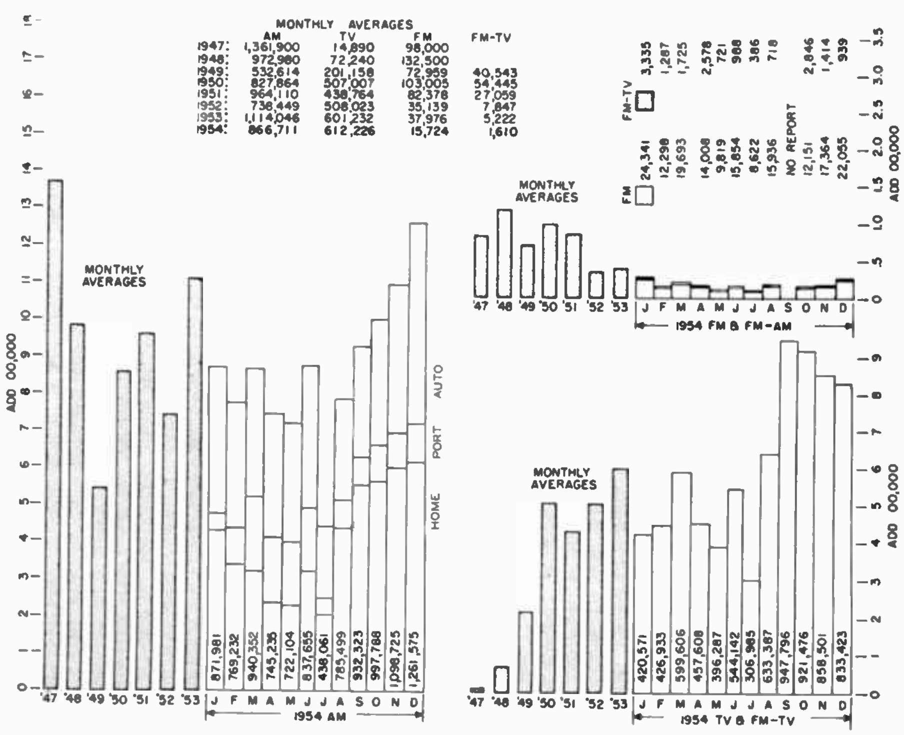
Catalog sheets C.7201, C.7202, and C.7203 describe and illustrate *RCA* mesh-type parabolic reflector antennas MI-31045. They may be obtained from Communications Equipment, *Radio Corporation of America*, Building 15-1, Camden 2, N. J.

TV-AM-FM SET PRODUCTION

Information based on latest reports from RETMA.

MONTHLY AVERAGES

	AM	TV	FM	FM-TV
1947:	1,361,900	14,890	98,000	
1948:	972,980	72,240	132,500	
1949:	532,614	201,158	72,959	40,543
1950:	827,864	507,007	103,005	54,445
1951:	964,110	438,764	82,378	27,059
1952:	738,449	508,023	35,139	7,847
1953:	1,114,046	601,232	37,976	5,222
1954:	866,711	612,226	15,724	1,610



Specifications are given in these catalog sheets, and radiation patterns show the high directivity and low side lobe characteristics of the antennas—which are designed for the 890-960 mc., 1700-1850 mc. and 1850-1990 mc. portions of the microwave spectrum.

Circle No. 75 on Reader Service Card

TV MICROWAVE RELAY EQUIPMENT

Raytheon's KTR-100A television microwave relay equipment is colorfully presented in a new eight-page brochure. Readily adaptable for broadcast, common carrier industrial or government bands, this equipment will now carry both color or monochrome video and audio simultaneously.

Copies of Bulletin 3-110 may be obtained from the *Raytheon Manufacturing Company*, Dept. 6130, 100 River St., Waltham 54, Mass.

Circle No. 76 on Reader Service Card

"JOB-PACKAGED" ANTENNA SYSTEMS

"'Job-Packaged' Antenna Systems" is the title of an article which was originally published in "Signal," the official journal of the Armed Forces Communications and Electronics Association in November-December, 1954. Available in reprint form from *Prodelin Inc.*, Kearny, N. J., it discusses *Prodelin's* experience during the past ten years in the pioneering and development of the complete engineered 'job-packaged' system. Photographs included in the reprint show various *Prodelin* products for microwave system use.

Circle No. 77 on Reader Service Card

WAVE GUIDES

An eight-page brochure has been published by the *F. C. Kent Company*, 64 Howard St., Irvington, N. J., specialists in forming wave guide tubes. Various basic wave guide shapes are shown, most of which can be combined in one piece as illustrated photographically. Engineering services are offered, and facilities are available for experimental and prototype quantities as well as production runs.

Circle No. 78 on Reader Service Card

MICROWAVE COMPONENTS

Such items as gaskets, wave guide switches, range extenders for vane-type attenuators, dummy loads, and countless other components may be made with *Crowley* Polyiron—a permeable dielectric material. In a 16-page bulletin, *Henry L. Crowley & Company, Inc.*, 1 Central Ave., West Orange, N. J., gives pertinent facts about the use of Polyiron at microwave frequencies, and illustrates several applications of this material.

Circle No. 79 on Reader Service Card

No. 2 *in a series*

design progress through inter-company co-operation

. . . coordinated by Airtron inc.

NEW...
DOUBLE-RIDGE WAVEGUIDE
for both X-band and C-band operation!

Recently, Airtron was confronted with a difficult problem—how to develop a waveguide that would perform satisfactorily for both "X" and "C"-Band operation.

Due to differences of opinion concerning the optimum frequency for airborne weather radar systems, equipment manufacturers have selected two different operating frequencies for their designs . . . 5.6 cm ("C"-band) and 3.2 cm ("X"-band). As a result, two different waveguide sizes were required. This meant that should it become advisable to switch from one frequency band to the other it would necessitate the installation of an entirely new waveguide system . . . as well as the replacement of the radar equipment.

This was highly impractical and, accordingly, a coordinated effort was set up among the airlines technical advisory organization (ARINC), leading manufacturers of radar equipment, and the engineering staff of Airtron.

Working as a team the theoretical and practical difficulties were overcome and the solution evolved in a new double ridge waveguide. The new design not only permits handling of both bands, but also results in a considerable reduction in size and weight for "C"-band and improved electrical properties for "X"-band.

This is just another concrete example of how Airtron's creative engineering . . . and their close association with leading manufacturers in all phases of electronics . . . can be of assistance to you . . . whether the components you need are new in design or so-called "standard" plumbing.

***FREE CATALOG** on Ridge Waveguide for Airborne Weather Radar . . . contains a complete description of the new ridge waveguide series. Write on your letterhead c/o Dept. J for your copy today!*

Airtron inc. Linden, New Jersey

Designers & Manufacturers of Rigid and Flexible Waveguide Components and Aircraft Accessories

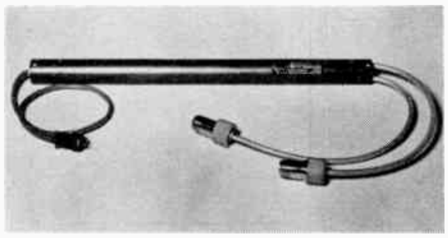
Branch Offices: Albuquerque • Boston • Chicago • Dallas • Dayton • Kansas City
Los Angeles • San Francisco • Seattle • London

For more information, circle No. 27 on Reader Service Card

NEW TUBES

TRAVELING-WAVE AMPLIFIER TUBE

Low power and high gain are featured in a new traveling-wave amplifier tube designed to operate over the 7 to 14 kmc. band. Announced by *Huggins Laboratories, Inc.*, 711 Hamilton Ave., Menlo Park, Calif., the unit requires a 400-gauss field and a 1200-volt regulated power supply. Approximate operating characteristics are 30-db gain and 5-mw. output.

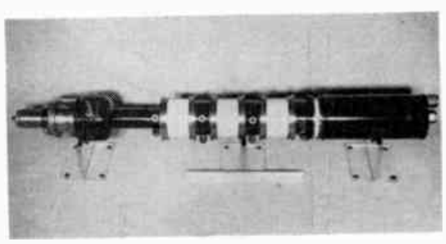


This tube will find its greatest use in applications where wide bandwidth and high gain are required at a low level, such as r.f. preamplifiers and untuned r.f. receivers, and in laboratory microwave measurement work. Grid control is provided for modulation and automatic gain-control applications.

Circle No. 80 on Reader Service Card

U.H.F. KLYSTRON

In c.w. operation at 850-1050 mc., the *Eimac* 3K50,000LQ delivers 10-kw. output with only 10-watts drive—a power gain of one thousand times. Of practical design, this new high-power u.h.f. amplifier klystron features resonant cavities completed outside the vacuum system, which is free of r.f. circuitry, permitting easy wide-range tuning and uncomplicated input and output coupling adjustment. Further information may be obtained from the Technical Services Department of *Eitel-McCullough, Inc.*, San Bruno, Calif.

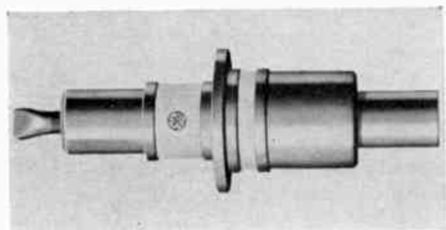


Circle No. 81 on Reader Service Card

MINIATURIZED LIGHTHOUSE TUBE

The Tube Department of the *General Electric Company*, Schenectady 5, N. Y., has announced a miniaturized lighthouse tube that permits pulsed power applications up to 4000 mc. Known as the GL-6442, it is a 2⅝"-long metal-and-ceramic tube of radically new design. The mechanical structure features an exceptionally strong grid flange for rigid mountings which, together with the use of ceramic and coplanar design, results in greater resistance to shock and vibration.

Type GL-6442 is intended for beacons, low power radar, microwave relays, navigation, special test equipment and telemetering. Peak power output at 3500 mc. is 2.0 kw. Shock-tested to 400 *g*, the tube operates safely in continuous commercial service up to 170°C seal temperature. Large-area silver-plated terminals assure low-loss contacts.

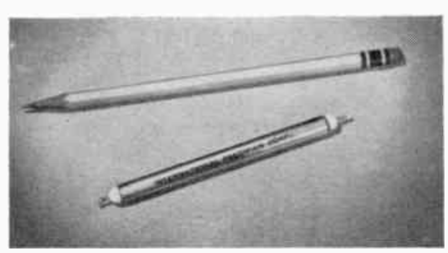


Circle No. 82 on Reader Service Card

SELENIUM RECTIFIERS

Shown in the photograph is one of a series of hermetically sealed, high voltage selenium rectifiers currently being produced by *International Rectifier Corporation* for use in airborne equipment where adverse atmospheric conditions, severe vibration and rigid electrical specifications must be met. Engineering data for specific applications and Bulletin H-2 are available from *International Rectifier Corporation*, 1521 E. Grand Ave., El Segundo, Calif.

With a maximum a.c. input of 3300 volts r.m.s., the U100HM unit pictured has an output rating of 1420 volts d.c. and 1.5 ma. at 35° C ambient temperature into a resistive load. At 71° C ambient temperature (typical airborne ambient), this unit delivers 1.2 ma. at 1360 volts d.c. from 2130 volts r.m.s. a.c. input.



Circle No. 83 on Reader Service Card

News Briefs

(*Continued from page* 36)

good and bad performance by such materials.

When a small transducer is placed against the material to be tested, it beams a short ultrasonic signal through the material. The analyzer then records the return pulses reflected by the material for comparative information.

Circle No. 84 on Reader Service Card

AUDIO MAGAZINE EDITORS

Dr. Vincent Salmon, manager of the sonics section at Stanford Research Institute, Stanford, Calif., has been appointed editor of the "Journal of the Audio Engineering Society." He succeeds Lewis S. Goodfriend, now editor of "Noise Control" published by the Acoustical Society of America.

Circle No. 85 on Reader Service Card

First Microwave System

(*Continued from page* 24)

ing operations are performed rapidly with hardly a break in normal service.

Circuit Details

A diagram of a typical station is shown in Fig. 1. Communications which are applied to the microwave system from the multiplex equipment are fed to a reactance tube modulator which frequency-modulates a 40-mc. oscillator to a peak deviation of ±1.5 mc. Multiplication is not required to attain the carrier frequency range.

First, the 40-mc. signal is shifted to 70 mc. by beating with a 110-mc. oscillator. Then, additional heterodyning with a microwave frequency oscillator in the transmitter unit produces the carrier.

Incoming signals at a terminal station are received by the same parabolic reflector antenna which radiates the transmitted carrier in the opposite direction. A duplex filter arrangement separates the transmitting and receiving branches, and suppresses the receiver image response. Received signals are applied to a mixer stage, excitation for this stage being provided by the same microwave oscillator which generates the outgoing carrier. The 30-mc. i.f. amplifiers and limiters feed the discriminator, which provides the 300-cycle to 160-kc. base-band complement. By also using the discriminator d.c. output to control the high frequency oscillator signal, the i.f. signal is effectively centered in the i.f. passband. This action constitutes an additional a.f.c. loop which always maintains the receiver unit in exact tune with the incoming signal. At a terminal station, this signal is applied to a base-band unit, and then further demodulated by the multiplex equipment into individual channels.

At a repeater station, the received carrier is heterodyned to 30 mc. After this signal passes a first limiter stage, it is shifted to 70 mc. by heterodyning with a 40-mc. oscillator. The 70-mc. signal is then applied directly to the mixer of the transmitter, where it is heterodyned with the r.f. oscillator signal to produce the carrier which is propagated to the next station. In this manner, through channels can pass through numerous relay points—including drop repeater stations — with a minimum of crosstalk and variations in levels.

For all operational users of microwave, the 2450-2700 mc. band offers an opportunity to establish a system with relative ease, unencumbered by restrictions imposed by existing systems, and with freedom to choose ideal station locations. Type MM-26 equipment, the first to be designed specifically for this band, makes use of proved design features and conventional circuits, and can be relied upon to provide the all-weather dependability for which microwave is noted.

Double Ridge Wave Guide

(*Continued from page* 19)

scribed by Vogelman. For both *C* band and *X* band, attenuation was found to be 0.047 db/ft. at 5400 mc. and 0.043 db/ft. at 9375 mc. Using 12′ or 14′ runs with elbows and straight sections, measurements of attenuation were checked by the insertion loss method and were found to agree very closely with the standing wave method, so that the values tabulated were felt to be accurate within at least 5%.

The attenuation of .047 db/ft. for *C*-band operation can be compared to the published value for aluminum 2″ x 1″ wave guide of .018 db/ft., and is roughly 2½ times as great. Such attenuation is well within the goal set for this guide, and it is felt that with production samples .05 db/ft. at *X* band or *C* band can be guaranteed.

An entirely different picture is presented by the attenuation at *X* band, which is less than the standard attenuation for 1.000″x0.500″ guide (nominally about .06 db/ft.), so that there is some saving in using this double ridge guide at *X* band. It is, of course, slightly larger than the equivalent *X*-band guide, and thereby exhibits higher peak power-handling capabilities. The principal feature of the double ridge guide, obviously, is its much reduced size in comparison to an equivalent *C*-band wave guide. Its cross-sectional area is one-half that of *C*-band wave guide.

In the electrical measurements of the straight sections, elbows and other double ridge wave guide components, an interesting observation is made. Apparently, the stiffness of the broad wall of the wave guide due to corrugation by the double ridge adds considerably to the rigidity of the guide and, thus, individual discontinuities along the length of the guide which normally account for production VSWR's are appreciably reduced. Therefore, it is felt that somewhat lower VSWR's can be achieved with double ridge wave guide despite the fact that for an equivalent operating frequency range the gap dimensions are more critical than those of conventional guide. On the whole, the tolerances for this particular double ridge guide are no more severe than they are for 1.000″ x 0.5000″ guide.

Because of the extreme operating bandwidth, the use of choke flanges with this wave guide is out of the question. The runs that are planned (from radio equipment rack to the nose of the aircraft) require a pressurized junction and, therefore, a pressurized contact flange has been designed based on a combination r.f. and air gasket principle which has seen considerable use in duplexers and similar applications. This gasket design has been adopted for a number of miniature contact flange applications.

Under ordinary conditions, the gap existing between flange faces is very small, and it has been determined experimentally that the VSWR contributions are exceptionally low even with a gap as large as 0.015″. It also has been determined that a joint of this type will take up to the full peak power rating of the wave guide without breakdown provided the gap spacing is not greater than .008″. By bringing the mounting screws close to the gasket groove, the resulting flange junction is much more compact than the *C*-band standard flanges and is inherently insensitive to frequency operation.

The basic hole layout is derived from the principles that have been set forth for the miniaturized contact flanges which are now up for standardizaton at RETMA. Figure 3 is a photograph of a flange and gasket designed to mate with a plain flange having tapped holes around the periphery.

Construction

Construction of a double ridge flexible wave guide has been made possible by the use of *Airtron* type "S" two-piece flexible tubing. This tubing is stamped from beryllium copper sheets in two identical half-sections which are mated and high-temperature-brazed along the narrow edges, resulting in an annular bellows structure which has excellent mechanical flexibility (Fig. 4). The peak power-handling capabilities required by the system must be taken into account in designing the gap spacing to give maximum peak power performance over the broad bandwidth. It is possible by means of these techniques to obtain peak power-handling capabilities of 500 kw. at *C* band and 400 kw. at *X* band without any sacrifice in electrical properties for the double ridge flexible wave guide.

These flexible wave guides normally are furnished jacketed with a low temperature neoprene rubber for insurance of airtightness and protection of the flexible metal tubing in service. Because of the longer guide wavelength in double ridge guide at the lower frequencies, its use is not practical for the internal plumbing components of the receiver-transmitter unit. Therefore, as a rule, either *C*-band or *X*-band components with single step transitions to double ridge guide have been employed, usually in the form of a choke flange transition combination. The receiver - transmitter units generally slide into a shock mount where a spring-supported output wave guide section mates with the output of the RT unit. This section then is connected through a piece of double ridge flexible guide to the rigid double ridge wave guide run to the antenna. A similar piece of flexible wave guide is used between the transmission line and rotary joint input. In the design of antenna components, there is considerable advantage in the use of double ridge wave guide for the rotary joint where the reduced wave impedance is advantageous for coaxial transition design.

Figure 5 shows a wave guide system for one of the *C*-band weather penetration radars where double ridge guide has been used throughout. The rotary joint has double ridge wave guide input and output along with a complex *E*- and *H*- plane twist section to connect to the feed assembly. The feed assembly is unique in that it uses a dielectric ring focus feed which has an inherent transition from double ridge guide to circular dielectric-filled guide for the feed section. This results in a much smaller over-all diameter, less masking of the dish area, and a more efficient antenna of the same wavelength range. The feed is a precision casting employing a linear tapered transition to the dielectric ring focus feed, all of which contributes to extremely good peak power-handling capabilities.

Directional couplers, especially as reflectometers for measuring line VSWR's, have been constructed in double ridge guide along with tuners for matching out the long wave guide runs between the receiver-transmitter unit and the antenna. The design of these directional couplers follows more or less conventional techniques with both broad wall to broad wall coupling, narrow wall to narrow wall coupling, and crossguide coupling designs available for various values in coupling and directivity as required by the particular application.

Double ridge guide has made complete the integration of the aircraft wiring and wave guide installation for *C*-band and *X*-band weather radars. Its successful use in this commercial weather penetration radar has opened the way to other applications for airborne radar equipment at other frequencies. Designs have been started for double ridge wave guide at 3000 mc. which feature a 60% reduction in size with 6 megawatts peak power-handling capability at atmospheric pressure. It is hoped that these techniques can be extended to other airborne applications with the resultant saving in size and weight.

Editor's Note: For further information on the subject of ridge wave guide, see the article entitled "Characteristics of Ridge Wave Guide" on page 25. See also the abstract entitled "Microwave Components for Double Ridge Wave Guide" appearing in the January, 1955, issue of RADIO-ELECTRONIC ENGINEERING.

MICROWAVE MANUFACTURERS' DIRECTORY

Directory of the major manufacturers of microwave equipment and a listing of their products. See also the Product Directory on page 56.

MANUFACTURERS	PRODUCTS
Adler Communications Laboratories 1 Le Fevre Lane, New Rochelle, N. Y. *Sales Manager*, C. J. Auditore	Microwave systems and components, power generating equipment, towers.
Airborne Instruments Laboratory, Inc. 160 Old Country Rd., Mineola, N. Y. *Director of Sales*, E. R. Godfrey	Test equipment, VSWR indicators, pressure windows, strip-line components.
Aircraft Armaments, Inc. P. O. Box 126, Cockeysville, Md. *Vice-President*, R. B. Chapman III	Test equipment, frequency stabilizers, special-purpose components.
Aircraft Armaments, Inc., Commercial Products Division 4003 Seven Mile Lane, Baltimore, Md. *Acting Manager*, M. J. Frank	Detectors, crystal mounts, wave guide fixtures, power meters.
Airtron Inc. 1101 W. Elizabeth Ave., Linden, N. J. *Sales Engineer*, Bob Terry	Rigid and flexible wave guides and components, VSWR standards, dummy loads.
Allied Research & Engineering Division, Allied Record Manufacturing Company 6916 Santa Monica, Hollywood, Calif. *Sales Manager*, William G. Onderdonk	Wave guides and components.
Amerac Incorporated 116 Topsfield Rd., Wenham, Mass. *Sales Manager*, Owen I. Haszard	Wave guides and components, test equipment, antennas, wavemeters.
American Phenolic Corporation 1830 South 54th Ave., Chicago 50, Ill. *Sales Manager*, Richard E. Hall	Cables and connectors.
Amperex Electronic Corp. 230 Duffy Ave., Hicksville, L. I., N. Y. *President*, Sam Norris	Magnetrons, hydrogen thyratrons, reflex klystrons.
Andrew Corp. 363 E. 75th St., Chicago 19, Ill. *Sales Manager*, Robert P. Lamons	Parabolic antennas and accessories, rigid and flexible coaxial line.
Arma Division, American-Bosch-Arma Corp. Roosevelt Field, Garden City, N. Y. *Vice-President, Sales*, L. R. Fiedler	Antennas, wave guides and components.
Autel Electronics Co. 1948 Farmingdale Rd., Westfield, N. J. *President*, G. J. Uminski	Engineering and developmental work on microwave equipment.
Automatic Signal Division, Eastern Industries, Inc. Regent St., E. Norwalk, Conn. *Sales Manager*, P. L. Green	Radar for measuring vehicle speeds.
Bendix Aviation Corporation, Red Bank Division Eatontown, N. J. *Sales Manager*, N. P. Barny	Klystrons, *TR* tubes.
Bird Electronic Corporation 1800 E. 38th St., Cleveland 14, Ohio *Sales Manager*, Walter Widlar	Coaxial switches and filters, load resistors, wattmeters.
Bludworth Marine Division, National-Simplex-Bludworth, Inc. 92 Gold St., New York 38, N. Y. *Vice-President*, Willard C. Blaisdell	Radar equipment.
Bogart Manufacturing Corp. 315 Seigel St., Brooklyn 6, N. Y. *Sales Manager*, David Krieger	Test and measuring equipment, wave guides and components, antennas.
Bogue Electric Manufacturing Co. 52 Iowa Ave., Paterson, N. J. *Sales Manager*, J. Rambusek	Power generating systems.
Bomac Laboratories Inc. Salem Rd., Beverly, Mass. *Sales Manager*, Earle D. Benson	Magnetrons, klystrons, hydrogen thyratrons, switching tubes, wave guide components.
Bone Engineering Corporation 701 W. Broadway, Glendale 4, Calif. *General Manager*, Wm. L. Worthen	Wave guides and components, antennas.
Browning Laboratories, Inc. 750 Main St., Winchester, Mass. *Vice-President*, William B. Wilkens	VSWR amplifiers, klystron power supplies.
Bruno-New York Industries Corporation 460 W. 34 St., New York 1, N. Y. *Sales Manager*, E. H. Godfrey	Power meters, bolometer elements, coaxial attenuators.
Budd-Stanley Co., Inc. 43-01 22nd St., Long Island City 1, N. Y. *Sales Manager*, Jules Simmonds	Wave guides and components, antennas, attenuators, dummy loads.
Budelman Radio Corporation 375 Fairfield Ave., Stamford, Conn. *Sales Manager*, William Fingerle, Jr.	Microwave systems, and multiplexing equipment.
Byron Jackson Co. 2010 Lincoln Ave., Pasadena, Calif. *Engineer*, John Hawkins	Signal generators, power meters, slotted lines, coaxial filters.
Canoga Corporation 5955 Sepulveda Blvd., Van Nuys, Calif. *Sales Manager*, G. H. Nibbe	Antennas, duplexers, special components.
Cascade Research Corporation 53 Victory Lane, Los Gatos, Calif. *Sales Manager*, Jerome S. Jaffe	Unidirectional transmission line, microwave amplitude modulators, ferrite duplexers.
Centralab, Division of Globe-Union Inc. 910Y E. Keefe Ave., Milwaukee 1, Wis. *Sales Manager*, D. E. Thatcher	Printed circuits, insulators, capacitors.
CGS Laboratories, Inc. 391 Ludlow St., Stamford, Conn. *Vice-President*, M. L. Jackson	Oscillator cavities, wave guide equipment.
Chemalloy-Electronics, Inc. Gillespie Airport, Santee, Calif. *President*, Samuel Freedman	Calorimeters, water loads, cast wave guides.
Collins Radio Company 1930 Hi-Line Drive, Dallas 2, Texas *Sales Manager*, T. E. Daniels	Communications equipment, antennas and reflectors, packaged microwave systems, test equipment.
Color Television Incorporated 973 E. San Carlos Ave., San Carlos, Calif. *Sales Manager*, Carl C. Trost	X-band VSWR indicators, antennas.
Columbia Wire & Supply Co. 2850 Irving Park Rd., Chicago, Ill. *Sales Manager*, L. A. Harris	Coaxial cable.
Co-Operative Industries, Inc. 100 Oakdale Rd., Chester, N. J. *Sales Manager*, V. C. Bonardel	Flexible and rigid wave guides and assemblies.
Corning Glass Works Corning, N. Y. *Gen. Sales Mgr.*, Campbell Rutledge, Jr.	Microwave windows, attenuator plates.
Crowley & Co., Inc., Henry L. 1 Central Ave., W. Orange, N. J. *Sales Manager*, Ray E. Walker	Dummy loads, polyiron, wave guide switches and terminations, attenuators.
Cubic Corporation 2841 Canon St., San Diego 6, Calif. *Sales Manager*, Donald E. Root	Test equipment, wave guide components, attenuators, dummy loads.
Dalmo Victor Company 1414 El Camino Real, San Carlos, Calif. *Sales Manager*, Eugene L. Rogers	Wave guides and components, antennas, rotary switches.
Decade Instrument Company Box 153, Caldwell, N. J. *Sales Manager*, John Gilmore	Wave guides.
DeMornay-Bonardi 780 S. Arroyo Parkway, Pasadena, Calif. *Sales Manager*, L. C. Spoor	Test equipment, dummy loads, wave guide components, power supplies, VSWR equipment.
Designers for Industry Inc. 2915 Detroit Ave., Cleveland 13, Ohio *Vice-Pres., Contracting*, J. E. Burnett	Research and development on components, test equipment, microwave systems.
Diamond Microwave Corporation 7 North Ave., Wakefield, Mass. *General Manager*, Albert S. Hovannesian	Wave guides and components, test and measuring equipment.
Douglas Microwave Co., Inc. 11 Beechwood Ave., New Rochelle, N. Y. *Sales Manager*, Herbert Hendlin	Wave guides and components, test and measuring equipment.
Du Mont Laboratories, Inc., Allen B., Communication Products Division 1500 Main Ave., Clifton, N. J. *Sales Manager*, James B. Tharpe	Microwave relay equipment.
Eitel-McCullough, Inc. 798 San Mateo Ave., San Bruno, Calif. *Sales Manager*, O. H. Brown	Klystrons, tetrodes and triodes.
Electron-Radar Products 1041 N. Pulaski Rd., Chicago 51, Ill. *Sales Manager*, J. J. Bailey	Antennas, attenuators, power meters, wavemeters.
Electro Precision Products, Inc. 139-30 34th Rd., Flushing, N. Y. *Sales Manager*, J. J. McCann	Coaxial connectors, wave guide equipment.
Empire Devices Products Corp. 38-15 Bell Blvd., Bayside 61, N. Y. *President*, Michael T. Harges	Coaxial mixers and attenuators, impulse generators.
Engineering Associates 434 Patterson Rd., Dayton 9, Ohio *Sales Manager*, Charles C. Littell, Jr.	Receivers and test equipment.
Espey Mfg. Co. 528 E. 72nd St., New York 21, N. Y. *Sales Manager*, Charles G. Kalt	Test equipment, cavities, wave guide assemblies.
Federal Manufacturing and Engineering Corporation 199-217 Steuben St., Brooklyn 5, N. Y. *Sales Manager*, Robert S. Schlanger	Heterodyne frequency meters, signal generators.
Federal Telecommunication Laboratories, Division of I.T.&T. 500 Washington Ave., Nutley, N. J. *Vice-President*, J. G. Copelin	Microwave relay equipment, microstrip, traveling-wave tubes.
Federal Telephone & Radio Company, Division of I.T.&T. 100 Kingsland Rd., Clifton, N. J. *Sales Manager*, W. D. Siddall	Microwave communication systems.
Franklin Electronics Inc. 415 W. Pike St., Philadelphia 40, Pa. *Sales Manager*, Burton W. Dempster	Sweep signal generators, crystal holders, klystron power supplies.
Frequency Standards P. O. Pox 504, Asbury Park, N. J. *Sales Manager*, J. Kelsey Burr III	Coaxial and wave guide wavemeters.
F-R Machine Works, Inc., Electronics & X-Ray Division 26-12 Borough Pl., Woodside 77, N. Y. *Sales Manager*, Henry Feldmann	Test equipment, VSWR amplifiers, spectrum analyzers, wave guide components.
Gabriel Electronics Division, The Gabriel Company Endicott St., Norwood, Mass. *Sales Manager*, John Martin	Passive reflectors, antennas and antenna feeds.

Garod Radio Corporation..................Spectrum analyzers.
70 Washington St., Brooklyn 1, N. Y.
Sales Manager, M. Raphael

General Ceramics Corporation..............Ferrite cores for gyrators, switching and attenuator elements.
Keasbey, N. J.
Sales Manager, F. F. Sylvester

General Communication Company..........*X*-band test equipment, coaxial switches.
681 Beacon St., Boston 15, Mass.
Sales Manager, J. B. Hamre

General Electric Company..................Microwave communication equipment.
Electronics Park, Syracuse, N. Y.
Sales Manager, E. W. Kenefake

General Electric Company..................Klystrons, magnetrons, radar switching tubes.
1 River Road, Schenectady, N. Y.

General Radio Company...................Coaxial connectors and elements, mixers, baluns, bolometers and bridges, terminations, test equipment.
275 Massachusetts Ave.,
Cambridge 39, Mass.
Sales Manager, Myron T. Smith

General R-F Fittings Co., Inc...............Coaxial and wave guide fittings, attenuators, antennas, wavemeters, probes.
702 Beacon St., Boston 15, Mass.
Sales Manager, F. E. Marshall

Gertsch Products, Inc......................Microwave generators and frequency meters.
11846 Mississippi Ave.,
Los Angeles 25, Calif.
Sales Manager, E. P. Gertsch

Goodyear Aircraft Corporation.............Test equipment, radar, radomes, antennas.
1210 Massillon Rd., Akron 15, Ohio
Radar & Elec. Sales, H. P. Partenheimer

Graham Manufacturing Co., Inc., The.....Wave guide and coaxial components, terminations, slotted sections, tuners, tube mounts.
47 Bridge St., E. Greenwich, R. I.
Sales Manager, Richmond Viall, Jr.

G. W. Associates...........................Custom wave guide components, test equipment.
P. O. Box 2263, El Segundo, Calif.
Sales Manager, V. V. Gailbraith

Hewlett-Packard Company.................Wave guide and coaxial components, test equipment, terminations, loads.
275 Page Mill Rd., Palo Alto, Calif.
Sales Manager, W. Noel Eldred

Huggins Laboratories.....................Traveling-wave tubes, backward-wave amplifiers.
711 Hamilton Ave., Menlo Park, Calif.
Sales Manager, R. A. Huggins

Hycon Mfg. Company.....................Wave guides and components for *X* and *C* band, adapters, frequency meters, attenuators.
2961 E. Colorado Ave., Pasadena, Calif.
Sales Manager, John R. Thompson

Industrial Products Company,
Division of Danbury-Knudsen Inc.........Coaxial connectors and switches, wave guide assemblies.
Danbury, Conn.
Sales Manager, Frank C. Knudsen

I-T-E Circuit Breaker Company,
Special Products Division...............Antenna systems, reflectors, radar equipment.
601 E. Erie Ave., Philadelphia 34, Pa.
Sales Manager, S. M. King

Kay Electric Company....................Gain sets, signal and noise sources, VSWR equipment, test and measuring equipment.
14 Maple Ave., Pine Brook, N. J.
Sales Manager, John Gilmore

Keller Products Inc........................Reflectors and radomes.
41 Union St., Manchester, N. H.
Sales Engineer, Robert I. Solow

Kennedy & Co., D. S.......................Antennas, radomes, lenses, wave guides and components.
432 S. Main St., Cohasset, Mass.
Sales Manager, C. W. Creaser

Kent Co., F. C.............................Wave guide tubing.
64 Howard St., Irvington, N. J.
Sales Manager, W. H. Kean, Jr.

Kings Electronics Co.......................Wave guides and components, test equipment, dummy loads, attenuators, directional couplers.
40 Marbledale Rd., Tuckahoe 7, N. Y.
Sales Manager, William R. Clayton

Korb Engr. & Mfg. Co......................Tuned cavities.
30 Ottawa Ave., Grandville, Mich.
Sales Manager, A. W. Korb

Lavoie Laboratories, Inc...................Test equipment, radar systems, wave guides and components.
Matawan-Freehold Rd., Morganville, N. J.
Sales Manager, J. H. Smiley

Lewis & Kaufman, Ltd.....................Tubes.
P. O. Box 337, Los Gatos, Calif.
President, Jack Kaufman

Lieco, Inc...................................Wave guides and components, terminations, adapters, assemblies.
147 Ocean Ave., Lynbrook, L. I., N. Y.
Sales Manager, A. Zeitz

Litton Engineering Laboratories...........Water loads, phase changers, calorimeters.
P. O. Box 949, Grass Valley, Calif.
Sales Manager, Glenn Lewis

Loral Electronics Corp.....................Radar receivers, signal generators, microstrip.
794 E. 140th St., New York 54, N. Y.
Microwave Sales, W. C. Evans

Luhrs & Co., C. H.........................Microwave switches and phase shifters.
297 Hudson St., Hackensack, N. J.
President, C. H. Luhrs

Magnavox Co., The........................Radar test equipment.
Fort Wayne 4, Ind.
Mgr., Electronic Sales, David W. Martin

Makepeace Co., D. E., Division of
Union Plate & Wire Co....................Wave guides and components, assemblies, antenna feeds.
Pine & Dunham Sts., Attleboro, Mass.
Sales Manager, Walter Channing, Jr.

Manson Laboratories......................Hard and soft tube modulators.
207 Greenwich Ave., Stamford, Conn.
Partner, Sandford Jacobson

Marconi Instruments Ltd..................Test equipment, wavemeters, spectrum analyzers, klystrons.
23-25 Beaver St., New York 4, N. Y.
Sales Manager, R. J. Bailey

Mark Products Co.........................Helical beam antennas, beacon antennas.
6412 W. Lincoln Ave., Morton Grove, Ill.
Sales Manager, E. Harris

Maxson Corporation, W. L., The...........Radar antennas.
460 W. 34th St., New York 1, N. Y.
Sales Manager, J. W. Bjorkman

Measurements Corporation................Signal generators.
Boonton, N. J.
Sales Manager, Nelson D. Doland, Jr.

Meridian Metalcraft, Inc...................Wave guides.
213 W. Whittier Blvd., Whittier, Calif.

Metals & Controls Corporation,
General Plate Division..................Wave guide tubing.
Attleboro, Mass.
Product Manager, John E. Woodward

Metal Textile Corporation..................Wave guide gaskets, r.f. shielding, knitted-mesh tube shields.
647 E. 1st Ave., Roselle, N. J.
Sales Manager, O. P. Schreiber

Mico Instrument Company..................Coaxial wavemeters, miniature inductors.
80 Trowbridge St., Cambridge 38, Mass.
Sales Manager, R. F. Walker

Microlab..................Coaxial attenuators, terminations and filters, stub tuners, frequency multipliers.
70 Okner Parkway, Livingston, N. J.
Sales Manager, H. A. Augenblick

Microwave Associates Inc...................Wave guide test equipment, magnetrons, *TR* and *ATR* tubes, silicon diodes.
22 Cummington St., Boston 15, Mass.
Sales Manager, D. W. Atchley, Jr.

Microwave Development Labs., Inc...........Wave guide components and assemblies, directional couplers, cavities.
92 Broad St., Wellesley 57, Mass.
Sales Manager, Nathaniel Tucker

Microwave Services, Inc...................(Consultants)
45 Rockefeller Plaza, New York 20, N. Y.
President, V. J. Nexon

Model Engineering and Mfg. Inc...........Wave guide components and fittings, signal generators.
50 Frederic St., Huntington, Ind.
Sales Manager, A. E. Williams

Motorola Communications and
Electronics, Inc...................Microwave relay equipment for television and communications, radar equipment.
4501 W. Augusta Blvd., Chicago 51, Ill.
Sales Manager, James E. Stewart

Narda Corporation, The..................Wave guide components, frequency meters, bolometers, tuners, impedance meters.
66 Main St., Mineola, N. Y.
Sales Manager, William A. Bourke

New London Instrument Company, Inc......Signal generators, noise sources.
P. O. Box 189, New London, Conn.
Sales Manager, Dale Pollack

N.R.K. Mfg. & Eng. Co...................Wave guide components, horns, dummy loads, rotary joints, switches.
4601 W. Addison St., Chicago 41, Ill.
Sales Manager, Frank Neukirch

Onan & Sons, Inc., D. W...................Power generating systems.
2515 University Ave., S.E.,
Minneapolis, Minn.

Panoramic Radio Products, Inc.............Spectrum analyzers.
10 S. Second Ave., Mt. Vernon, N. Y.
Sales Manager, Bernard Schlessel

Penta Laboratories, Inc...................Traveling-wave tubes.
216 N. Milpas St., Santa Barbara, Calif.
Sales Manager, J. E. Lannan

Petroff, Peter A...................Wave guide components, directional couplers.
127-9 Water St., New York 5, N. Y.
Proprietor, Peter A. Petroff

Philco Corporation,
Government and Industrial Division......Complete microwave systems, test equipment, systems planning.
4700 Wissahickon Ave., Phila. 44, Pa.
Industrial Sales Mgr., G. A. Hagerty

Polarad Electronics Corp...................Signal generators, spectrum analyzers, power meters, klystron tube testers.
43-20 34th St., L.I.C. 1, N. Y.
Sales Manager, Alfred A. Goldberg

Polytechnic Research &
Development Co., Inc...................Wave guide components, test and measuring equipment, attenuators.
202 Tillary St., Brooklyn 1, N. Y.
Sales Manager, Harry C. Nelson

Premier Instrument Corp...................Wave guide components, crystal mounts, cavities.
52 W. Houston St., New York 12, N. Y.
Vice President, Irving M. Gross

Press Wireless Laboratories, Inc.............Adapters, attenuators, dummy loads, test equipment, *TR* boxes, echo boxes.
25 Prospect Pl., W. Newton 65, Mass.
Sales Manager, L. Roy Lapidus

Prodelin, Inc...................Coaxial lines and fittings, antennas, adapters, towers.
307 Bergen Ave., Kearny, N. J.
Sales Manager, J. F. Cosgrove

Pye Limited..................Microwave television links.
200 Fifth Ave., New York, N. Y.
William Cagney

Radiation, Inc...................*S*-band wavemeters, cavities, and detector mounts. *L*-band amplifiers and detectors.
Melbourne, Fla.
Sales Manager, W. W. Dodgson

Radio Corporation of America.............Complete microwave systems, antennas and mounts, test equipment, transmission line.
Camden, N. J.
Mgr. Microwave Sales, D. C. Bright

Radio Engineering Laboratories, Inc........Microwave radio communications equipment, *STL* microwave links.
36-40 37th St., L.I.C. 1, N. Y.
Vice-President, Frank A. Gunther

Raytheon Manufacturing Company.........Microwave relays for television and communications, magnetrons, klystrons, accessories.
Waltham 54, Mass.
Prod. Plan. Mgr., A. E. Keleher, Jr.

Resdel Engineering Corporation............Doppler radar speed-measuring equipment.
2351 Riverside Dr., Los Angeles, Calif.
Sales Manager, J. P. Moran

Roger White Electron Devices Inc...........Traveling-wave tubes, backward-wave oscillators, attenuators, sweep generators.
12 W. Island Rd., Ramsey, N. J.
Sales Manager, Patrick E. Dorney

Rohn Manufacturing Company.............Towers.
116 Limestone, Bellevue, Peoria, Ill.
Sales Manager, Dwight Rohn

Sanders Associates, Incorporated...........Printed circuits, lightweight parabolas, engineering and design service, complete systems.
137 Canal St., Nashua, N. H.
Sales Manager, Grant C. Vietsch

Sarkes Tarzian Inc.,
Broadcast Equipment Division...........Microwave relay links.
537 S. Walnut St., Bloomington, Ind.
Sales Manager, Biagio Presti

Schutter Mfg. Co., Carl W................Wave guides, fittings, and components, test equipment, coaxial line components.
80 E. Montauk Highway
Lindenhurst, N. Y.
Partner, Carl W. Schutter

Sierra Electronic Corporation.............Directional couplers, reflection coefficient meters.
1050 Brittan Ave., San Carlos, Calif.
Sales Engineer, C. A. Walter, Jr.

Sperry Gyroscope Company,
Division of the Sperry Corporation.......Test equipment, klystrons, traveling-wave tubes.
Great Neck, N. Y.
Sales Manager, W. J. Henderson, Jr.

Spincraft Inc...................Antennas and reflectors.
4122 W. State St., Milwaukee 8, Wis.
Sales Manager, R. W. Fink

Standard Metals Corporation...............Wave guide tubing.
262 Broad St., N. Attleboro, Mass.
Sales Manager, Lloyd W. Chase

Stewart Engineering Company............Traveling-wave tubes and amplifiers, backward-wave oscillators.
P. O. Box 277, Soquel, Calif.
Sales Manager, R. F. Stewart

Stoddart Aircraft Radio Co., Inc............Coaxial attenuators.
6644 Santa Monica Blvd.,
Hollywood 38, Calif.
Chief Engineer, A. T. Parker

Sylvania Electric Products Inc..............Magnetrons, *TR* and *ATR* tubes, klystrons, traveling-wave tubes.
100 Sylvan Rd., Woburn, Mass.
Sales Manager, E. H. Ulm

Technicraft Laboratories, Inc...............Rigid and flexible wave guides and components, attenuators.
Thomaston-Waterbury Rd.,
Thomaston, Conn.
Sales Manager, George R. Houk

Telechrome, Inc...................Microwave noise generators.
88 Merrick Rd., Amityville, N. Y.
Sales Manager, H. Charles Riker

Telectro Industries Corp...................Wave guides and components, wavemeters, mixers, couplings, test equipment.
35-16 37th St., L.I.C., N. Y.
Secretary-Treasurer, Stanley Rosenberg

Telerad Manufacturing Corporation........Wave guides and components, frequency meters, attenuators, antennas, radar beacons.
1440 Broadway, New York 18, N. Y.
Sales Manager, Charles George

Thompson Products, Inc.,
Electronics Division..................Coaxial switches, polar recorders, wave meters.
2196 Clarkwood Rd., Cleveland 3, Ohio
Sales Manager, F. J. Weihmiller

Titeflex, Inc...................Rigid and flexible wave guides.
500 Frelinghuysen Ave., Newark, N. J.
Gen. Sales Mgr., Gordon J. Wygant

Tobe Deutschmann Corporation............Power line filters.
Norwood, Mass.
Sales Manager, S. I. Perry

Tower Construction Co...................Microwave towers and reflectors.
1923 Geneva St., Sioux City, Iowa
Owner, M. M. Lasensky

Transco Products Incorporated............Manually and remotely controlled coaxial switches, antennas.
12210 Nebraska Ave.,
Los Angeles 25, Calif.
Sales Manager, Wm. P. Stratton

Transitron, Inc...................Signal generators.
154 Spring St., New York 12, N. Y.
Sales Manager, S. K. Lackoff

Tremer Manufacturing Company, The......Wave guide and coaxial assemblies, antennas.
Box 47, Bel Air, Md.
Sales Manager, James R. Ashwell

Universal Microwave Corporation..........Wave guides and components, slotted sections, attenuators, terminations.
380 Hillside Ave., Hillside, N. J.
Sales Manager, William J. Dolan

Vacuum Tube Products..................*TR* tubes, microwave triodes.
506 S. Cleveland St., Oceanside, Calif.
Manager, H. W. Ulmer

Varian Associates..................Klystrons, klystron power supplies, water loads, microwave spectroscopy equipment.
611 Hansen Way, Palo Alto, Calif.
Sales Manager, W. M. Silhavy

Vectron, Inc...................Spectrum analyzers, marker generators.
406 Main St., Waltham 54, Mass.
Sales Manager, S. K. Gibson

Waveline, Incorporated..................Wave guide instruments and assemblies, VSWR amplifiers, signal generators.
P. O. Box 470, Caldwell, N. J.
Sales Manager, Robert H. Koenig

Weinschel Engr. & Mfg. Corp...............Coaxial attenuators, bolometer preamplifiers, thermistor mounts.
10505 Metropolitan Ave.,
Kensington, Md.
Sales Manager, Harry Musicant

Western International Co...................Wave guide components, coaxial cable fittings.
45 Vesey St., New York 7, N. Y.
Sales Manager, E. R. Reilly

Westinghouse Electronic Corporation,
Electronics Division..................Complete microwave systems.
2519 Wilkens Ave., Baltimore 3, Md.
Sales Manager, F. J. Ludemann

Westinghouse Electronic Corporation,
Electronic Tube Division................Cavities, magnetrons, *TR* and *ATR* tubes, hydrogen thyratrons.
Box 284, Elmira, N. Y.
Sales Manager, V. G. Rydberg

Weston Laboratories, Incorporated.........Test and measuring equipment, test sets, dummy loads, spectrum analyzers.
Old Littleton Rd., Harvard, Mass.
Sales Manager, Herbert W. Gordon

Weymouth Instrument Co...................*S*-band wave guides and components, coaxial cables and fittings, wavemeters.
1440 Commercial St.,
E. Weymouth, Mass.
General Manager, Ralph L. Tedesco

Wheeler Laboratories, Inc................Microwave components for radar and test equipment on special order.
122 Cutter Mill Rd., Great Neck, N. Y.
Chief Engineer, David Dettinger

Wind Turbine Company..................Towers and reflectors.
E. Market St., West Chester, Pa.
Sales Manager, Davis B. Oat

Woodwelding, Inc...................Cavity resonators.
3000 W. Olive, Burbank, Calif.
Sales Manager, Clarence R. Greenwood

TECHNICAL BOOKS

"HANDBOOK OF MICROWAVE MEASUREMENTS" edited by Moe Wind and Harold Rapaport. Published by Polytechnic Institute of Brooklyn, 55 Johnson St., Brooklyn 1, N. Y., in two volumes. Over 1000 pages. $12.00.

Designed to meet the needs of both engineering and technical personnel, this publication comprises a unified collated handbook of the numerous and diverse microwave measurement methods. It has been divided into 20 major sections and four appendices, with 25 contributing authors represented.

Each section presents highly detailed procedural information concerning many different methods and techniques for measuring a particular characteristic quantity. In most cases, the procedures are given in step-by-step fashion. In addition, each section includes a substantial amount of associated theory, equipment description, discussion of accuracies, etc.

Where feasible, the measurement procedures and pertinent calculations are supplemented by illustrative examples. All pertinent illustrations (approximately 500) are presented in a separate volume so that they may be viewed simultaneously with the associated text.

"TRANSISTOR AUDIO AMPLIFIERS" by Richard F. Shea, Electronics Division, *General Electric Company*, Syracuse, N. Y. Published by *John Wiley & Sons, Inc.*, 440 Fourth Ave., New York 16, N. Y. 219 pages. $6.50.

The primary aims of this book are to provide the basic fundamentals of transistor applications and to show how these fundamentals may be used in the construction of audio amplifiers. Clearly, and employing only a minimum of mathematics, the author explains how the reader may: (1) intelligently apply this basic information in his designs; (2) avoid pitfalls; and (3) achieve the ultimate in performance from transistor devices.

Treatment is general, and is applicable to the great majority of specifications available from transistor manufacturers. Practical data is presented on the variation of transistor parameters with operating point, with temperature and between units. Various methods of coupling transistor stages together are analyzed; and a number of examples are given of the design of amplifiers intended for a variety of applications, ranging from preamplifiers to relatively high-power output amplifiers.

PRODUCT DIRECTORY

Product cross index for companies which are listed in the Manufacturers' Directory on pages 52 to 54.

ANTENNAS and REFLECTORS

Amerac Incorporated
Andrew Corp.
Arma Division,
American-Bosch-Arma Corp.
Bogart Manufacturing Corp.
Bone Engineering Corp.
Budd-Stanley Co., Inc.
Canoga Corporation
Collins Radio Company
Color Television Inc.
Dalmo Victor Company
Electron-Radar Products
Gabriel Electronics Div.,
The Gabriel Company
General R-F Fittings Co.
Goodyear Aircraft Corp.
I-T-E Circuit Breaker Co.
Keller Products Inc.
Kennedy & Co., D. S.
Kings Electronics Co.
Makepeace Co., D. E., Div.
of Union Plate & Wire Co.
Mark Products Co.
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Prodelin Inc.
Radio Corporation of America
Radio Engineering Labs., Inc.
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Spincraft Inc.
Technicraft Labs., Inc.
Telerad Manufacturing Corp.
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Tower Construction Co.
Transco Products Inc.
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Prodelin Inc.
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Stoddart Aircraft Radio Co.
Thompson Products, Inc.
Transco Products Inc.
Tremer Manufacturing Co.
Weinschel Engr. & Mfg. Corp.
Western International Co.
Weymouth Instrument Co.

MICROWAVE RELAYS

Adler Communications Labs.
Budelman Radio Corporation
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Designers for Industry Inc.
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Federal Telecomm. Labs.
Federal Telephone & Radio Co.
General Electric Company
Motorola Communications and
Electronics, Inc.
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Pye Limited
Radio Corporation of America
Radio Engineering Labs., Inc.
Raytheon Manufacturing Co.
Sanders Associates, Inc.
Sarkes Tarzian Inc.
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RADAR EQUIPMENT

Automatic Signal Division,
Eastern Industries, Inc.
Bludworth Marine Division,
National-Simplex-Bludworth
General Electric Co.
Goodyear Aircraft Corp.
I-T-E Circuit Breaker Co.
Lavoie Laboratories, Inc.
Loral Electronics Corp.
Magnavox Co., The
Maxson Corporation, W. L.
Motorola Communications and
Electronics, Inc.
Raytheon Manufacturing Co.
Resdel Engineering Corp.
Telerad Manufacturing Corp.
Wheeler Laboratories, Inc.

TEST and MEASURING EQUIPMENT

Airborne Instruments Lab., Inc.
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Airtron Inc.
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Bird Electronic Corp.
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Byron Jackson Co.
Chemalloy-Electronics Inc.
Collins Radio Company
Color Television Inc.
Crowley & Co., Inc., H. L.
Cubic Corporation
DeMornay-Bonardi
Designers for Industry Inc.
Diamond Microwave Corp.
Douglas Microwave Co., Inc.
Electron-Radar Products
Empire Devices Products Corp.
Engineering Associates
Espey Mfg. Co.
Federal Mfg. & Engrg. Corp.
Franklin Electronics Inc.
Frequency Standards
F-R Machine Works, Inc.
Garod Radio Corporation
General Communication Co.
General Radio Company
Gertsch Products, Inc.
Goodyear Aircraft Corp.
G. W. Associates
Hewlett-Packard Company
Hycon Mfg. Company
Kay Electric Company
Kings Electronics Co.
Lavoie Laboratories, Inc.
Litton Engineering Labs.
Loral Electronics Corp.
Marconi Instruments Ltd.
Measurements Corporation
Microlab
Microwave Associates Inc.
Model Engrg. & Mfg. Inc.
Narda Corporation, The
New London Instrument Co., Inc.
N.R.K. Mfg. & Eng. Co.
Panoramic Radio Prod. Inc.
Philco Corporation
Polarad Electronics Corp.
Polytechnic Research &
Development Co., Inc.
Press Wireless Labs., Inc.
Radiation, Inc.
Radio Corporation of America
Roger White Electron Devices
Schutter Mfg. Co., Carl W.
Sierra Electronic Corp.
Sperry Gyroscope Company
Telechrome, Inc.
Telectro Industries Corp.
Telerad Manufacturing Corp.
Thompson Products, Inc.
Transitron, Inc.
Universal Microwave Corp.
Varian Associates
Vectron, Inc.
Waveline, Incorporated
Weinschel Engr. & Mfg. Corp.
Weston Laboratories, Inc.
Weymouth Instrument Co.
Wheeler Laboratories, Inc.
Woodwelding, Inc.

TUBES

Amperex Electronic Corp.
Bendix Aviation Corp.
Bomac Laboratories Inc.
Eitel-McCullough, Inc.
Federal Telecomm. Labs.
General Electric Company
Huggins Laboratories
Lewis and Kaufman, Ltd.
Manson Laboratories
Marconi Instruments Ltd.
Microwave Associates Inc.
Penta Laboratories, Inc.
Raytheon Manufacturing Co.
Roger White Electron Devices
Sperry Gyroscope Company
Stewart Engineering Co.
Sylvania Elec. Products Inc.
Vacuum Tube Products
Varian Associates
Westinghouse Electric Corp.

WAVE GUIDES and COMPONENTS

Aircraft Armaments, Inc.
Airtron Inc.
Allied Research & Eng. Div.,
Allied Record Mfg. Co.
Amerac Incorporated
Arma Division, American-Bosch-Arma Corp.
Autel Electronics Co.
Bogart Manufacturing Corp.
Bomac Laboratories Inc.
Bone Engineering Corp.
Budd-Stanley Co., Inc.
Cascade Research Corp.
Chemalloy-Electronics Inc.
Co-Operative Industries, Inc.
CGS Laboratories, Inc.
Cubic Corporation
Dalmo Victor Company
Decade Instrument Company
DeMornay-Bonardi
Diamond Microwave Corp.
Douglas Microwave Co., Inc.
Electro Precision Prod., Inc.
Espey Mfg. Co.
Federal Telecomm. Labs.
F-R Machine Works, Inc.
General R-F Fittings Co.
Graham Mfg. Co., Inc.
G. W. Associates
Hewlett-Packard Company
Hycon Mfg. Company
Industrial Products Company
Kennedy & Co., D. S.
Kent Co., F. C.
Kings Electronics Co.
Korb Engr. & Mfg. Co.
Lavoie Laboratories, Inc.
Lieco, Inc.
Luhrs & Co., C. H.
Makepeace Co., D. E., Div.
of Union Plate & Wire Co.
Meridian Metalcraft, Inc.
Metals & Controls Corp.
Metal Textile Corporation
Microwave Dev. Labs., Inc.
Model Engrg. & Mfg. Inc.
Narda Corporation, The
N.R.K. Mfg. & Eng. Co.
Petroff, Peter A.
Polytechnic Research &
Development Co, Inc.
Premier Instrument Corp.
Radiation, Inc.
Schutter Mfg. Co., Carl W.
Sierra Electronic Corp.
Standard Metals Corp.
Technicraft Labs., Inc.
Telectro Industries Corp.
Telerad Manufacturing Corp.
Titeflex, Inc.
Tremer Manufacturing Co.
Universal Microwave Corp.
Waveline, Incorporated
Western International Co.
Westinghouse Electric Corp.
Weymouth Instrument Co.
Wheeler Laboratories, Inc.

Microwave Measurements

(Continued from page 14)

type utilizes lossy substances to dissipate the difference in input and output power levels. In precision designs, metals in the form of very thin films are utilized as the lossy medium.

Dissipative attenuators are available for both coaxial[14] and wave guide systems[15]. They are so designed as to match bilaterally the characteristic impedance of the guide in which they are inserted over a broad frequency range. Their attenuation response remains flat within a narrow tolerance range.

Coaxial attenuators in popular use are either *T* types or distributed types, as shown in Fig. 13. The first uses lumped resistive elements to form either one or more *T* sections; this type is most useful at lower frequencies. At higher frequencies, the distributed type is utilized. It employs compensation sections arranged symmetrically at either end of the main section for correcting mismatches. The frequency design limit is approximately 10,000 mc.

Wave guide attenuators for rectangular guides use resistive elements inserted parallel to the electric field of the propagating TE_{10} mode. In precision types, the resistive element is a metalized glass plate which may be inserted either from one of the narrow side walls or through a slot milled in the center of the upper wall. The former is referred to as the vane type while the latter is known as the flap type (Fig. 14). Both types of design provide bilateral matching and possess negligible insertion losses when the film is completely out of the electric field. In the vane type, various methods are available for matching the resistive element to the guide (Fig. 12). In the flap type, the resistive element is shaped as an arc of a circle.

A recently designed rotary wave guide attenuator[16] consists of two fixed end sections made up of rectangular-to-round guide transitions and a center section of round guide which can rotate. Each section has a resistive film stretched across a diameter. The attenuation of this unit is a function of the angle through which the center section is rotated. Its phase shift is negligible.

Many methods have been devised for measuring attenuation[5] at microwave frequencies. The kind of detection and the type of reference standard serve to distinguish between the various methods, which either measure relative power levels or compare an unknown attenuation to that of a reference standard in a substitution procedure.

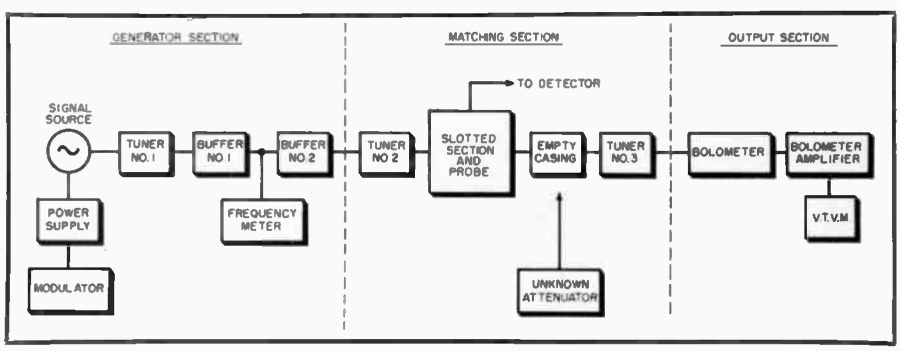
Bolometer-Voltmeter

A convenient and accurate method for measuring relative powers is based upon amplitude-modulating the microwave source with square waves and detecting with a bolometer amplifier and voltmeter arrangement. The bolometer is usually of Wollaston wire. The period corresponding to the modulating frequency is selected to be large as compared to the thermal time constant of the bolometer. As a consequence, the resistance change follows the microwave power level at the modulation rate. Since the bolometer is biased by a constant current source, the resistance variation produces an audio voltage across its terminals whose frequency is that of the modulating signal and whose amplitude is proportional to the microwave power level. Typical time constants of Wollaston-wire bolometers range from 80 to 250 μsec. Modulating frequencies are limited to approximately 1000 cps. For small deviations from linearity, the bolometer should be operated at power levels below 200 μw.; its sensitivity is about 20 μv./μw.

The audio component from the bolometer is applied to a narrow-band tuned amplifier and its output is read on a vacuum-tube voltmeter. Since the audio voltage is directly proportional to the microwave power, the ratio of any of two different power levels is equal to the corresponding output voltage ratio. The voltmeter scale can be calibrated to read decibels directly.

Shown in Fig. 15 is a typical setup involving the bolometer-voltmeter method of measuring attenuation. Measurement proceeds in the following way after the system has been matched for a desired frequency.

Fig. 15. Equipment line for measuring attenuation by bolometer-voltmeter method.



With the unknown attenuator replaced by an empty casing or line length, the output meter indication is adjusted for a convenient level N_1. Without disturbing the whole system, the unknown is inserted in place of the empty section, and the output read as N_2. N_1 is then checked. If it has remained stable, the attenuation will correspond to ½ $(N_1 - N_2)$ provided that the meter is calibrated for linear detection. The maximum attenuation range is approximately 50 db.

In measuring the attenuation of a variable attenuator after the insertion loss corresponding to its minimum setting has been determined by the procedure described above, attenuation is inserted and N_2' read until the whole unit is calibrated. Level N_1 is again checked to make certain that it has not varied before accepting the results. The average of several stable runs is used for each value of attenuation.

Substitution

Measurement of attenuation by substitution methods is based upon comparing the unknown attenuation with a reference standard. The general procedure is to maintain the output power level constant as unknown attenuation is introduced by removing a similar amount from the standard attenuator. Therefore, the decrease in the setting of the reference standard is equivalent to the inserted unknown attenuation. Various arrangements are possible depending upon the type of standard employed.

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Electronics

Altitude Corrector for Tracking Radars (McQuistan)	157	June
A-M System Measures Microwave Attenuation (Korewick)	175	Jan.
Automatically Deiced X-band Beacon Antenna (Thomas, Jr.)	152	Jan.
Broadband Rotary Waveguide Attenuator (Hand)	184	Jan.
Cavity - Resonator Design Charts (Spencer)	186	May
Circular Radar Cuts Rain Clutter (White)	158	Mar.
Circular-Waveguide Chart (Hudson)	194	Oct.
Designing Surface-Wave Transmission Lines (Goubau)	180	Apr.
Direct VSWR Readings in Pulsed R-F Systems (Rosenthal & Badoyannis)	162	Dec.
Dual-Mode Horn Feed for Microwave Multiplexing (LeVine & Sichak)	162	Sept.
Four-Megawatt Klystron	200D	Nov.
Helically Coupled Traveling-Wave Tube (Lacy)	132	Nov.
How Long-Line Effect Impairs Tunable Radar (Hull, Novick & Cordray)	168	Feb.
Improved Demodulator for Radar Ranging (Goodell)	170	June
Machine Methods Make Strip Transmission Line (Packard)	148	Sept.
Measuring Microwave Antenna Patterns (Small & Hatcher)	184D	Nov.
Microwave Applications of Gas Discharge (Arams)	168	Nov.
Microwave Market Picture (Carroll)	152	Oct.
Microwave Relay for Japanese Television (Nomura, Surzki, Mita & Sawazaki)	152	June
Microwaves Carry Television Across the Alps	180D	Nov.
Microwaves Gage Surface Irregularities	210D	Aug.
Moving Target Detection by Pulse Doppler Radar (Sargent)	138	Sept.
Output Windows for Tunable Magnetrons (Chen)	170	May
Phantastron Computes Pulse-Width Ratios (Findley)	164	Jan.
Pulling-Figure Tester for Microwave Oscillators (Dyke & Cohn)	170	Dec.
Radar Detects Ocean Currents	254D	Mar.
Radar Doppler Nomograph (Schooley)	180	Dec.
Radar Duplexer Uses Dual T-R Tubes (Heins)	149	Aug.
Radar Offers Solution to Mid-Air Plane Collision (Brantley)	146	Nov.
Stable Power Supplies for Microwave Standards (Ernst)	168	Jan.
Voltage-Tuned Microwave Oscillator	242D	Mar.
Weather Radar Operates in C Band	200D	Oct.

Proceedings of the IRE

A Developmental Medium-Power Traveling-Wave Tube for Relay Service in the 2,000 mc. Region (Siekanowicz)	1091	July
A Gas-Discharge Noise Source for Eight-Millimeter Waves (Bridges)	818	May
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An Analysis of Passive Reflector Antenna Systems (Greenquist & Orlando)	1173	July
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Radar Recording System for Air Traffic Control (McLucas)......	70	July
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Radio Astronomy (Lovell & Clegg)

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(*Continued from page* 31)

and uncertainties caused by amplifier characteristics are completely eliminated. This unit is available with center frequencies of 9.25 kmc. (RG-52/U) and 5.65 kmc. (RG-50/U).

Push-pull outputs are provided by two microwave diodes which terminate the colinear arms of the magic tee. These output voltages can be applied directly to the vertical deflection plates of a cathode-ray tube. With care, bandwidths of 100 mc. can be attained, and the pulse thus viewed on the CRT is virtually distortion-free.

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INDEX OF ADVERTISERS

Microwave Economics

(*Continued from page* 20)

clusively, the costs might be higher than when the overhead for personnel and test equipment is spread over several related fields.

One microwave system operator has been reluctant to make public maintenance cost information because the figures seem to be so ridiculously small that many might refuse to accept them as correct. In other cases, the figures appear high. Therefore, because of the various accounting approaches, it has been difficult to arrive at accurate figures.

Another yardstick for measuring microwave maintenance costs has been the use of a quotation of an outside service organization. This, too, has been misleading. If the same organization is engaged to maintain two, three or more microwave systems in the same general area, it can quote a much lower figure —since the same personnel can be used to work on all of the systems. On the other hand, a service organization must charge a much higher rate to maintain a single short microwave system in an area where the company does not already have established facilities and resident personnel. The cost of maintaining a 250-mile microwave system, including labor, material and transportation, has been estimated in one instance to run from about $16,000 to $18,000 annually.

It is reasonable to assume that the cost of operating a microwave system is less than that of maintaining open-wire lines, since a microwave system requires maintenance only at terminal and repeater sites. Maintenance is therefore concentrated at certain specific points, easily located and identified. It is also true that there are a great many different components which could fail at any of these points. However, experience has borne out the fact that once the original "bugs" have been whipped failures become infrequent, particularly if preventive maintenance is employed.

Conclusion

The graph in Fig. 1 indicates the estimated relative costs of private microwave circuits and leased wire service, while Fig. 2 shows the estimated initial costs of private wire lines vs. private microwave systems.

Except where existing private wire line facilities are in excellent condition, it is a safe assumption that microwave can provide more facilities at lower cost. When a comparison is to be made between the cost of a private microwave system, a new private open-wire line system or leased wire service, microwave appears to be lowest in cost for like facilities except in very short-haul systems.

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