Electronic Engineering

EDITORIAL, ADVERTISING AND PUBLISHING OFFICES, 28, ESSEX STREET, STRAND, W.C.2.

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Monthly (published last Friday of preceding month) 2/- net. Subscription Rate: Post Paid 12 months 26/-.

Vol. 21. No. 257 **July, 1949**

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Decline and Fall

IN the April issue of our American contemporary *Electronics* there appeared a message from James McGraw, President of the McGraw Hill Publishing Co. Inc., to American Industry entitled "Now is the time to fight Socialism in Washington." This apostrophe was continued in the May issue and has as its theme "the rapid progress down the dreary road of industrial stagnation" (to quote from Mr. McGraw) of British Industry due, in the main, to the pre-war shortsightedness of our Industrialists and to bad planning of our Socialists since 1945.

All this, of course, may make good material for the American reader, but such statements can be dismissed as generalisations, and like all generalisations, they are false and misleading.

While we do not claim that British industry has a monopoly of all the virtues, neither has it a monopoly of all the vices.

We admit that Britain's industrial and economic position is perilous and that without American help in the form of Marshall Aid we should be "in the red," but without penetrating the arcana of present-day economics and politics, we should like to be permitted to say a word or two about British Industry in reply. On the material side there is much replanning and rebuilding to be done before Britain can regain her economic independence, and on the human side among employer and employed alike there is a sense of frustration and lack of enterprise which is more frequently referred to as lack of incentive.

Although not qualified to speak for British Industry as a whole, we should have said that there are in it still some very bright spots. There does not, for example, appear to be anything wrong with the shipbuilding industry, and the Austin "A90" has already given its message from the motor industry.

In the Electronic industry, of which we can claim to have intimate knowledge, there is ample evidence that it is live and active, and the industry which leads the world in television, which has produced such notable "firsts" as the Magnetron and Radar, is showing no signs of decay.

To the foreigner our methods often appear tortuous and tempo seems to be in keeping with the notice bearing the words "Dead Slow" which appears at the entrance to Somerset House in the Strand, but this is illusory; Britain has no need yet for a Gibbons.

A Magnetic Digital Storage System

By ANDREW D. BOOTH, Ph.D.*

DESCRIPTIONS have appeared[1,2] of storage devices for use in serial operation calculating machines, but in this country at least, little emphasis has been placed on the other possible type of computing system, namely, that employing parallel operation. It is not proposed to give any discussion of computing machines in this paper but for completeness it must be stated that in serial operation machines the digits of a number become available, and are used, one at a time starting usually from the least significant, whereas in a parallel operation machine all the digits of any number become available at the same time.

Without wishing to become controversial, it may be remarked that von Neumann, who was the originator of many of the current ideas on calculating machines, has abandoned the serial operation machine in favour of its parallel operation counterpart.

Requirements for a Storage Device

In either type of calculating machine the requirements of the storage device are similar, and are as follows:

(1) The storage should be permanent if desired.

(2) The contents of any position must be erasible at will and capable of replacement by new data.

(3) The volumetric efficiency should be high.

(4) The access and replacement time of stored data should be small.

The delay line storage device of Wilkes[1] and the cathode-ray tube memory of Williams[2] satisfy all of the above requirements except (1) and to a less extent (3). Either of these devices loses all its stored data if a power supply failure occurs. In addition, in the forms described by the authors, neither is directly suitable for a parallel operation machine.

The idea of using the well known principles of magnetic sound[3] recording for the storage of digital data seems to have occurred to a number of designers at about the same time, the system to be described in this paper, however, is thought to be the first in actual operation.

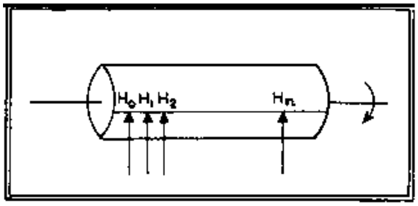
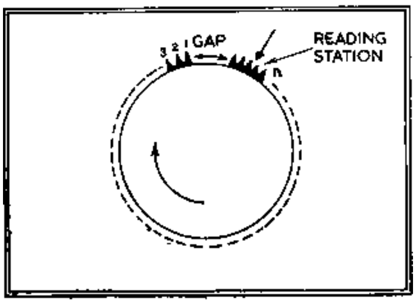


Fig. 1. Magnetic drum and read/record heads

Fig. 2. Magnetic state of clock pulse track



Principles of the Magnetic Memory

Essentially, the storage device consists of a cylindrical drum coated with permanent magnetic material and rotating under a series of read/record heads arranged along a generator of the cylinder. In Fig. 1 H_1-H_n are a set of these heads.

All of the digits of any particular number, which is in binary form (*e.g.*, Wilkes[1]), are recorded and read off simultaneously by the heads.

Successive numbers are recorded in sequence as the drum rotates and to distinguish between them an extra track (H_0) is added which contains a set of equispaced positive "clock" pulses.

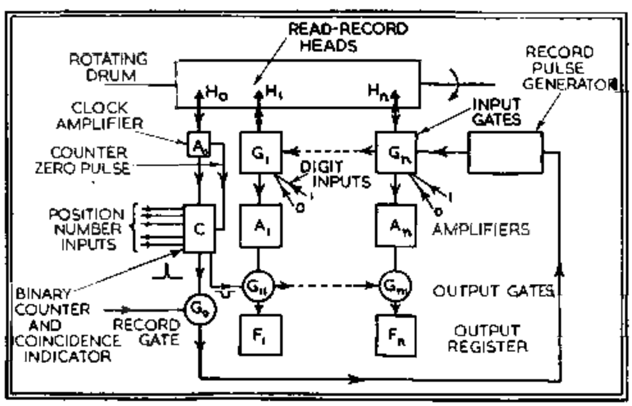
In order to determine the position of the first number it is necessary to indicate the start of this clock pulse track. This could be done in various ways; for example, it might start with a single negative pulse, or alternatively a separate track might contain a single pulse to indicate the zero position of the clock pulse track. In fact, it turns out to be much simpler to leave a small gap, clear of any pulses, at the end of the clock pulse track, and to use this as a zero indication. The general appearance of the magnetic state of the clock pulse track is then shown in Fig. 2.

In order to go to any position on the drum and to read or record there, all that is necessary is to count from the zero position on the clock track and to arrange that the counter emits a pulse when it reaches the given position. A schematic diagram of the whole memory is given in Fig. 3.

The positive pulse input from the clock track head is amplified and sent to the binary counter C, which is arranged to zero on receipt of a pulse from the shaping circuit contained in A_0.

The contents of C are compared with the required memory location as shown by a set of position number inputs; when the two numbers

Fig. 3. Schematic of magnetic storage



* Director, Birkbeck College Electronic Computer Project, Visiting Professor of Physics, University of Pittsburgh, U.S.A.

agree a pulse is emitted by a circuit. Normally this pulse opens a set of gates G_{11}-G_{n1}, which allow the output pulses from the digit track heads H_1-H_n to set a series of flip-flop storage elements F_1-F_n to the digit pattern recorded under the heads in the given position. When it is desired to record in a given position a gate G_0 allows the above coincidence pulse to trigger a "record pulse" generator which sends either positive ("1") or negative ("0") pulses, via the input gates G_1-G_n, to the heads. It should be noted that prior to the record operation the input gate will have been set to "0" or "1" positions from digit input leads, and that the nature of the storage is such that the input data automatically erases that already present.

In the present memory, intended for use with A.R.C. (Automatic Relay Computer), the input gates G_1-G_n, the record gate G_0 and part of the counter-coincidence circuit are relay elements, and the output flip-flops set relays to operate the remainder of the machine.

The Magnetic Circuit

While many highly specialised magnetic recording media exist, these are at present difficult to obtain in suitable form, and it was decided to use a thin plating of electrolytic nickel. Although the magnetic properties of this seem to leave much to be desired, the medium is quite good enough for the purpose in hand. In the final design a plated layer between .0005 in. and .001 in. in thickness was used. Extensive experiments showed that up to 100 digits/in. could be recorded, but for safety it was decided to use only a 50 digits/in. packing

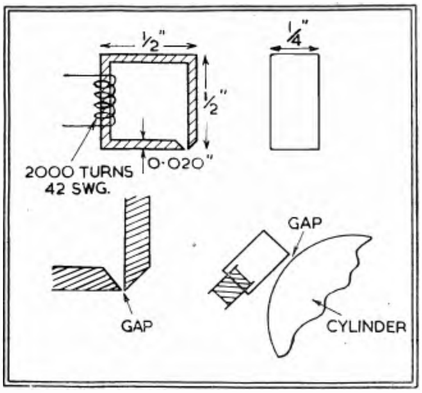


Fig. 4. Early recording head

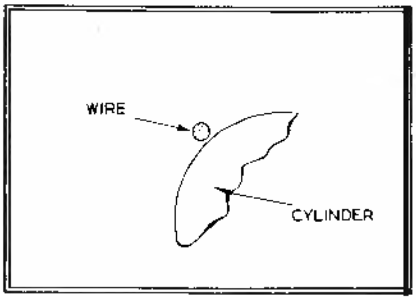
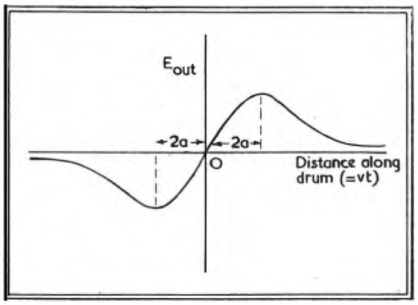


Fig. 5. Single wire head

Fig. 6. Output voltage from single wire head



as this allowed for considerable variations in head construction. The surface speed of the drum was 25 ft./sec.

The first models of the recording heads were of the form shown in Fig. 4.

Single laminations of .020 in. silicon iron were used and the heads were run in contact with the cylinder as shown. Using 2,000 turns on the magnetising coils it was found that the shortest recording pulse which could be used was 35 µsec. This left much to be desired and further experiments were instituted.

About this time Dr. Julian Bigelow* suggested using a single, very fine wire as recording head.

This was to be mounted in close proximity to the drum surface and pulsed with a current of between 10 and 50 amps. Since the current flows for considerably less than 1 µsec. this does not damage the wire. It can be shown that if the input pulse is short enough for the recording medium not to move appeciably during the pulse, the output voltage follows the law:

$$E_{out} = K\, v^2 i t / (4a^2 + v^2 t^2)$$

where
v = surface speed of medium
i = recording current
a = distance of wire centre from drum surface
t = time.

The general form of this function is shown in Fig. 6.

In the present memory, with digit packing of 50 in., it follows that for non-interference of pulses $4a << .020$ in. or $a << .005$ in.; this means that wires of diameter less than .002 in. must be used. Handling becomes difficult with .001 in. diameter wire and problems arise in the design of step-up transformers for ratio of 1:100 and bandwidths of 250 Kc/s. where the input impedance is about 1Ω.

As a comparison, tests were made using a .002 in. diameter single wire and a single lamination head of the general type shown in Fig. 4, but reduced to one-half the linear dimensions. With ten turns this gave precisely the same output as the single wire, thus indicating losses of about 90 per cent.

It had been evident that the performance improved as the linear dimensions of the heads decreased and a series of experiments were tried with very small heads. These resulted in the design shown in Fig. 7.

Using a single 32-gauge wire as magnetising source, the output signal was three times greater than that from a .001 in. diameter wire, indicating that the loss in efficiency is no longer important. With the same design it proved possible to insert four turns of 42-gauge wire through the window and 12 times the single wire head output was obtained. The output pulse shape is identical with that of Fig. 6.

In order to record "1" and "0" on the medium the simple procedure of pulsing the head with sufficient current to cause magnetic saturation of the nickel was adopted. Thus, if "1" is recorded with a pulse of +20 amps., to record "0" a −20 amp. pulse is superimposed.

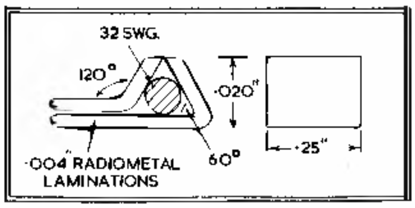


Fig. 7. Final head design

* Chief Engineer, Electronic Computer Project, Institute for Advanced Study, Princeton, U.S.A.

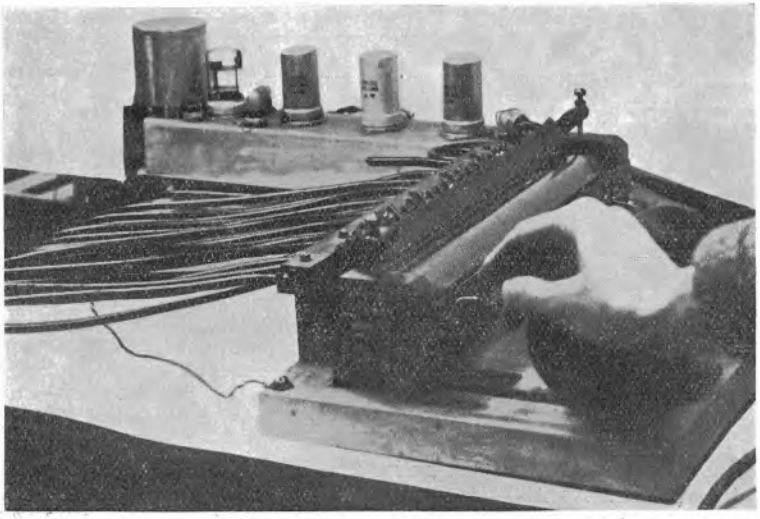


Fig. 8. Model of drum with heads mounted in position

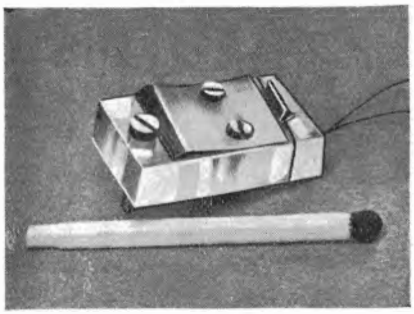


Fig. 9. One of the final read/record heads

Mechanical Construction

A photograph of the cylinder and head assembly is given in Fig. 8.

For mathematical reasons it was decided to have 21 binary digit numbers and to store 256 such quantities. With the packing of 50 digits/in. and surface speed of 25 ft./sec., this resulted in a cylinder 2 in. in diameter and 12 in. long rotating at 3,000 r.p.m. The maximum waiting time for reading or recording is 20 m.sec. and the mean time 10 m.sec.

The heads, shown in detail in Fig. 9, are mounted on a brass bar and are individually adjustable by means of a simple screw assembly. Coarse adjustment is provided for aligning the main bar and the drum surface.

Circuits

At the outset it can be stated that all relays are of the Siemens high speed variety with 1000 + 1000Ω coils. The measured time of closure or operation of these is less than 2 m.sec. Relays are drawn in the normal position.

The Clock Track Amplifier.

On this track it is necessary to reproduce with accuracy the sharp transition between the two turning points in output voltage shown in Fig. 6, and it was decided that a bandwidth of at least 200 Kc/s. was needed. The amplifier circuit of Fig. 10 proved adequate.

It will be noticed that the grid coupling and screen resistor by-pass time constants are so chosen that there is a steep reduction in gain below 10 Kc/s. This makes the amplifier very much more stable and makes inter-stage decoupling unnecessary. In particular, 50 c/s. pick-up and microphonic noise from V_1 are imperceptible. V_3 is biased below cut-off to enable the noise background from the medium to be clipped off. This is necessary, since the gap at the end of the clock pulse track (Fig. 2) may contain a noise pulse of sufficient amplitude to trigger the counter after it has been set to zero.

The output of V_3 is fed directly to the input of the binary counter and a portion is rectified by the IN34 germanium diode and applied as a negative potential to the grid leak of the blocking oscillator tube V_4. This keeps the latter from firing until the clock pulse track gap is reached, when the charge on C leaks away via R. The firing of V_4 sends a pulse via the output winding of T to the grid load resistor of the counter, thus "zero-ing" the latter.

The Counter and Coincidence Senser.

The counter used is an ordinary scale-of-two circuit with buffer amplifier to remove unwanted pulses. The circuit constants are chosen so that the counter is reliable up to 100 Kc/s.

Counter Unit

It will be seen from Fig. 11 that when any one of the counter stages C_n is in the same state ("0" or "1") as its associated relay H_n, the potential of the grid of the corresponding coincidence valve falls below cut off. When counter con-

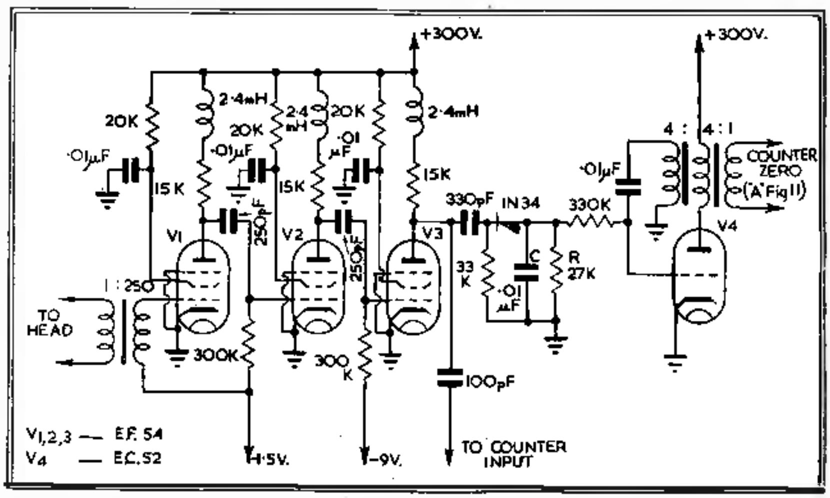


Fig. 10. Clock pulse amplifier, shaper and counter zero generator

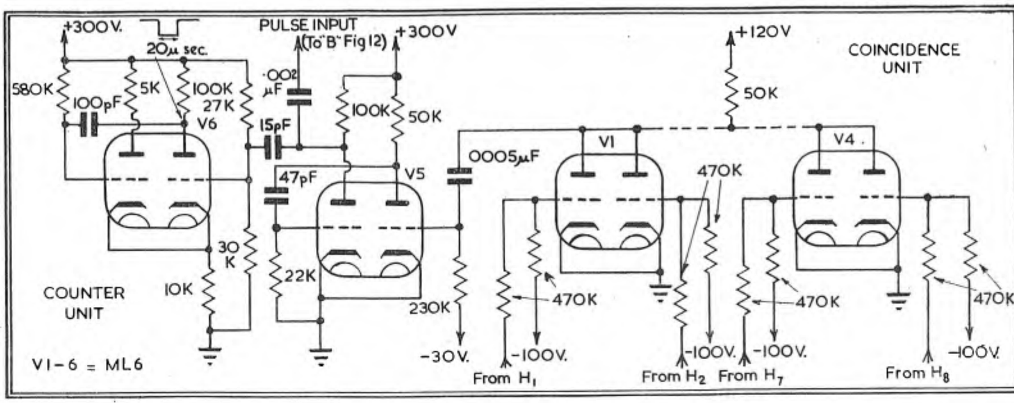


Fig. 11. Counter and coincidence unit

tents and relay do not agree, however, the coincidence valve conducts. Since the resistance of any coincidence valve is only about 7 KΩ, if at least one valve is conducting the potential at the common anode load cannot rise above $7/57 \times 120 = 15$ volts, which is well below the cut-off of the first stage of V_5. The second stage of V_5 acts as an inverter and pulse shaper, since a sharp positive trigger pulse is required for the input pulse generator.

V_6 generates a negative pulse of 220 volts amplitude and 15 μsec. duration which is used to gate the outputs from the digit amplifiers into their respective flip-flops.

The Input Pulse Generator.

Since the heads have an input impedance of less than 0.1 Ω and require pulse currents of 10-20 amps., a special generator had to be designed. Thyratron circuits were tried, but were found to be unreliable and liable to parasitic oscillation. Eventually the circuit shown in Fig. 12 was devised and gives completely satisfactory results.

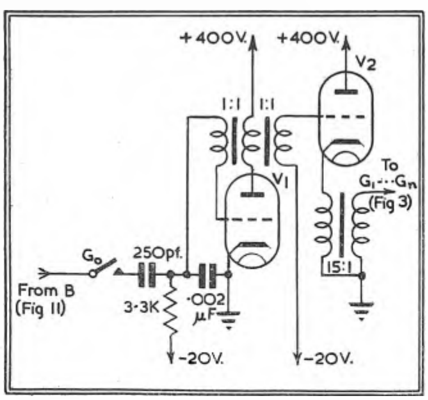


Fig. 12. Input pulse generator

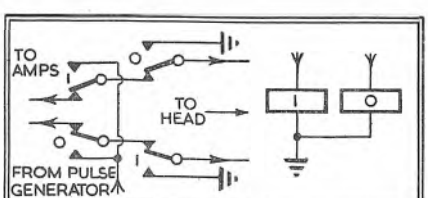


Fig. 13. Relay input gate

In the present memory the record gate G_0 is a relay, but it would be simple to substitute an electronic element. In the absence of a gating pulse via G_0 the blocking oscillator is held off by the bias. The transformer produces a pulse of less than 1 μsec. duration and the cathode follower transformer enables the whole head array to be pulsed.

The Input Gates.

These are constructed from relay elements and are shown in Fig. 13.

Each gate element consists of two relays having two change-over contacts which are activated from the main circuits of the machine. When relay "1" is operated the head is pulsed in the positive sense, and when relay "0" is operated in the negative sense.

The gate action isolates the digit track amplifiers during pulsing, as the stray pulse which crosses the relay contacts due to capacitative coupling does not effect the input transformers, which have extremely low input impedance.

The Digit Amplifiers.

These are perfectly straightforward R-C coupled amplifiers, again constructed to give low gain below 10 Kc/s. A typical circuit is shown in Fig. 14.

The Output Gate.

It is desired to gate the amplifier output into a flip-flop circuit at a given position only, the two possible amplifier output pulse shapes being shown in Fig. 15.

Since the clock pulse occurs at the origin in the above sketches, it is

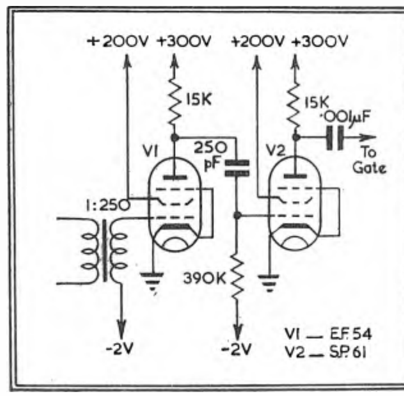


Fig. 14. Typical digit amplifier

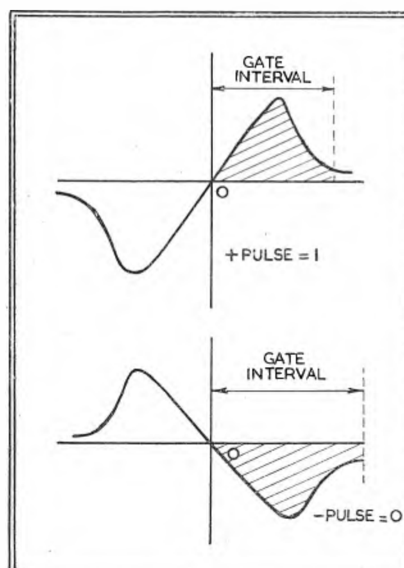


Fig. 15. Output waveforms for "1" and "0"

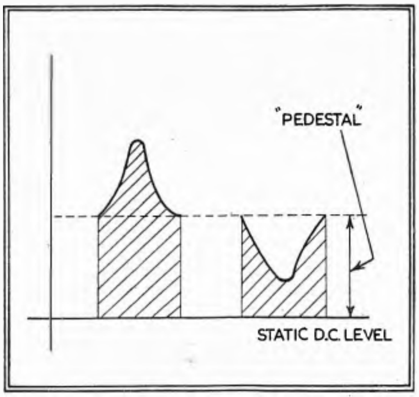


Fig. 16. Output from common gate circuits

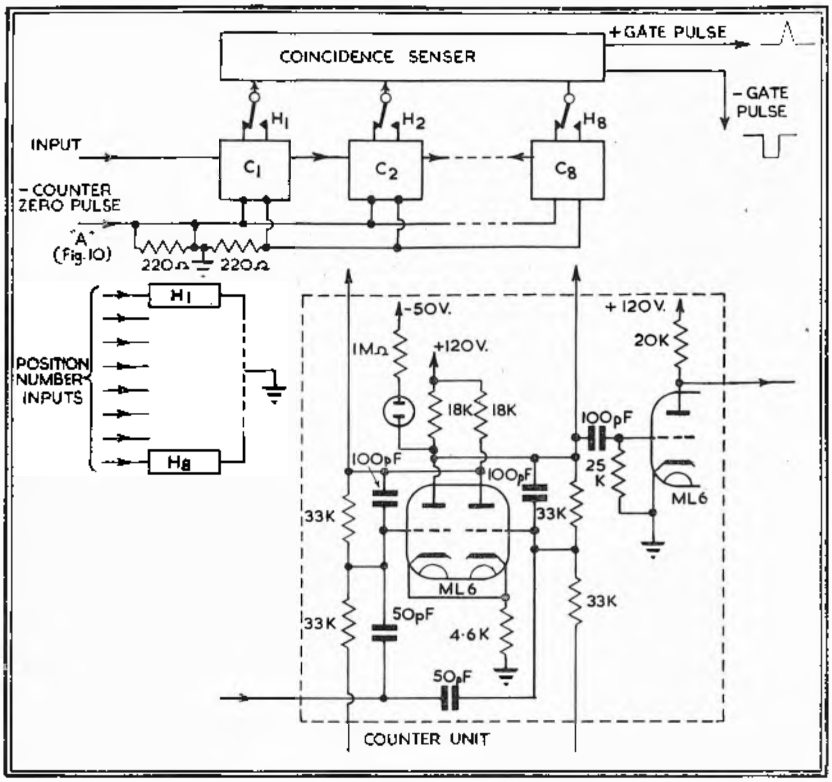


Fig. 19. Counter and coincidence senser

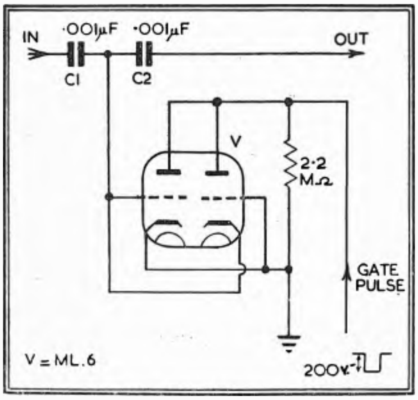


Fig. 17. Gate circuit

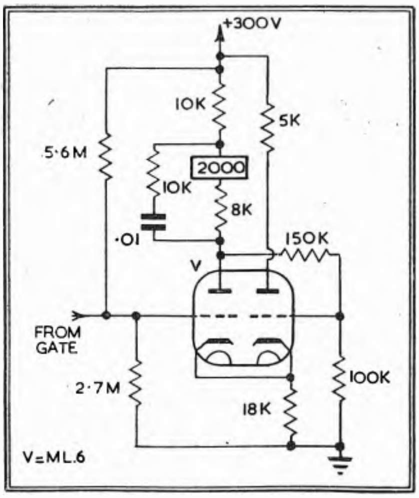


Fig. 18. Toggle output circuit

possible to generate a gate signal which extends over one-half of the output pulse only, and thus to select a positive or negative pulse corresponding to unity or zero. Most of the published gate circuits have the disadvantage of placing the output on a "pedestal" as shown in Fig. 16, or else of transmitting pulses of one sign only.

To remedy this defect the circuit of Fig. 17 was devised.

In the absence of a gate pulse the twin triode grids act as diodes and short-circuit incoming signals of either sign to earth. On applying a large negative pulse to the two anodes the electrons are repelled to the cathodes and the resistance of the grid circuits rises sharply. If, in this condition, a voltage variation occurs on C_1 it is transmitted via C_2 to the flip-flop; in the absence of the gate pulse, however, nothing passes.

The Output Stage.

This consists of the standard cathode-coupled toggle, shown in Fig. 18.

For reliable operation it was necessary to compensate the inductance of the relay coil, and the network shown behaves like a pure resistance.

Conclusion

It will be seen from the above circuit descriptions and from the photograph of Fig. 8 that the storage system described in this paper is considerably more compact than any hitherto disclosed. Although in its present form it is somewhat slow in operation it is quite easy to speed up the rotation of the cylinder and to record and read data at several stations around the drum. In this way availability times of better than 1 millisecond could be realised. Work is at present proceeding along these lines and it appears that the necessary modifications are trivial in nature.

The author wishes to express his sincere thanks to Dr. Geoffrey Gee, Director of Research, and to the Board of the British Rubber Producers' Research Association for supporting this work, and also to Miss X. Sweeting and Dr. R. W. Williams for assistance in construction.

References

[1] Wilkes and Renwick ELECTRONIC ENGINEERING 20, 208, (1948).
[2] Williams and Kilburn, *Journal I.E.E.* (In press.)

A High Voltage Ring Modulator

For Use as a "Phase-conscious Rectifier" in Electronic Circuits

By M. J. TUCKER, B.Sc.*

THE need for "phase-conscious rectification" occurs in the design of certain instruments and servo systems, and a similar problem can occur in the design of "Synchrodyne" receivers,[1] particularly in the phase-control circuit.[2] Two voltages are provided: a reference, or "polarising" voltage of constant amplitude, and the signal voltage which is initially derived from the same source, but whose amplitude has been modulated and varies about zero. "Phase-conscious rectification" of the signal produces an output proportional to its amplitude and positive or negative according to the sign of the amplitude - changing this sign is equivalent to a phase change of π, hence the term "phase-conscious." The process is basically one of multiplication, i.e., modulation, of the signal by the reference voltage, and may be performed by the conventional methods of modulation.

The ring-modulator is one of the best devices for this purpose, but the conventional design will not handle signals of more than a fraction of a volt, whereas, since D.C. amplification usually adds considerable complication to a circuit, it would often be preferable to apply the output of the modulator directly to the grid of an output stage. D. G. Tucker[3] has recently shown how the performance of a ring modulator may be improved by the use of biases of a fraction of a volt in the modulator arms. It is shown in this article that such bias also increases the voltage handling capacity of the modulator, and that much larger bias may be used for this purpose. Under suitable conditions these very large biases also have the advantage of "swamping" the rectifier characteristics, thus making them behave more nearly as true switches, so that the modulator efficiency is less dependent on the carrier or polarising voltage (*see* Figure 9).

* Royal Naval Scientific Service.

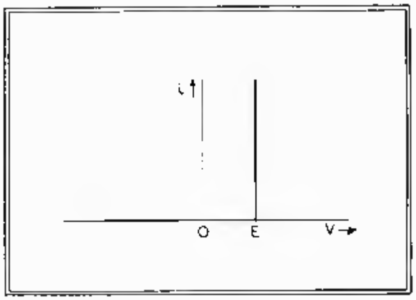


Fig. 1. Idealised rectifier characteristic

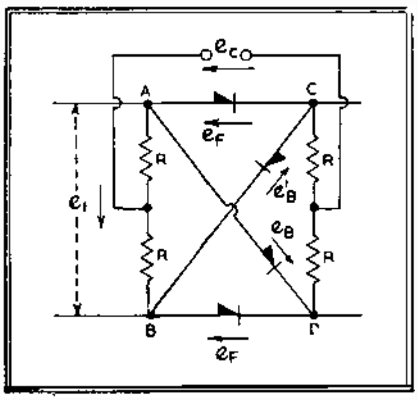


Fig. 2. Simple ring modulator circuit. The voltages marked are instantaneous values

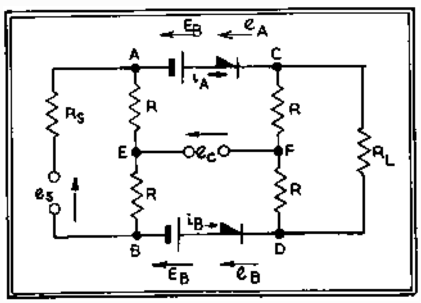


Fig. 3. The circuit is considered when AC and BD are about to conduct

Limiting Signal Voltage to a Ring Modulator

To explain the limiting factor clearly, it will be assumed temporarily that the rectifier elements have an infinite reverse resistance and a zero forward slope resistance, but with a forward voltage "threshold" of E, i.e., the elements pass no current with forward voltages of less than E (Figure 1).

A simple form of modulator is shown in Figure 2. The idealised action is that of a commutator switch that reverses the input-output connexions every half-cycle of the carrier or polarising voltage e_c. This switching is produced by the action of the carrier voltage on the four rectifier elements. During one half-cycle the arms AC and BD will conduct, and during the other half-cycle the arms AD and BC.

When e_c is zero, it is apparent that the voltage e_1 across AB cannot exceed $\pm 2E$, as at this voltage current flows round either ABC or ADE, and any excess voltage will be shorted out. By summing e.m.f's round these paths, it can be shown that the same limiting voltage holds for any value of e_c.

In this idealised case, therefore, $\pm 2E$ is the limiting value of the input voltage.

If a bias battery of voltage E_B is now inserted in the correct sense in series with each rectifier element, the voltage required across each arm to make it conduct will be $(E + E_B)$ and the limiting input voltage is raised to $\pm 2(E + E_B)$.

With practical rectifier elements, if E is now the voltage at which the elements pass an appreciable current and e_F and e_1 are instantaneous values, by summing e.m.f.s round ACB and ADB, it can be shown that

$$\text{limiting } e_1 = \pm(2E_B + E + E_F)$$

e_F can be taken as being always

greater than E, as even when the elements are not conducting, this voltage must be developed before any current can pass, so that a conservative value of the maximum permissible e_1 is:

$$e_1 \text{ max.} = \pm 2(E_B + E) \quad \ldots\ldots \quad (1)$$

During the time that the carrier voltage is less than $\pm(E_B+E)$ no rectifiers should be conducting, and there is thus a period when the output voltage should be zero: this can be seen clearly in those oscillograms in Figure 4 which are for low input voltages. The effect of the signal on this interval is discussed below as "Distortion without overload." By the use of suitable bias, this interval can be adjusted so that the modulating function contains very little third harmonic.[3]

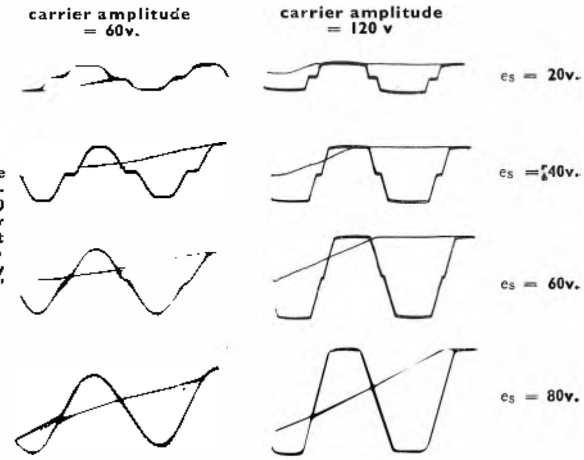


Fig. 4. Oscillograms of the modulation of DC by a battery-biased ring modulator. Bias 30 volts Diodes 6H6 Carrier feed resistors 25K Input resistance 10K. Output direct to C.R.O. deflector plates. Ideally these should be "Square" waveforms

The Effect of Large Biases on Reverse Resistance

The reverse resistance of metal and crystal rectifiers decreases rapidly as the reverse voltage is raised, and the use of large biases will thus reduce the efficiency and stability of the modulator, and owing to the non-linearity of the reverse resistance, large signals may be distorted. It is therefore preferable to use thermionic diodes where possible.

Distortion Without Overload

It has been shown that above a certain voltage some shorting out of the input takes place, and this may be regarded as overload. However, distortion also takes place at smaller input voltages due to the fact that some of the input appears across those rectifier elements which are not conducting, and so alters the point at which conduction commences.

Considering the circuit shown in Fig. 3, where two of the modulator arms have been omitted for clarity, the instantaneous voltages across the rectifier elements when neither is conducting are given by:

$$e_A = e_c - E_B - e_s\ R/(R_S+2R) \quad \ldots\ldots \quad (2)$$

$$e_B = e_c - E_B - e_s\ R/(R_S+2R) \quad \ldots\ldots \quad (3)$$

where $e_c = A \sin \omega t$.

Taking the case when e_s is positive, it is thus apparent that the conduction of AC is in advance of that of BD.

If AC is conducting and BD is not, the current i_A through AC will add another term to the right hand side of equation (3) giving:

$$e_B = e_c - E_B - e_s\ R/(R_S+2R) - Ki_A \quad \ldots\ldots \quad (4)$$

where K is a positive factor in terms of the various resistances (*see* (c) below).

Ideally the two rectifiers should commence conduction together at a time unaffected by the signal; the last terms in equations (2) and (3) and the last two terms in equation (4) therefore represent distortion.

During the time when only one rectifier is conducting, the voltage across the output has components from both the signal and the carrier, and this can clearly be seen in the oscillograms of Figure 4. These show the distortion produced on the modulation of a D.C. input using a battery biased ring modulator. Here, as soon as one rectifier starts conducting, the output rises steadily with a portion of the carrier waveform (since the input is steady) until the output voltage reaches the input voltage across the modulator terminals, at which point the second rectifier starts conducting, and the output voltage is derived solely from the input. In the last two oscillograms of the left-hand series, the carrier voltage is never high enough to achieve this latter state, and so the second rectifier never commences conduction.

The influence of various factors on this effect will now be considered.

(a) Carrier voltage ("Polarising voltage"). It is obvious that the most effective means of minimising this distortion is to have a large carrier voltage, as this will shorten the interval during which only one rectifier is conducting.

(b) Bias. There is some advantage in making the bias as small as possible within the limits given by equation (1), so that the time which the distortion occurs is as near as possible to the time at which the carrier voltage passes through zero. The carrier voltage will then be changing most rapidly, and if the signal is an A.C. in phase with the carrier (as in simple phase-conscious rectification), the instantaneous signal voltage will be least.

(c) Input and output impedance. The factor Ki_A in equation (4) can be shown to be given by:

$$Ki_A = \frac{[e_c + e_s/(2+X) - E_B](4+X+Y)}{4+3X+3Y+2XY+Z(2+X)(2+Y)} \quad \ldots\ldots \quad (5)$$

where $X = R_s/R$, $Y = R_L/R$,

and $Z = \dfrac{e_A/i_A}{R}$

To obtain some idea of the importance of this effect, it is possible to

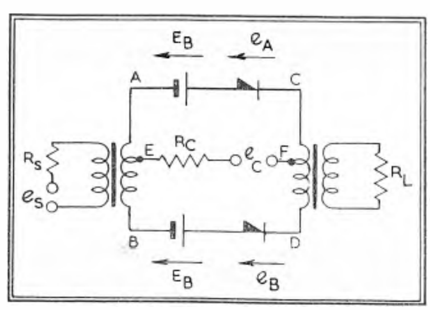


Fig. 5. The circuit is considered when AC and BD are about to conduct

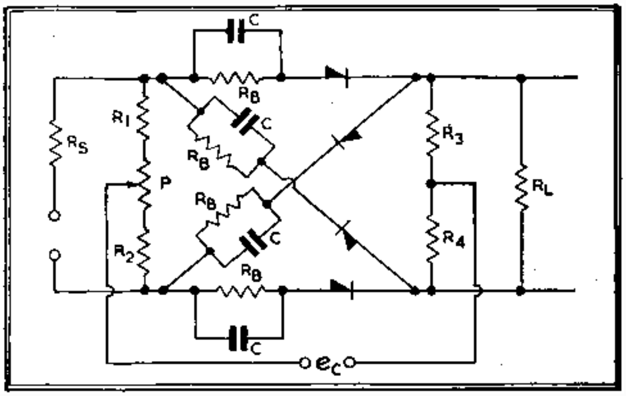


Fig. 6. A method of Auto-Bias.

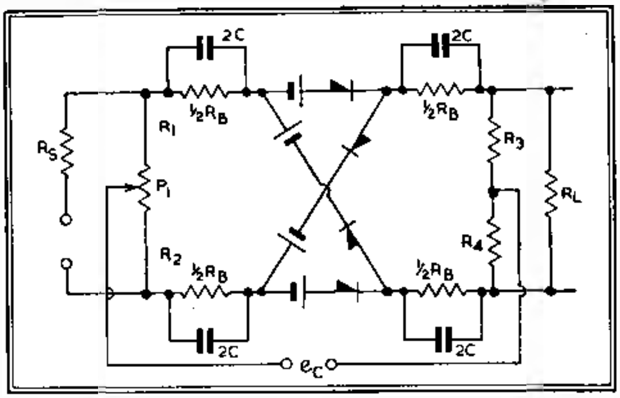


Fig. 7. Circuit equivalent to Fig. 5

calculate the value of e_s which is just sufficient to prevent the second arm conducting at all (this is not quite happening in the oscillogram in Figure 4 where $A = 60$ volts, $e_s = 40$ volts). To simplify the result it will be assumed that the forward resistance of the rectifier elements is zero and that they start conducting at zero voltage, so that $Z = 0$ and the critical $e_B = 0$. Then substituting equation (5) in (4) we can obtain the critical signal voltage e_s.

If $X = Y = 1$ or $X = 0$ and $Y \to \infty$,

Critical $e_s = A - E_B$ where A is the carrier amplitude.

If $X = Y = .5$,

Critical $e_s \approx .65\ (A - E_B)$.

Here e_s refers to the instantaneous value when the carrier voltage is a maximum.

It is thus possible for the effect to be serious when using large biases and signals.

To reduce the value of Ki_A to a minimum, X and Y should be as large as practicable.

In transformer coupled modulators (Fig. 5), it can be shown that the equation equivalent to (4) above is

$$e_B = e_c - E_B - e_s - i_A\ (R_c - R_s - R_L)$$

where it is assumed that the forward voltage across the rectifiers is zero, and that the transformers are perfect with a ratio of 1 : 2 and 2 : 1 respectively. Thus, when $R_c = R_s + R_L$, distortion due to the last term vanishes.

Method of Biasing

A convenient method of auto-biasing is shown in Figure 6. The current through the rectifier produces bias voltages in the correct sense across the decoupled resistors R_B. The resistance required give a ratio B of bias voltage to carrier amplitude may be calculated from the following formula:

$$\frac{R_F}{R_B} = \frac{1}{2\pi}\left[\sin^{-1}B + \left(\frac{1}{B^2} - 1\right)^{\frac{1}{2}}\right] - .25.$$

$$\approx \frac{1}{2\pi}\left[B + \left(\frac{1}{B^2} - 1\right)^{\frac{1}{2}}\right] - .25.$$

Where R_F is the resistance of each carrier feed resistor, and R_B is the resistance of each decoupled bias resistor.

The signal causes the currents through the various arms to alter, and the effect of the decoupled resistors is very similar to that of the circuit shown in Figure 7. Low frequencies, and in particular D.C., in the input or output may thus be considerably attenuated.

If the output feeds into a high impedance circuit—for instance, a valve grid—this effect may be reduced for certain purposes by replacing R_3 and R_4 by capacitors. In the case of phase-conscious rectifiers, it has been found by experiment that this produces non-linearity in the curves of output against the cosine of the phase angle, and of input against output, particularly in the former. The non-linearity decreases as the impedance of the capacitors is increased, and was hardly noticeable on the graphs when the impedance of the capacitors was approximately the same as that of R_1 and R_2. It should be borne in mind that these capacitors

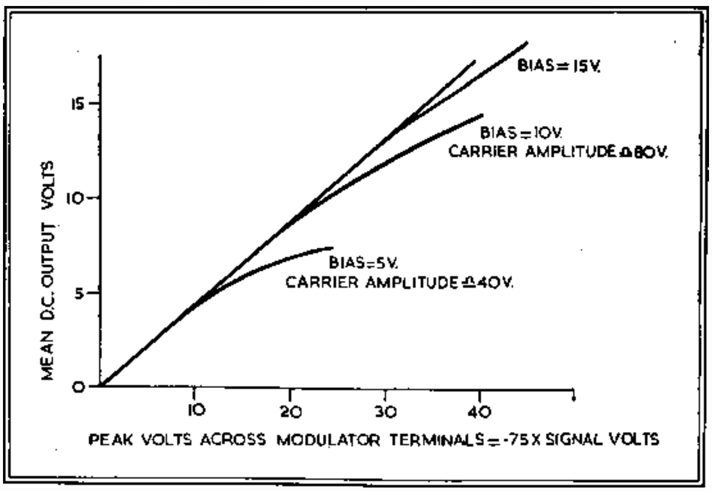


Fig. 8. Curve of output against input for a phase conscious rectifier. Zero Phase-angle

produce a phase shift in the carrier current.

Experimental Results

Experiments were performed with an auto-biased modulator similar to Fig. 6. The resistors had values:

$$R_L \gg R_B = R_1 = R_2 = R_3 = R_4 = 3R_9 = 30{,}000 \text{ ohms } P_1$$

and the rectifier elements were 6H6 diodes.

The modulator was tested as a phase-conscious rectifier at audio-frequency, so that the input and carrier ("polarising") voltages were of the same frequency.

(1) The curves in Fig. 8 are largely self-explanatory. It will be noted that the output starts falling off when the peak voltage across the modulator terminals is twice the bias voltage.

(2) The curve in Fig. 9 indicates that the modulator efficiency is practically independent of the bias and carrier voltages as long as these are higher than the critical value.

(3) A graph of output against the cosine of the phase angle with an input about two-thirds of the limiting value was also drawn. Though the curve was linear within experimental error, there was some slight consistent indication of the output being smaller than expected for small phase angles. The deviation was less than 2 per cent of the maximum output.

Conclusions

It is concluded that this form of biased ring modulator using diodes provides a satisfactory precision "phase-conscious rectifier" for use at voltages high enough to enable the output to be applied directly to the grid of an output stage, and the author has also found it very useful as a phase-conscious rectifier in certain measuring instruments in which the signal contains large spurious components.

This article is published with the approval of the Lords Commissioners of the Admiralty, but the responsibility for any statements of fact or opinions expressed rests solely with the author.

References

[1] D. G. Tucker: *Electronic Engg.*, 1947, March, August, September.

[2] J. Garlick: *Electronic Engg.*, 1948, February.

[3] D. G. Tucker: "Some Aspects of the Design of Balanced Rectifier Modulators for Precision Applications," *J.I.E.E.* (in press).

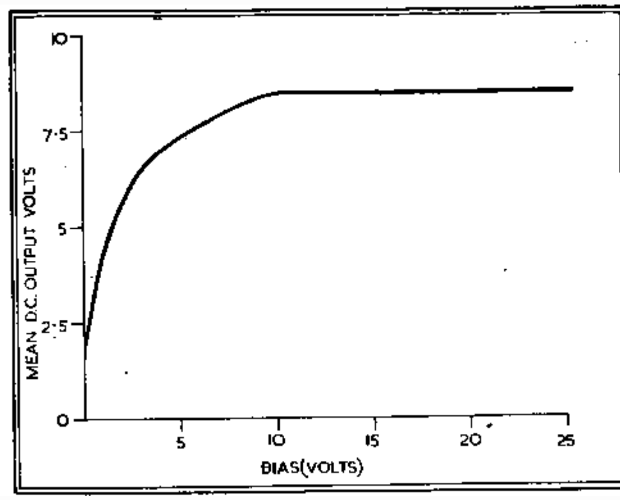
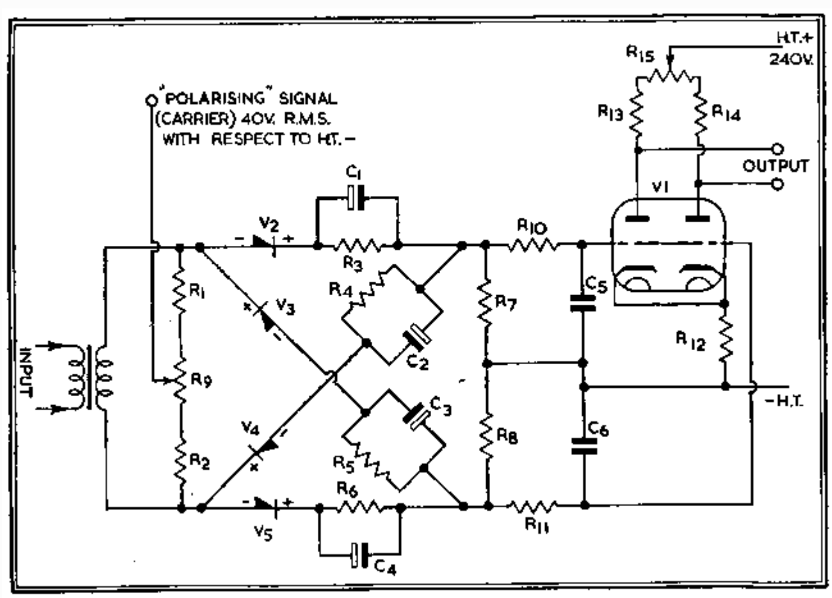


Fig. 9. Curve of output against bias. Input constant at 20 peak volts across modulator terminals



R_{1-8} —50K
R_9 —10K Preset
$R_{10,11}$—470K
R_{12} —220 Ω
$R_{13,14}$—10K
R_{15} —5K Preset

C_{1-4}—1 μF, 25V
C_{5-6}—0.1 μF
V_1 —6SN7
V_{2-5}—SENTERCEL "Uniplate" Rectifiers, Type 6A, or 6H6 Diodes

Fig. 10. A typical "Phase-Conscious Rectifier" circuit for use at Audio-frequencies down to 50 C.P.S. Sensitivity with output shorted is approximately 1.25 ma per volt R.M.S. input

VOLTAGE STABILISERS

—Part III

By F. A. BENSON, M.Eng., A.M.I.E.E.*

Stabilisers Employing Thermionic Valves (*Continued*)

A change of V_o is applied to the grid of V_1 after amplification by V_2 such that the change in the voltage drop across V_1 opposes the change in V_o. The cathode voltage of V_2 is held approximately constant by the neon tube V_3. The grid voltage of V_2 will only be slightly more negative than the cathode so that the grid will receive a fraction v/V_o of the variation in V_o where v is the voltage across V_3. The disadvantage of the circuit is that it cannot produce perfect stabilisation because some change in output is required to give a correction. Certain modifications can be made, however, to obtain better stabilisation. Since variations in V_o are produced principally by changes in input voltage and load current these latter changes can be used to give correction factors. The method of obtaining these corrections is illustrated in Fig. 21. The potentiometer chain is modified and two further resistors R_6 and R_7 are added. If the input voltage changes the change produces a variation in the grid voltage of V_1 by way of R_6, the potentiometer and the amplifier valve V_2. In this way the voltage drop across V_1 changes to oppose the change in input voltage and a variation of output voltage is prevented.

A fine control can be obtained for keeping the output voltage constant if the load current changes by inserting a resistor R_7 as shown. A change in load current produces a change in the voltage drop across R_7 which is applied to the grid of V_1 via the potentiometer and the amplifier valve V_2. In this way the output voltage change is counteracted.

A circuit for providing a stabilised supply of the order of 300 volts at currents from zero to about 160 mA which embodies the above improvements is shown in Fig. 22. Two CV124 valves are employed in parallel as the series element and a CV1091 pentode is used as the amplifier valve. The cathode voltage of the latter is held approximately constant by a CV188 neon tube. If a fault occurs in the circuit resulting in the amplifier valve taking no current (this may easily occur through failure of either the amplifier valve or the neon tube) then the output voltage rises. Since this may damage the equipment to which it is connected a safety precaution is taken by connecting a diode CV1092 directly to the anode of the CV1091. This diode is arranged so that when the anode voltage of the CV1091 exceeds a certain value it passes current and the output voltage is prevented from rising unduly.

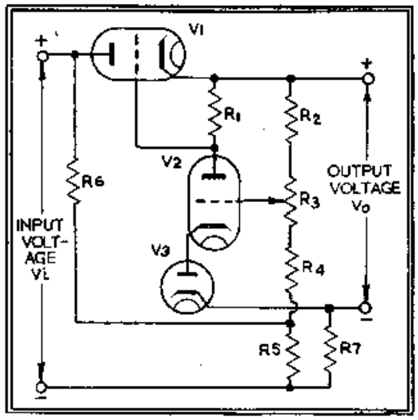


Fig. 21. Series-parallel circuit giving improved stabilisation

The performance of this stabiliser can be summarised as follows: As the load current varies from zero to 160 mA the output voltage only varies by about ±0.15 per cent and a ±10 per cent change in input voltage produces a variation of only about ±0.25 per cent in the output voltage.

The following circuits have been developed to supply a stabilised output voltage of about 1600 volts at a current of the order of 6mA. In each case calculations are made to illustrate the results to be expected. By a suitable choice of valves and other circuit parameters these circuits can be employed to cover wide ranges of current and voltage.

A parallel valve circuit is first considered. In this case a stabilised voltage of 400 volts is available across the neon tubes in addition to and independent of the 1600 volts supply. The circuit consists of a stabilising valve V_1 in series with four neon tubes CV188 across the supply voltage (Fig. 23). The neon tubes in addition to giving the auxiliary voltage also provide the reference voltage. A series resistor R_1 is included.

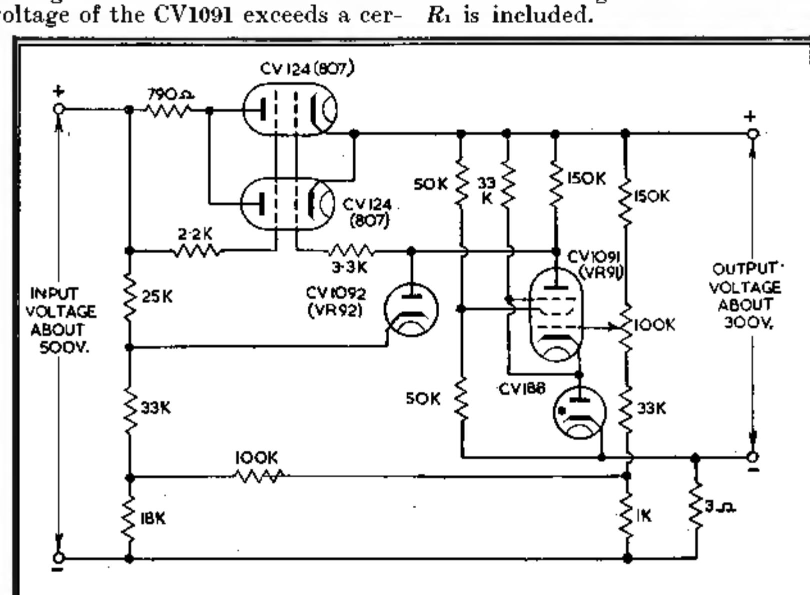


Fig. 22. Stabilised circuit for output voltage of 300 with current variation from zero to 160 mA

* Electrical Engineering Dept., University of Liverpool.

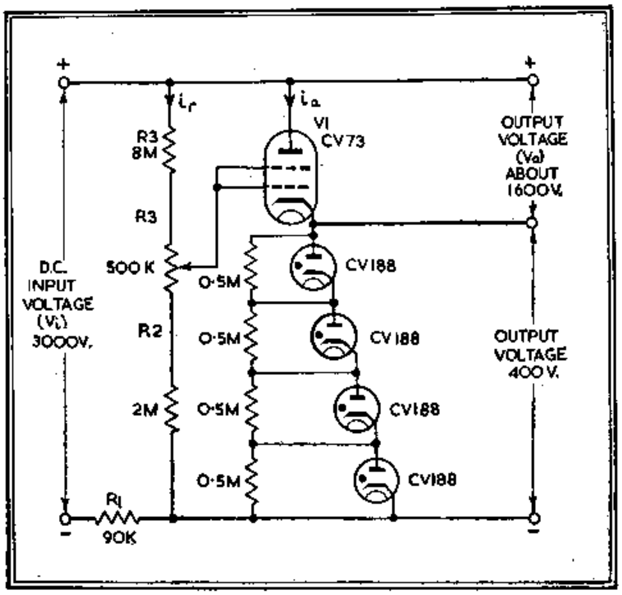


Fig. 23. Stabiliser circuit for output voltage of 1600 using a CV73 beam tetrode

Any high-slope triode is adequate as V_1 but a tetrode or a pentode can also be used. Tetrodes or pentodes may either be connected in the normal manner, supplies for the other grids being obtained from potentiometers across the supply voltage, or used as triodes, all the grids being strapped together. The valve must, of course, be capable of withstanding the input voltage between its anode and cathode and this limits the application of the circuit to voltages of about 3,000 volts or less. A CV73 beam tetrode is used in this case, being connected as a triode, and the output voltage is obtained from between its anode and cathode. Potentiometer R_2R_3 gives the necessary grid voltage for the valve.

Any change in voltage V_i changes the grid voltage of the CV73 valve (V_1) and thus its anode current. This current change produces a variation in the voltage across the series resistor R_1 which compensates for the change in V_i. For example, if V_i increases, voltage R_2i_r goes up where i_r is the current through potentiometer R_2R_3. Therefore, the grid voltage of V_1 becomes more positive so that the anode current i_a increases and the drop in voltage across R_1 increases (since i_a flows through R_1). This increase in voltage counteracts the increase in V_i and the output voltage remains substantially constant. It is advisable to insert a variable resistor in the line R_2R_3 so that small variations can be made in the values of R_2 and R_3 to obtain the best stabilisation.

The performance of this stabiliser will now be calculated. It is shown in the Appendix that the ratio of the percentage change of output voltage to the percentage change of input voltage, i.e., the quantity $\frac{dV_o}{V_o}\cdot\frac{V_i}{dV_i}$ is given by:—

$$\frac{dV_o}{V_o}\cdot\frac{V_i}{dV_i} = \frac{1}{1+\frac{v}{V_i}\left[\frac{R_1\left(\frac{\mu R_3}{ra}-1\right)-1}{R_2+R_3}\right]} \quad \ldots (1)$$

where v is the constant reference voltage, *i.e.*, the voltage across the neon tubes

μ is the amplification factor of the CV73

ra is the anode resistance of the CV73.

Also, the ratio of the percentage change of output voltage to the percentage change of load resistance R_L, i.e., the quantity $\frac{dV_o}{V_o}\cdot\frac{R_L}{dR_L}$ is given by:—

$$\frac{dV_o}{V_o}\cdot\frac{R_L}{dR_L} = \frac{1}{1+\frac{R_L}{ra}+\frac{R_L}{R_1}+\frac{R_L}{R_2+R_3}+\frac{\mu}{r_a}\left(\frac{R_2\,R_L}{R_2+R_3}\right)} \quad \ldots (2)$$

In this case $R_1 = 90\text{K}\Omega$: V_i = 3,000 volts.

Assume for optimum stabilisation $R_2 = 2.1\text{M}\Omega$, $R_3 = 8.4\text{M}\Omega$. The CV73 valve when connected as shown has the characteristics $\mu = 300$, $ra = 100\text{K}\Omega$. The characteristics of the CV188 neon tubes have already been given, thus v = 400 volts.

$$\therefore \text{ from (1) } \frac{dV_o}{V_o}\cdot\frac{V_i}{dV_i} = 0.03.$$

i.e., a change of input voltage of 10 per cent causes the output voltage to change by 0.3 per cent, *i.e.*, by about 5 volts.

From (2) it can be seen that $\frac{dV_o}{V_o}\cdot\frac{R_L}{dR_L}$ depends on the value of the load resistance R_L.

Assuming that $R_L = 260\text{K}\Omega$

$$\frac{dV_o}{V_o}\cdot\frac{R_L}{dR_L} = 0.006$$

i.e., a change in load resistance of 10 per cent causes the output voltage to change by 0.06 per cent, *i.e.*, by about 1 volt.

A series-valve circuit will now be considered. Fig. 24 shows one of a number of possible circuit arrangements. The stabilising valve, in this case a CV73 beam tetrode connected as a triode, is in series with the load and a series resistor R_1 is also included. The grid voltage of the CV73 is governed by the potentiometer R_2R_3. The reference voltage (v) is placed in series with R_2R^3 and is obtained from a single neon tube CV188 but in this case an auxiliary supply of the order of 100 volts is required.

Variation of input voltage V_i changes the grid voltage of the valve. Thus the voltage V_a across

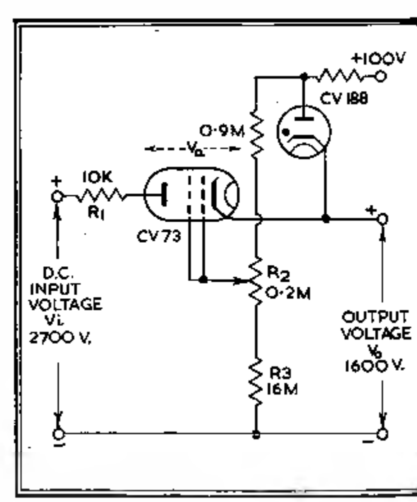


Fig. 24. Series-valve stabilising circuit using a CV73 beam tetrode

the valve varies and compensates for the change in V_i. This method is not particularly good as it is necessary to have a change in output voltage V_o in order to produce a change in grid voltage of the valve. The performance of this stabiliser will be calculated. It is shown in the Appendix that in this case the ratio of the percentage change of output voltage to the percentage change of input voltage is given by:

$$\frac{dV_o}{V_o}\cdot\frac{V_i}{dV_i} = \frac{1}{1+\dfrac{v}{V_i}\left[\dfrac{\mu R_3 - R_1 - r_a}{R_2+R_3}\right]} \quad \ldots\ldots\ldots (3)$$

and the ratio of the percentage change of output voltage to the percentage change of load resistance R_L is given by:—

$$\frac{dV_o}{V_o}\cdot\frac{R_L}{dR_L} = \frac{1}{1+\dfrac{R_L[R_1+R_2+R_3+r_a+\mu R_2]}{(R_1+r_a)\,(R_2+R_3)}} \quad \ldots\ldots (4)$$

It can be seen from (3) that the valve employed should be one having a high "slope."

In this case $R_1 = 10\text{K}\Omega$ $R_2 = 1\text{M}\Omega$ (say) $R_3 = 16\text{M}\Omega$ $V_i = 2{,}700$ volts $v = 100$ volts $\mu = 300$, $r_a = 100\text{K}\Omega$, Assume $R_L = 260\text{K}\Omega$.

From (3) $\dfrac{dV_o}{V_o}\cdot\dfrac{V_i}{dV_i} = 0.087$

i.e., a change in input voltage of 10% causes the output voltage to change by 0.87%, *i.e.*, by about 14 volts.

From (4)

$$\frac{dV_o}{V_o}\cdot\frac{R_L}{dR_L} = 0.022$$

i.e., a change in load resistance of 10% causes the output voltage to change by 0.22%, *i.e.*, by about 3.5 volts.

Many series-parallel valve circuits have been designed, each one is essentially a combination of the two previous arrangements. In these circuits there are several possible positions for the reference voltage, v. Three circuits will be considered in detail. In all of them the control grid of the series valve is connected to the anode circuit of the parallel valve and the latter behaves as a voltage amplifier.

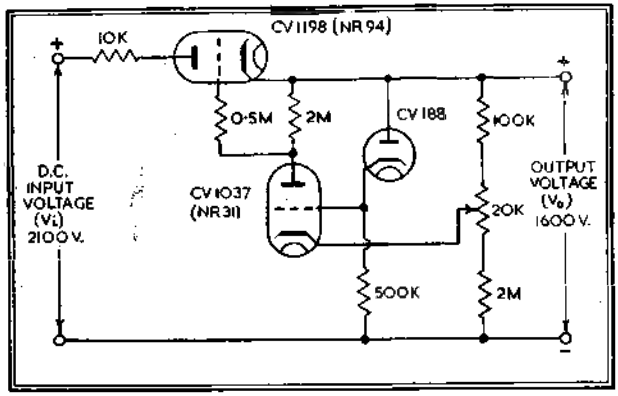


Fig. 25. Series-parallel stabiliser circuit using CV1198 and CV1037 triodes

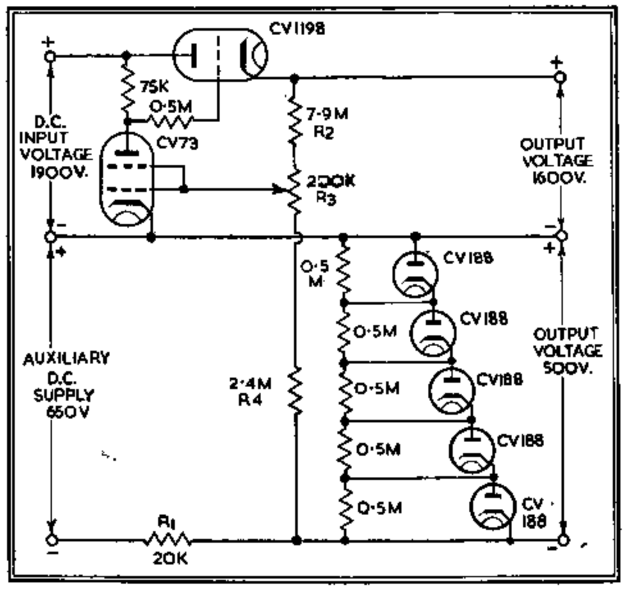


Fig. 26. Series-parallel stabiliser circuit similar to Fig. 25 (above) but using five neon tubes

In the first arrangement considered a CV1198 triode is used as the series valve and a CV1037 triode as the parallel one. The reference voltage obtained from a neon tube CV188 is placed between the cathode of the CV1198 and the grid of the CV1037 as shown in Fig. 25.

Any change in the output voltage changes the voltage of the cathode of the CV1037 with respect to its grid which has a fixed potential with respect to the positive of the output voltage. The change in cathode voltage changes the anode current of the CV1037 and hence the grid voltage of the CV1198. This produces a change in the voltage drop in the CV1198 which counteracts the change in output voltage. Analysing this circuit as in the above cases and remembering that for the CV1198 $\mu = 18$ and $r_a = 2{,}800$ ohms and for the CV1037 $\mu = 25$ and $r_a = 100\text{K}\Omega$ it can be shown that the ratio of the percentage change of output voltage to the percentage change of input voltage is 0.099, *i.e.*, a change of input voltage of 10% causes the output voltage to vary by 0.99%, *i.e.*, by about 16 volts, similarly a change in load resistance of 10% causes the output voltage to change by about 0.064%, *i.e.*, by about 1 volt.

Another satisfactory series-parallel circuit is shown in Fig. 26. Five neon tubes are employed to give the reference voltage v and in this case an auxiliary supply is also required. A stabilised voltage of 500 volts is available across the neon tubes if required. A CV1198 triode is used as the series valve and a CV73 beam tetrode connected as a triode is used as the parallel valve. Here the grid voltage of the CV73 is controlled by part of the sum of the output voltage and the reference voltage. Change in output voltage changes the grid voltage of the CV73 and therefore its anode current. This changes

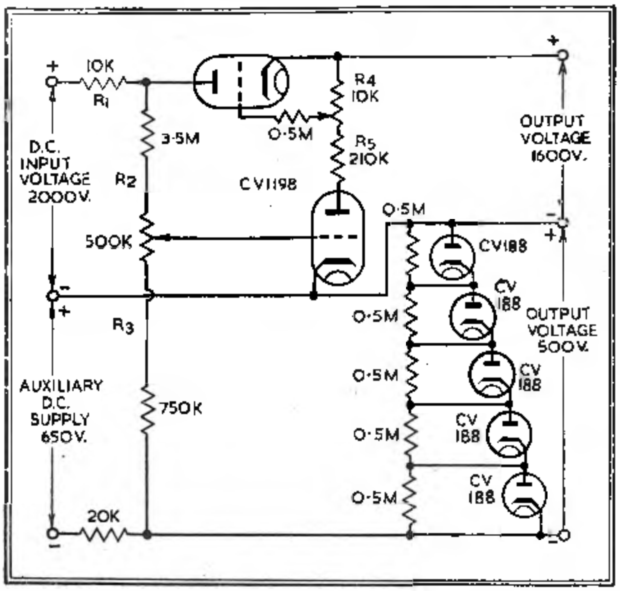


Fig. 27. Series-parallel stabiliser circuit with CV1198 triodes as both series and parallel valves. The grid of the parallel valve is controlled by the input voltage

the grid voltage of the CV1198 and hence its current and the voltage drop across it which counteracts the change in output voltage.

Analysing this circuit and remembering that for the CV1198 $\mu = 18$ and $r_a = 2{,}800$ ohms and for the CV73 valve when triode connected $\mu = 300$ and $r_a = 100\text{K}\Omega$ it may be shown that the ratio of the percentage change in output voltage to the percentage change in input voltage is 0.024 and in output voltage to the percentage the ratio of the percentage change in load resistance is 0.000019.

As stated earlier these circuits can be used for a wide range of voltages by choosing the components carefully. For example, in this circuit a stabilised output voltage of from 1,900-2,100 volts can be obtained by increasing the input voltage to 2300 volts and making $R_1 = 25\text{K}\Omega$, $R_2 = 2.7\text{M}\Omega$, $R_3 = 50\text{K}\Omega$, $R_4 = 550\text{K}\Omega$.

A third satisfactory circuit is shown in Fig. 27. In this circuit the grid of the parallel valve is controlled by the input voltage and not the output voltage as in the previous two circuits. CV1198 triodes are used for both series and parallel valves and five neon tubes CV188 together with an auxiliary supply give the required reference voltage. Any change of input voltage changes the grid voltage of the parallel valve and hence its anode current. Since the grid of the series valve is connected to the anode circuit of the parallel valve the grid voltage of the series valve is changed. Hence there is a variation in the voltage drop across the series valve which counteracts the change in input voltage and keeps the output voltage practically constant. The great advantage of this circuit is that the output voltage can be made independent of the input voltage, if as shown in the Appendix, the following condition is satisfied :—

$$R_5 \mu_p (R_3 + \mu_s R_4) = (R_2 + R_3)(R_1 + R_5 + r_{ap})$$

where :—

r_{as} = anode resistance of the series valve

r_{ap} = ,, ,, ,, ,, parallel valve

μ_s = amplification factor of series valve

μ_p = amplification factor of parallel valve

and $R_2 R_3 R_4$ and R_5 are the resistances shown in Fig. 27.

In the case illustrated :—

$$\mu_s = \mu_p = 20$$
$$r_{as} = r_{ap} = 2{,}800 \text{ ohms.}$$

Assume that $R_2 = 3.75\text{M}\Omega$, $R_3 = 1\text{M}\Omega$, $R_4 = 2.5\text{K}\Omega$. $R_5 = 217.5\text{K}\Omega$.

Then it will be seen that the above condition is approximately true.

The ratio of the percentage change of output voltage to the percentage change of load resistance for this circuit is of the order of 0.01.

Miscellaneous Circuits

Stabilisers Employing Barretter Tubes

THE barretter tube consists of an element of iron wire enclosed in a glass envelope which contains hydrogen. Over a certain range of voltage across such a tube its resistance increases nearly proportionally with the voltage, *i.e.*, the current through it remains substantially constant. This can be seen by reference to the typical characteristic of a barretter tube shown in Fig. 28. The voltage range and the current are governed by the dimensions of the iron wire. Thus, if a barretter tube is placed in series with a load across a power supply it will absorb fluctuations in the supply voltage. The voltage across the barretter changes to counteract the variations in the supply voltage.

Taylor[26] has described in detail one circuit where the barretter is placed in series with the primary of a transformer (Fig. 29) in order to keep the voltage on the latter constant. In the circuit described, as the input voltage varies over the range 105 to 130 volts, the voltage to the transformer primary remains constant at 88 volts to within ±1 volt. Even when the input voltage varies over the wide range 90 to 140 volts the output only varies by a maximum of 6 volts, *i.e.*, by about 7 per cent.

The characteristics of some available barretter tubes are given in the table below :—

Type	Current (amp.)	Voltage Range (volts)
301	0.3	138—221
302	0.3	112—195
303	0.3	86—129
304 (CV1202)	0.3	95—165
C1	0.2	90—230
C1C (CV1400)	0.2	90—230
C9	0.2	35—100
1927	0.18	60—120
1928	0.18	100—210

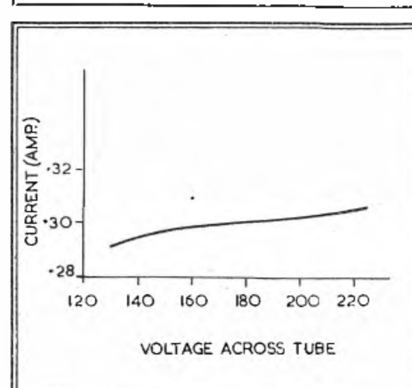


Fig. 28. Typical characteristics of barretter tube

Stabilisers Employing Metrosil

Metrosil (similar products are known under the trade names Atmite and Thyrite) may be employed with success in voltage stabilising circuits. Metrosil[27,28,29] is a solid which contains silicon carbide and has a non-linear volt-ampere characteristic. The current through a Metrosil disk varies as the fourth or fifth power of the voltage across it; *i.e.*, $I = AV^n$ or $V = BI^k$

where $n = 4$ to 5

$k = 1/4$ to $1/5$

I is the current through the disk

V is the voltage across the disk, and

A and B have values which depend on the size and shape of the disk and the material.

B varies from about 60 to 3,000. The material can be adapted to very wide ranges of both current and voltage.

Two common methods are available for employing Metrosil as a voltage stabiliser. In the first the Metrosil unit is connected in series with a resistance R across the supply voltage (Fig. 30). The resistance R is such that the voltage drop across it v is large compared with the output voltage V_o across the Metrosil. Then variations of input voltage V_i produce only small changes in V_o as shown below. Let the current in the circuit be I.

Then $I = AV_o^n$

Also

$$V_i = V_o + v, = V_o + RI = V_o + RAV_o^n$$

Therefore

$$\frac{dV_i}{dV_o} = 1 + RAn\,V_o^{n-1} = 1 + \frac{n(V_i - V_o)}{V_o}$$

i.e.,

$$\frac{dV_o}{V_o} = \frac{dV_i}{nV_i + V_o(1-n)} = \frac{dV_i}{nV_i}$$

approximately.

Thus the percentage change of output voltage is approximately $1/n$th of the percentage change of input voltage. That is, if the input voltage varies by ± 10 per cent the output voltage only varies by about ± 2 per cent. In the second method of arranging a voltage stabiliser using Metrosil a bridge circuit is employed. Two identical units of Metrosil M_1 and M_2 (Fig. 31) are placed in diagonal arms of the bridge, the other two arms of which contain identical resistances R_1 and R_2. At one particular value of input voltage the bridge balances, *i.e.*, at the point where the input voltage is such that the voltage across a Metrosil unit is equal to the voltage across a resistance. If the input voltage is increased from zero the output voltage starts at zero, rises to a maximum value, and falls again to zero, then increases in the reverse direction as shown in Fig. 32. If the working point of the bridge is arranged to be at the point P on the flat part of the curve, then over a certain range of input voltage (say Q_1Q_2) the output voltage is substantially independent of the input voltage. Ashworth, Needham and Sillars[29] have analysed the circuit and drawn up a table showing the relation between the various currents and voltages and the circuit parameters. The data presented, which includes the conditions for maximum efficiency, is useful when designing such a bridge. These methods of stabilisation are rather inefficient but have several advantages. The circuits are not limited to currents of a few milliamps as are circuits containing valves or neon tubes and are suitable for both direct and alternating current supplies. Further, there is no appreciable deterioration in performance with time as is frequently the case with valve circuits. But any circuit incorporating elements with non-linear volt-ampere characteristics usually provides harmonic voltages when used on A.C. which may be troublesome.

(To be continued)

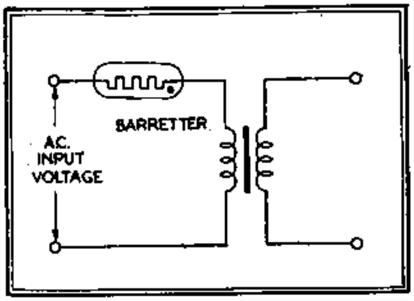


Fig. 29. Stabiliser circuit using barretter tube in series with transformer primary

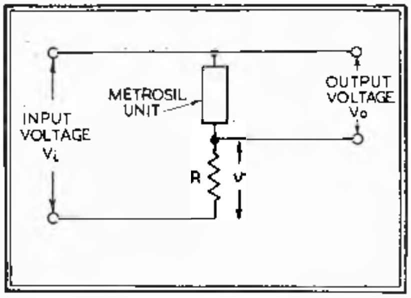


Fig. 30. Stabiliser circuit using a Metrosil unit

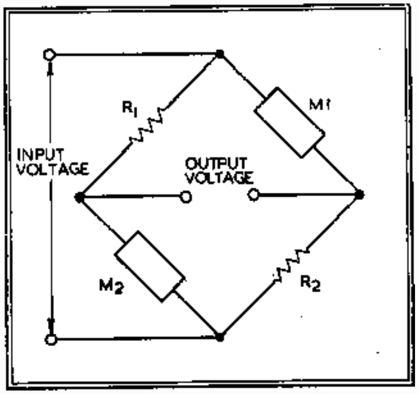


Fig. 31. Stabiliser circuit using Metrosil units in a bridge arrangement

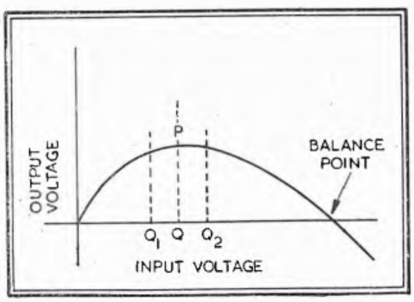


Fig. 32. Voltage characteristics of Metrosils

References

[26] S. G. Taylor: "Ballast Tubes as Automatic Voltage Regulators." *Electronics*, 15, 26. 1942.

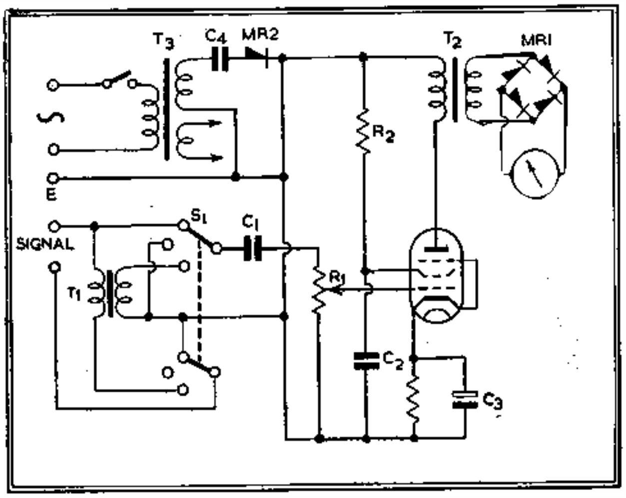
[27] "Metrosil. Its Characteristics and Applications Discussed." *The Electrician*, 133, 406. 1944.

[28] R. W. Sillars: "Metrosil." *Met. Vick. Gaz.* July, 1941.

[29] F. Ashworth, W. Needham and R. W. Sillars: "Silicon Carbide Non-Ohmic Resistors." *Journ. I.E.E.*, 93 (Part 1), 385. 1946.

A NEW VISUAL NULL INDICATOR

By MAJOR E. H. W. BANNER,
M.Sc., M.I.E.E., F.Inst.P.,



Schematic of the Null Indicator

THE high sensitivity of telephones to small audio-currents leads to their wide use for A.F. bridges, but there are occasions, such as in noisy rooms, where a visual indication is preferable, especially when increased sensitivity is required by valve amplification. The galvanometer, in some form, is then used. The earliest published use of such a null indicator appears to be in 1932, when the author described* a simple one-valve amplifier with screened input and output transformers feeding a rectifier microammeter as the indicator. Since that date many developments have occurred, mainly in the direction of increased sensitivity and various refinements. There is now a tendency to omit some of the complications while retaining the advantages, and a simple one-valve pentode amplifier has now been developed by Mr. S. J. Wright, B.Sc., A.Inst.P. For wide application two alternative impedances are provided, selected by a switch; these are a high impedance of 1 MΩ with one end earthed, and a low impedance with an input transformer in which the actual impedance varies from about 1 KΩ at 10 Kc/s. to about 100 Ω at 50 c/s. The overall frequency range is 40 c/s. to 20 Kc/s., the maximum sensitivity being in the range 100 c/s.- 2 Kc/s.

The instrument is contained in a small metal screening case carrying a 3½-in. instrument as the indicator, the other components being inside. The zero position of the pointer is to the left of the scale so that any deflexion moves the pointer over the scale. It is intended for 50 c/s. mains, but will also serve 40-100 c/s. Tappings deal with mains voltages of 110, 210, 230 and 250 V.

Controls are on the front of the panel and comprise a central *On-Off* switch, a *sensitivity* control and a three-position input switch for *High*, *Off* and *Low Impedance*. In the *Off* position the amplifier is short-circuited.

The circuit diagram shows the input transformer T_1, with double-pole switch S_1 serving to select the desired impedance range. A capacitor of 0.1 µF, C_1, passes A.C. and prevents the potential divider R_1 which forms the sensitivity control from being a conducting circuit between the terminals. The valve is a 6J7 pentode with an output transformer T_2 in the anode lead which passes signal current to the microammeter via a 4-element bridge rectifier *MR*1. The microammeter has shaped poles for maximum sensitivity in the zero position. It has a sensitivity of 0.1 in. on the scale for 0.1 µA near zero, with a resistance of 2KΩ. A transformer T_3 with a half-wave rectifier MR_2 and an electrolytic capacitor C_1 of 1,000 µF forms the power supply unit. From this R_2 of 0.1 MΩ and C_2 of 0.25 µF set the screen voltage. The cathode circuit contains the resistor R_3 of 4700 Ω and an electrolytic capacitor of 50 µF. A separate transformer winding T_3 feeds the valve heater.

The overall instrument sensitivity at maximum gain and high impedance is about 1 mV, the higher the frequency the greater the deflexion up to about 5 Kc/s., where it is 0.05 in., falling off above 15 Kc/s., all with an input of 1 mV. At low impedance the sensitivity is 0.01 in. deflexion at 0.03 mV at 50 c/s., and it increases with frequency.

The overload capacity of the instrument is high, as the valve is used insensitively with a low anode voltage, and by virtue of the nonlinear instrument characteristic due to the shaped pole-pieces the current through the microammeter does not exceed 1 mA even with 10 V applied to the input terminals.

It will be seen that the instrument comprises a sensitive and robust null indicator of high or low impedance as required, suitable to audio-frequency bridges in general.

Acknowledgment with thanks is made to Baldwin Instrument Co., Ltd., for permission to publish the design details of the instrument.

* *Journ. Sci. Inst.* IX (July 1932), p. 236.

EXPERIMENTAL V.H.F. TRANSMISSIONS

As has already been announced, the B.B.C. intend to make a full-scale trial of A.M. and F.M. as soon as the V.H.F. station now building at Wrotham is ready. In the meantime experimental V.H.F. transmissions with A.M. and F.M. are being made from two transmitters at Alexandra Palace. The carrier frequencies are 90.3 Mc/s. for F.M. and 93.9 Mc/s. for A.M. Both transmitters carry the Third Programme every day from 6 p.m. to midnight, and in addition the F.M. transmitter carries the Light Programme from 11 a.m. to noon and from 2.30 p.m. to 4.30 p.m. on Mondays to Friday inclusive. Vertical polarisation is normally used for both transmissions, but horizontal polarisation may be substituted at any time and the operating schedule may be altered without notice.

Projective Three-dimensional Displays—Part I

By D. M. MacKAY, B.Sc., A.Inst.P.*

A CATHODE-RAY tube as conventionally used gives a two-dimensional display. That is to say, it shows the way in which one variable depends on another, by means of a two-dimensional graph. It is true that, for example in television or radar, the *brightness* of the spot may be used to represent the dependent variable, which can then be shown as a function of *two* independent variables. In one sense this could be described as a "three-dimensional" display, but we shall here use the term to refer to displays in which the *position* of the spot is under the control of three variables.

There is no difficulty in making the position of the spot depend on more than two variables. Probably most of us who use oscilloscopes have at some time connected up X and Y leads, but omitted to make the "earthy" connexion, so that a stray 50 c/s. voltage has superimposed itself on the pattern and displaced it into a "waving carpet" (Fig. 1). More careful users may like to make the experiment deliberately. The simplest way is to insert the secondary winding of a suitable mains transformer in series with the lead which would normally be connected to the earthy terminal of the oscilloscope.

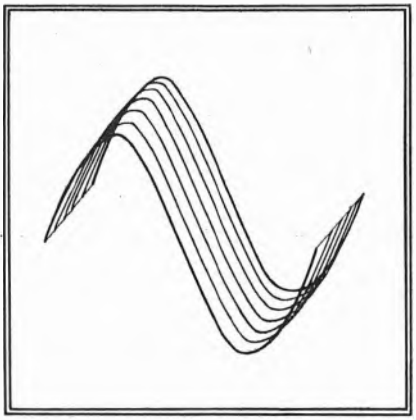


Fig. 1. A "waving" carpet

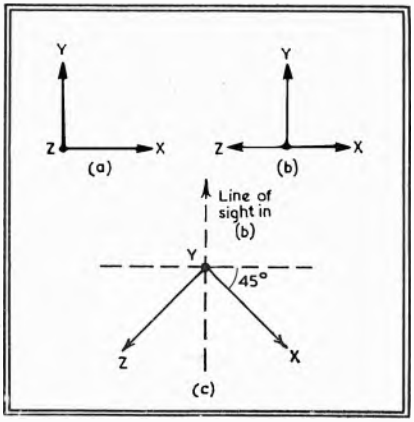


Fig. 2.
(a) View along Z axis
(b) View at 45° to X axis
(c) View of (b) along Y axis

The problem of devising a useful three-dimensional display lies rather in *separating* out the part which each of the three variables has played in producing a given pattern, since with three variables "in control", any one spot-position corresponds to an infinite number of possible combinations of variables.

Now a picture of a three-dimensional subject, on the screen of a C.R. tube, is essentially a projection of the subject, on a plane making certain definite angles with its three axes of reference.

We have thus two problems in this type of display—firstly to secure a reasonably accurate projection of three-dimensional data on the X-Y plane of the C.R. tube, and secondly to remove the ambiguities which exist in any single projection.

It should be mentioned that this projective method† is not the only way of displaying three dimensions. A comprehensive paper on the display of three-dimensional radar data has appeared recently,[1] and includes an account of optical methods of filling a small *volume* of space with data so as to form a "truly" three-dimensional picture.

Projection

Looking along any *axis*, X say, of a three-dimensional reference system, one has a "plan view" of the other two axes Y and Z. If, however, the line of sight is rotated to a position half-way between X and Z axes in the XZ plane, the view of the Y axis, will be unchanged, but the other direction of the field of view will include "some of X and some of Z." (Fig. 2.).

In mathematical terms what one sees is the projection of X and Z axes on the plane normal to the line of sight. The apparent horizontal co-ordinate x' of any point in the XZ plane will thus be the difference between the projections of its true co-ordinates x and z on the "plane of sight." In general, (Fig. 3), when the X axis has been rotated through an angle θ from the position of Fig. 2(a), i.e., when the Z axis makes an angle θ with the line of sight, the "visible co-ordinate" x' of a point P (x, z) is given by:

$$x' = x\cos\theta - z\cos\theta \quad \text{.............. (1)}$$

The corresponding "invisible" z' co-ordinate is given by:

$$z' = x\cos\theta + z\sin\theta \quad \text{.............. (2)}$$

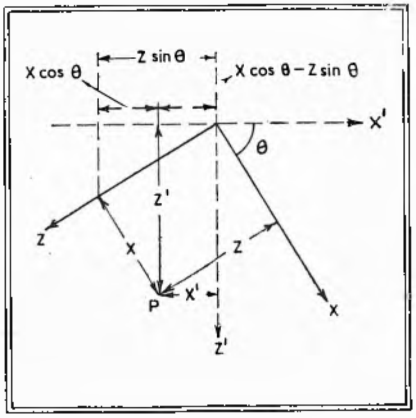


Fig. 3. Rotation of X axis through angle θ

Now let us assume that we have three voltages, x, y and z, of which y varies with x and z so as to describe a three-dimensional pattern. Clearly all that we have to do to obtain a view along the Z' direct-

* Wheatstone Physics Laboratory, University of London King's College.

† The first published account of projective technique is believed to be the Patent application of Parker et. al.[2]. Mention should also be made of a report by Dumont Laboratories[3], and a paper by Schmitt[4] on similar lines.

tion, is to mix the X and Z voltages in the proportions $\cos\theta$ and $\sin\theta$ before applying the resultant to the X-plates of our C.R. tube. In fact, if we apply a fraction $x\cos\theta$ to one X-plate, and $z\sin\theta$ to the other, the tube will subtract them automatically and give the required X' deflexion to the spot according to Equation (1). The result will be a view of the pattern described by x, y and z, from ground level as it were, and at an angle θ to the Z axis. (Fig. 4, see page 252).

More generally, the line of sight may be at an angle oblique to all three axes. The rule which we have found for the simple case can easily be extended, and in its general form can be stated thus:

To obtain a projection on a plane in which the axis X', Y' are specified by direction cosines $(l_1m_1n_1)$ and $(l_2m_2n_2)$ relative to the X, Y Z axes, mix the x, y, z voltages in the proportions of the direction cosines of X' and Y'. In other words, make

$$x' = l_1x + m_1y + n_1z \quad \text{.............. (3)}$$

$$y' = l_2x + m_2y + n_2z \quad \text{.............. (4)}$$

and if z' is required,

$$z' = l_3x + m_3y + n_3z \quad \text{.............. (5)}$$

where $(l_3m_3n_3)$ are the direction cosines of the line of sight.

Rotation

In everyday life, the two-dimensional projection of the solid world on the retina of the eye is given "depth" in a number of ways. The tension in the focusing muscles, the convergence of the eyes and the different views seen in binocular vision, and, of course, long experience of familiar objects, all help us to distinguish between a small object near at hand and a large one farther away. Sometimes, however, even these are insufficient, and we have to take the trouble to move our point of view to see another aspect of the field, from which the ambiguity is resolved. This important facility of *relative rotation*—so commonly used, for example, in "parallax" methods of optical measurements—is fortunately very simple to secure in our projective displays, and provides the key to the problem which confronted us at the beginning of this article.

There are many ways in which we may choose to rotate our pattern, but one of the most convenient methods is to carry out the selection of aspect in two independent stages.

The first corresponds to the transformation which we considered (Equations 1 and 2), which effectively rotates the pattern about the Y axis. With ganged attenuator-controls to mix continuously-variable proportions of x and z according to Equations 1 and 2, we can select any angle of view (θ) at the turn of a knob.

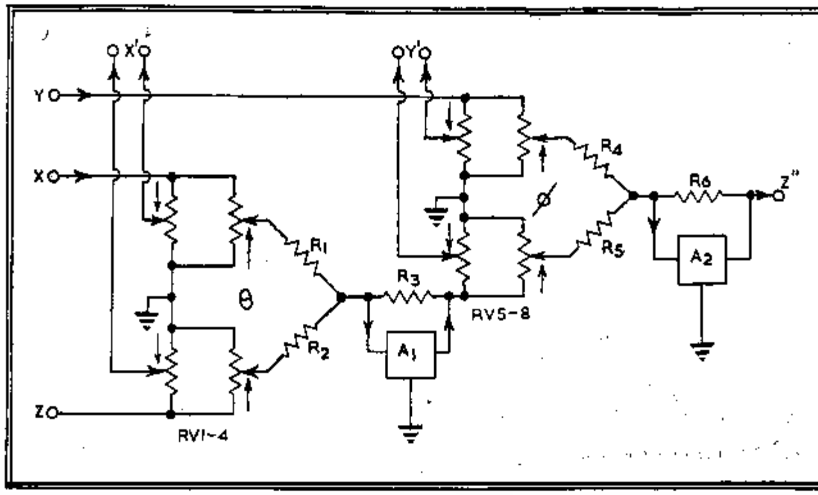


Fig. 5. A resistive resolving circuit

Ganged potentiometers are very suitable for this purpose, though "resolvers" of other kinds, such as magslips,[1] may be used over limited frequency ranges. (We shall return to practical considerations).

The second stage of aspect—selection can conveniently correspond to rotation about the X' axis—choice of the *angle of elevation* of the line of sight. The principle is the same as before, but in this case we must combine y with the voltage z' which is synthesised in the first operation (Equation 2) so as to form:

$$y' = y\cos\theta - z'\sin\theta \quad \text{.............. (6)}$$

and if we wish:

$$z'' = y\sin\theta + z'\cos\theta \quad \text{.............. (7)}$$

Here z'' is the "invisible" co-ordinate normal to the face of the C.R. tube. Its use in providing perspective will be discussed below.

These two facilities can together remove any structural ambiguities present in a given projection, since any surface which is seen "edge-on" under one rotation is "opened out" under the other.

A Practical Circuit

A practical circuit to effect the transformations which we have been considering is shown in Fig. 5. The two stages of rotation, about Y- and X'-axes respectively, can be followed quite separately. RV_{1-4} and RV_{5-8} are ganged potentiometers which theoretically should be graded according to sine and cosine laws, but may in practice be linear, with suitable modifications. In the first stage, voltages $x\cos\theta$ and $z\sin\theta$ are derived from RV_1 and RV_3 and passed to the X-plates (preferably through a balancing amplifier). RV_2 and RV_4 are "cross-connected" to RV_1 and RV_3 so that voltages $x\sin\theta$ and $z\cos\theta$ are supplied to the adding circuit R_{1-3}. The latter is one form of the well-known "anode-follower" circuit, in which approximately equal resistances are used in the input and feedback paths of the sign-reversing amplifier A_1. A_1 should have a frequency-response extending at least to the lowest frequency present in x, y or z, but its linearity is of negligible importance owing to the complete negative-feedback. The output is given by the formula:

$$v_o = \frac{\alpha.m}{1+\alpha+2m}(x\sin\theta + z\cos\theta) \ldots (8)$$

Where α is the gain of A_1, and m is the ratio R_3/R_1, R_1 and R_2 being equal. Equation (8) represents simple addition if we make $m = \frac{\alpha - 2}{\alpha + 1}$, and it is clear that, if the gain is large, the value of m required will not differ much from unity, whatever the actual value of α. Changes in gain (or non-linearity) will have correspondingly little effect on v_o, which is then equal to $-z'$. A single valve can provide ample gain for most purposes.

The second stage—a rotation through θ—is identical in principle with the first, but since A_1 changes the sign of z', the voltage applied to the Y-plates is $y\cos\theta + z'\sin\theta$, while the "perspective" voltage z'' is $-(y\sin\theta - z'\cos\theta)$. Both z' and z'' are developed at low impedance, since feed-back reduces the output impedance of A_1 and A_2 to a few hundred ohms. The output of A_2 can thus be directly connected to the "perspective" circuits, and can be quite heavily loaded without ill effects. z'' can readily be increased by making R_6 approximately $\alpha \times R_5$. One must, however, ensure that A_2 can deliver the correspondingly large peak output voltage.

The design of RV_{1-4} and RV_{5-8} is not critical if the measuring techniques adopted are to be of the "scale-free" sort described below.

If accuracy is required, mechanical linkages can be designed to make linear potentiometers follow the required sinusoidal law. For most purposes, however, it is sufficient to obtain "3-point" correction by a device such as that shown in Fig. 6.

If the complete range of RV corresponds to angles from 0° to 90°, the ratio in the half-way position corresponds to an angle of 45°, and should ideally have a value sin 45° or 0.707. This can be arranged by connecting a shunt resistance R_8 as shown, with a value approximately $\frac{3}{8} \times RV$. Where a load resistance such as R_7 is present, R_8 can easily be modified to allow for its effect. In general, for a ratio of 0.7 at 45°,

$$R_8 = 3RV/8 + 14(RV/R_7)$$

It should be mentioned that somewhat expensive continuously-rotating sine-cosine potentiometers exist, with centre-tapped elements and facilities for extracting both sine and cosine fractions of the applied voltage. A push-pull input is required (relative to centre-tap). Using these, one is no longer restricted to one quadrant of view, (though, of course, all other quadrants provide only replicas or mirror images of the first).

Again, if push-pull signals are available, there is no reason why ordinary centre-tapped linear potentiometers should not be used to give 180° rotations if desired. The example described here is merely the simple one which the author has found adequate for electronic computation work and class lectures, and is by no means exhaustive of the possibilities.

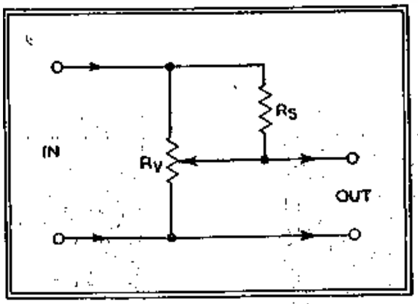


Fig. 6. "3 point" correction circuit

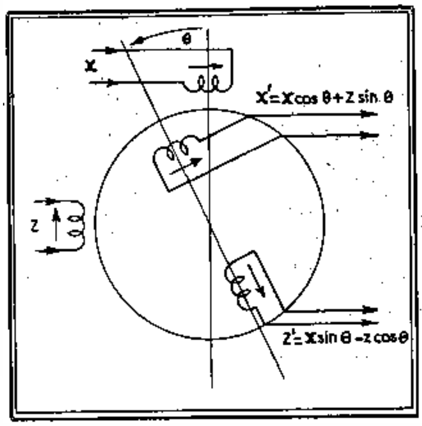


Fig. 7. A magslip resolver

The use of magslip resolvers will only briefly be mentioned, as their frequency-characteristics make them unsuitable for general-purpose work, and in particular they are incapable of resolving steady or low-frequency potentials.

In one form, illustrated in Fig. 7, two windings at right angles produce magnetic fields proportional to x and z. Two rotating coils, also at right angles, have voltages induced in them proportional to $x\cos\theta + z\sin\theta$, and $x\sin\theta - z\cos\theta$, respectively, where θ is the angle shown.

Thus one unit performs all the operations required for a given rotation—a strong point in favour of magslips when the nature of the voltages x, y and z makes it possible to use them. Their sine-cosine law is very accurately followed, and they are, of course, capable of continuous rotation.

Perspective

There is one remaining ambiguity which we have not yet removed—a rather more subtle one. A pattern such as Fig. 8(a) can be pictured in two ways—one with AB nearer to the observer than CD, the other with AB farther away. Both are equally justifiable views. In other words, "turning the pattern inside out" makes no difference. What it lacks is *perspective*, the property by which receding parallel lines appear to converge. Thus, Fig. 8(b) on the other hand leaves us in no doubt that CD is behind AB. What we have to do is to make the *scale* of our picture vary with the *depth*, which is in our case the "unseen" co-ordinate z''.

In practical terms, we must contrive to adjust the deflexion-sensitivity of our display (or, what amounts to the same thing, the gain of our x' and y' amplifiers) in sympathy with z''. Fig. 9 illustrates this. We wish to display a point P which has an X'-co-ordinate x' and is nearer to the observer E (co-ordinate z_e) than the origin O by an amount z''. Since, however, our display is all in one plane $OX'Y'$, the point P is actually represented by a point P', the projection of P from E, on the $X'Y'$ plane. The X'-co-ordinate of P' must therefore be, not x', but:

$$x' \times z_e(z_e - z'')$$

The simplest method of modulating x' in this way is to control the accelerating voltage of the C.R. tube. Since the sensitivity in an electrostatic tube is inversely proportional to the accelerating voltage V, the effect of subtracting a voltage $\alpha \times z''$ from V is exactly what we require, if we make $\alpha = V/z_e$.

For example, if the observer is 3 ft. away, and if the picture-scale is 1 ft. per 1,000 volts, then $\alpha = V/3$ where V is in kilovolts.

Two points of detail may need attention:

The *focus* of an electrostatically focused tube remains unaltered only if the ratio of potentials applied to the gun is kept constant. It is desirable therefore to apply $\alpha.z''$ not merely to the accelerating anode, but to the whole potential-divider feeding the gun, as indicated in Fig. 10(a). C_1 and C_2 are small capacitors chosen to maintain the ratio at high frequences. With electrostatic deflexion, astigmatism may be troublesome, and it is preferable to feed $\alpha.z''$ into the C.R. tube circuit via the last H.T. smoothing capacitor (Fig. 10(b)).

Similar considerations apply to magnetically deflected tubes, but the sensitivity is then inversely proportional to $\sqrt{V}$, so that the law is less exactly followed.

McKAY . PROJECTIVE

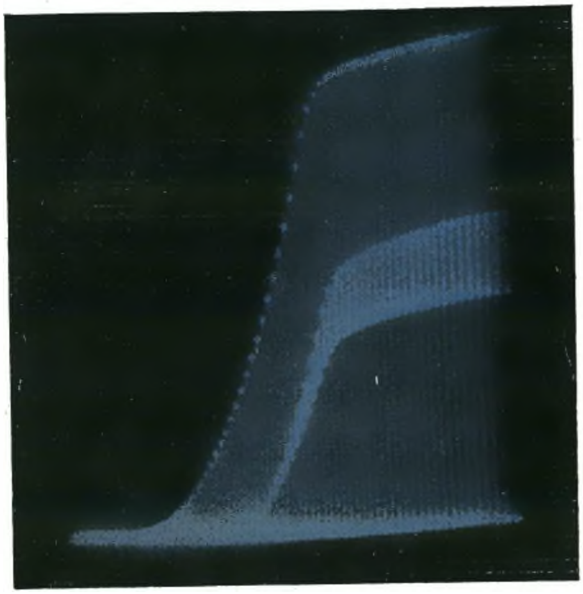


Fig. 4 (a).

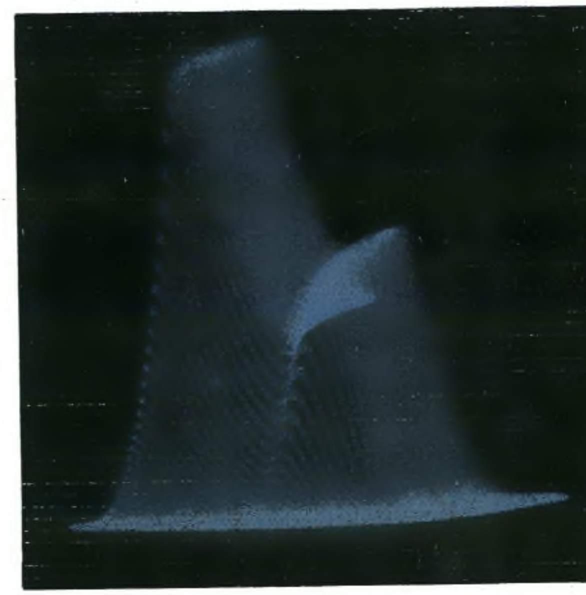


Fig. 4 (b).

Fig. 4. Three elevations of a surface $y=f(x, z)$
(a) Along X-axis
(b) At 45° to X— and Z-axis
(c) Along Z-axis

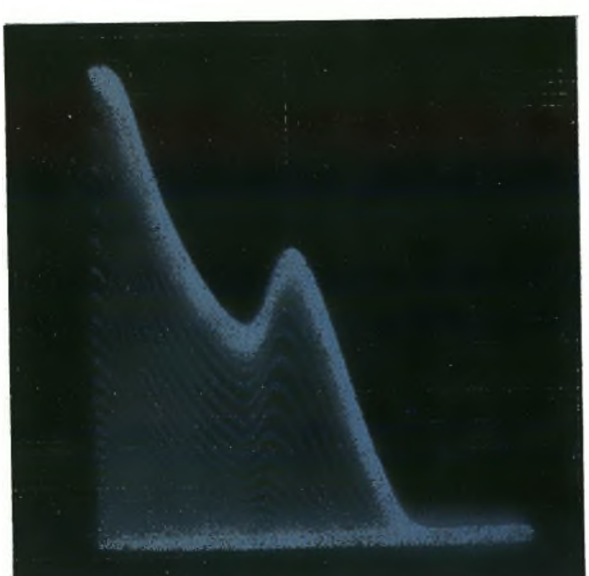


Fig. 4 (c)

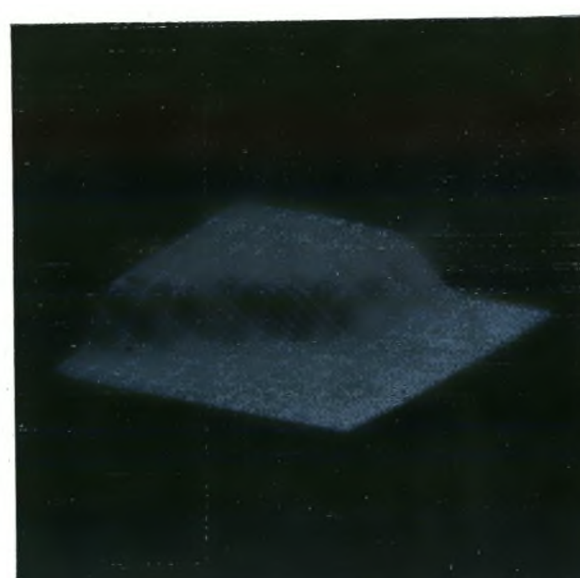


Fig. 19 (a).

THREE-DIMENSIONAL DISPLAYS

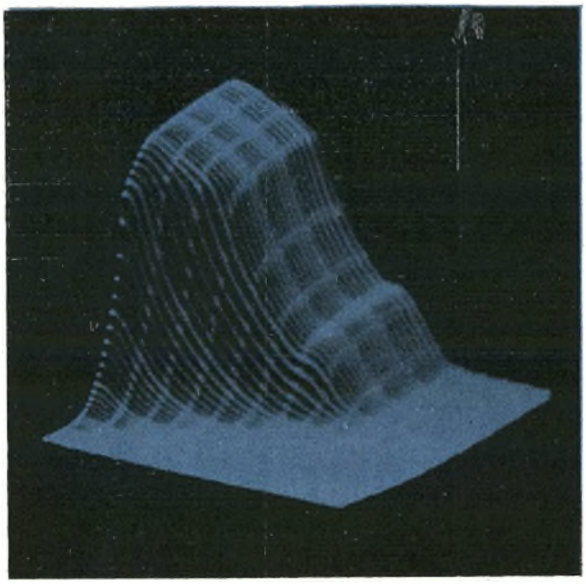


Fig. 19 (b).

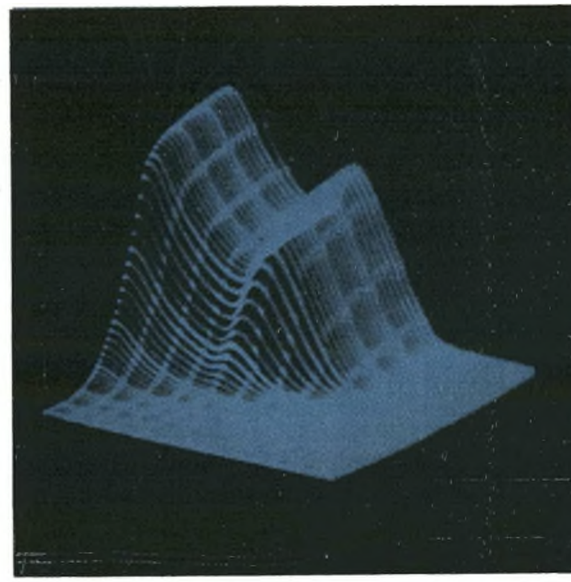


Fig. 19 (c).

Fig. 19. Five stages in the development of a secondary-emission " valley " in the characteristic surface of a tetrode

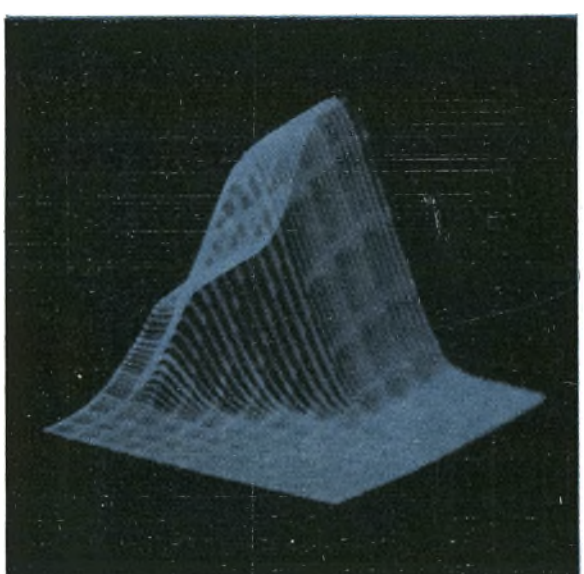


Fig. 19 (d).

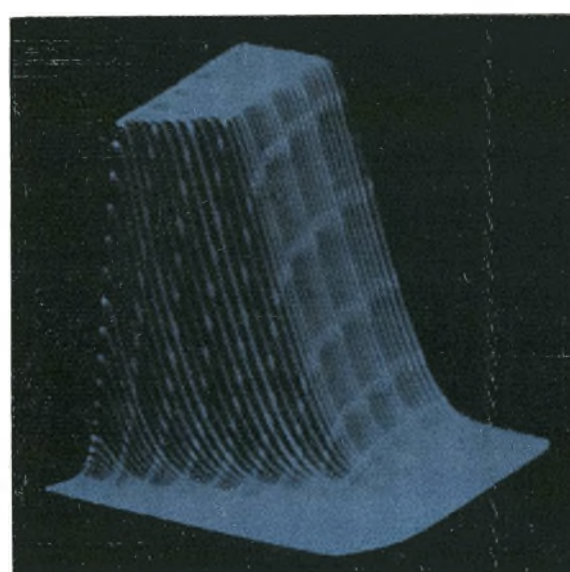


Fig. 19 (e).

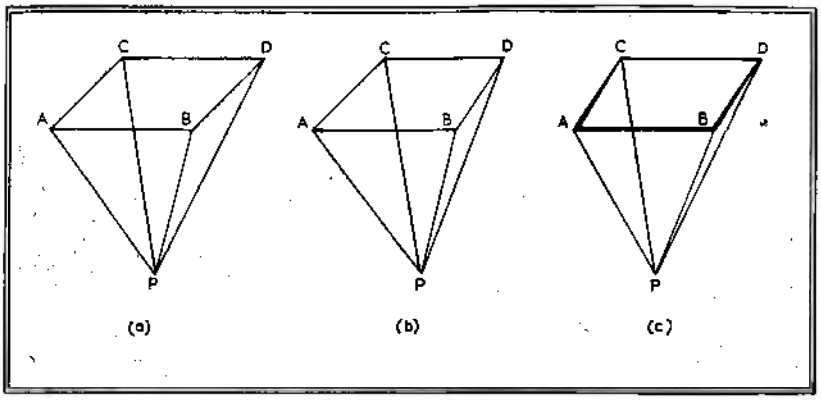
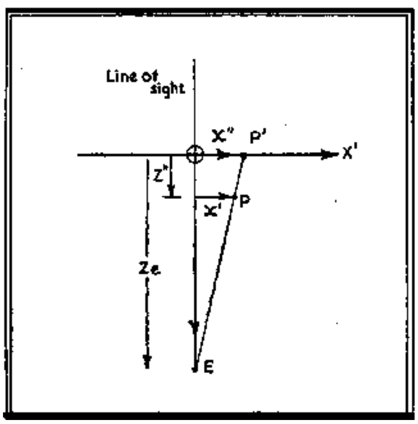


Fig. 8 (a) (b) and (c). The problem of perspective



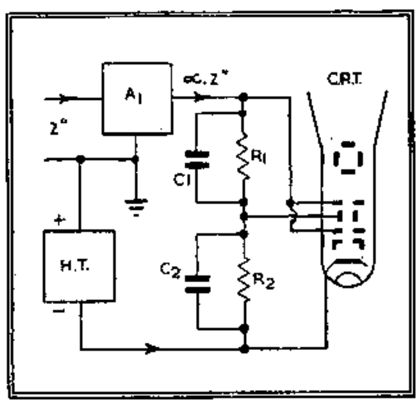
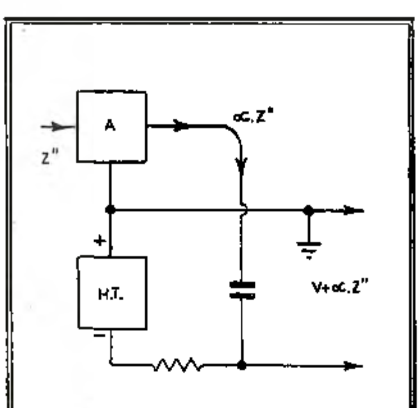
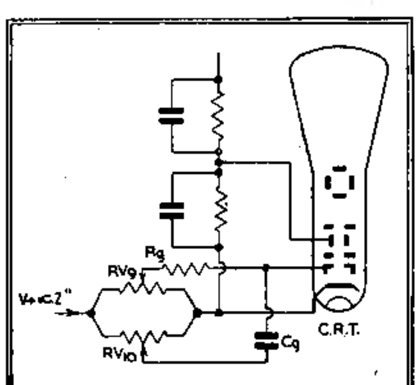


Fig. 9 (above). A point P (x', Z"), is seen by the eye E (O, Ze) as a point P' on the X' axis at a distance $x'' = \left(\frac{Ze}{Ze-Z''}\right) x'$ from O

Fig. 10. (a) above and 10 (b) and (c) below. Three methods of obtaining perspective convergence





The *brightness* of the trace will tend to increase with accelerating voltage, making the more distant portions of the picture appear brighter. To counteract this it is simplest to feed a fraction of z'' to the grid circuit of the C.R. tube, so as to increase the bias as z'' increases. One way of doing this is shown in Fig. 10(c). Here RV_9 controls the standing grid bias, while RV_{10} controls the fraction of the modulation appearing, via C_g, between grid and cathode.

The last point brings us to a second method of dealing with the ambiguity of Fig. 8(a), which is illustrated in Fig. 8(c). If we can arrange to brighten the parts of the picture which are nearer, the eye seems to be quite deceived. (Fig. 8(c) is identical in structure with Fig. 8(a), but the enhanced brightness of AB leaves us in little doubt that CD is farther away.

In many cases this method alone is sufficient to remove ambiguity, and is considerably simpler to achieve than the first, since grid-modulation can be applied directly, and z'' requires only to be attenuated.

The two methods in combination are, of course, still more effective, and can be applied, for example in Fig. 10(c), simply by "over-compensating" on RV_{10}.

Stereoscopic Displays[5]

We shall not consider here in detail the addition of stereoscopic vision to projective displays, which is rather outside the scope of the present paper. Fundamentally the problem involves the presentation of two projections from slightly different points of view, either alternately on one tube, or on two tubes with their screens optically superposed. Means must then be provided to ensure that the left eye sees only the one (left-hand) view, while the right eye sees only the other.

(To be continued)

REFERENCES

[1] Parker, E. & Wallis, P.R.J., *Inst. Elec. Eng.*
[2] Parker, Wallis & Woroncow, *Brit. Prov. Pat. App.* 9942/46, 30/3/46.
[3] *Dumont Lab. Engg. Report No. 92*, 20/9/46.
[4] Schmitt, O. H., *J. App. Phys.* **18**, p. 819, 1947.
[5] See, for example, *I. E. Radar Convention Papers* 1946.

The Electromagnetic Horn

—Part 1

By W. D. OLIPHANT *

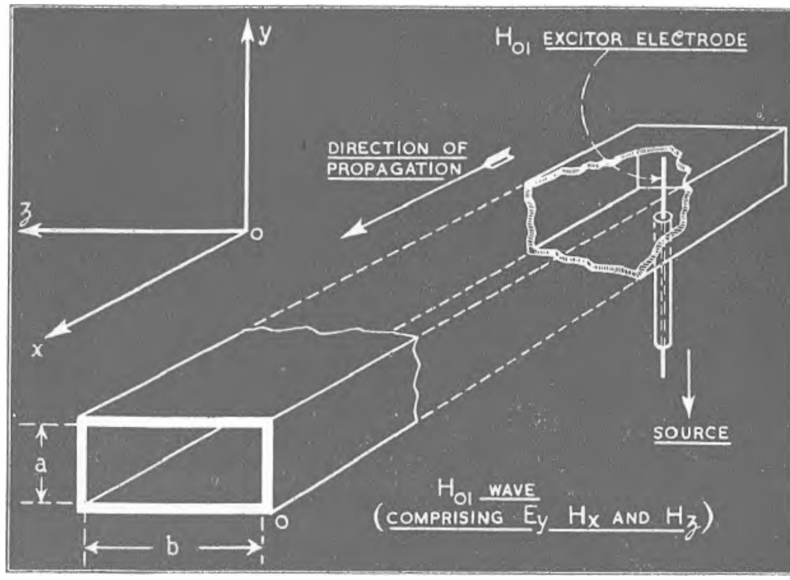


Fig. 1 Rectangular Hollow Tube Wave Guide. (Relevant Dimensions and axes of reference)

EARLY theoretical analyses[1] had indicated the possibility of propagating electromagnetic waves along dielectric wires and through hollow conducting tubes, but only recently has the practical realisation and importance of the subject been demonstrated. This has been made possible by the means for generating frequencies of the order of 300 Mc/s. and upwards, when the physical dimensions of the guide apparatus come within practical laboratory limits.

Transmission phenomena in dielectric wires and through conducting tubes are entirely different in themselves and they also differ from normal free-space wave propagation and from propagation along lines or cables. The properties of hollow-tube wave guides, and in particular those of rectangular and circular section, have received considerable theoretical and practical investigation, and a selection of the published papers is given [2, 3]. Natural extensions of the subject are the cavity resonator and the electromagnetic horn, the former providing a means for utilising the phenomenon of resonance and of replacing the familiar tuned circuit at hyper-frequencies, and the latter providing a means for radiating or absorbing electromagnetic energy in a highly directive manner and thus of replacing the orthodox aerial array and its associated reflector system. The present paper will deal with the theory and practice of the electromagnetic horn primarily as a radiator of energy, but, in accordance with the general theorem of reciprocity, the inverse property of energy absorption is understood everywhere to apply.

Basically, an electromagnetic horn is the open end of a hollow tube wave guide wherefrom the guided waves are launched into free space and the radiation pattern depends on the configuration of the guide end. It will be shown that, by flaring the open end into a horn structure of suitable dimensions, the radiation efficiency and directivity may be considerably increased and secondary lobes and other spurious effects, such as backward radiation, reduced to a negligible amount. By comparison with other highly directive aerial systems at hyper-frequencies, the horn compares very favourably and its inherent simplicity, both constructionally and operationally, indicate considerable advantage in its use.

The action of the flared mouth may be regarded as providing an approximate impedance match between the guide and the external medium, and in this way, subject to considerations associated with the relation between wavelength and physical dimensions, it may be compared with its dynamical analogue, the acoustic horn. The precise horn

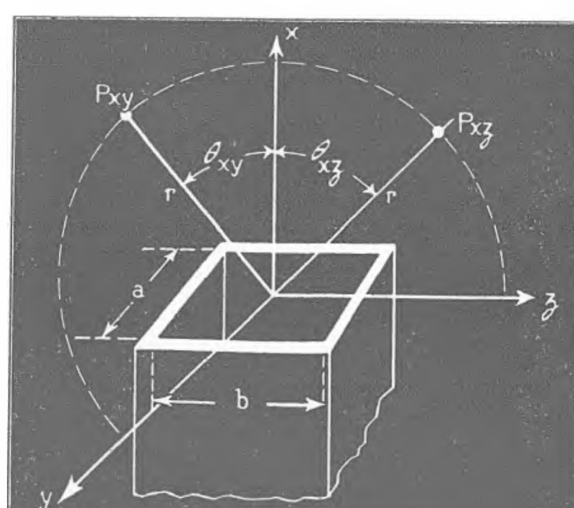


Fig. 2. Rectangular tube guide radiation (co-ordinate system at open end)

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configuration is dependent primarily on the guide section to which it is attached, and, of the rectangle and circle, the former presents the simpler construction and it, at the same time, makes possible the radiation of a true linearly polarised wave. The flare may be produced in two directions to form a pyramidal horn, or in one direction only to form a sectoral horn. The characteristics of such horns will be developed step by step, commencing with the rectangular hollow tube wave guide.

Part I.—Theoretical Considerations

Guided Waves in Conducting Tubes of Rectangular Section

The guided wave in a non-dissipative twin wire or concentric feeder possesses a field which is wholly normal to the axis of the system; that is to say, the axial components of the E (electric) and H (magnetic) intensities of the wave are zero, and the system will transmit waves of all frequencies with the same phase velocity. In the hollow conducting tube, on the other hand, there must always exist an axial component of either (or sometimes both) the E or H intensities. In accordance with the accepted notation, a tube-guided wave possessing both a longitudinal and transverse component of the E field but only a transverse component of the H field is called an E-wave or transverse magnetic wave (*TM*-wave). A wave possessing both a longitudinal and transverse component of the H field but only a transverse component of the E field is called an H-wave or transverse electric wave (*TE*-wave).

In each case there exists a fundamental wave denoted by E_0 or H_0, and, in addition, geometric harmonic waves wherein the nth harmonic is denoted by E_n or H_n. Furthermore, the harmonic waves are extended in "order"; thus the nth harmonic wave of mth order is designated E_{nm} or H_{nm}. Each wave, of whatever type, harmonic or order, has its own critical or cut-off frequency below which the waves are rapidly attenuated and above which they are freely transmitted. This critical frequency is governed by the tube dimensions. A tubular wave guide thus exhibits the properties of a high-pass filter, and in the transmission band introduces considerably less loss than do the parallel wire or coaxial cable counterparts.

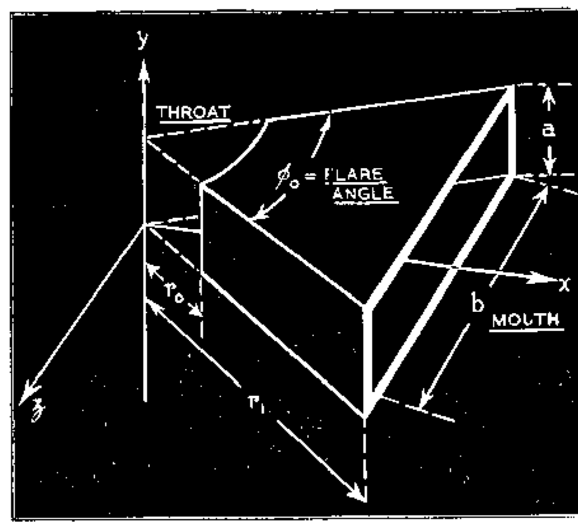

Fig. 3. The sectoral Horn

A typical rectangular hollow tube wave guide with relevant dimensions and axes of reference is shown in Fig. 1, and it is assumed for present purposes that the guide is non-dissipative. The type of guided-wave which possesses the most outstanding properties is the fundamental transverse electric wave of the first order—the H_{01} wave—and attention will therefore be confined to it alone. This type of wave is characterised by an E field intensity which is normal to the direction of propagation (x-axis) and parallel to the side a (y-axis). The intensity distribution along the z-axis is a half-period sinusoid, the maximum value occurring at the centre of the section. When the open-ended tube is employed as a radiator of energy, this intensity distribution produces a displacement current sheet across the mouth whose current elements are all parallel and of equal phase, and which therefore all produce similarly polarised component space waves. The resultant space wave is thus vertically polarised and the radiation characteristic is a single-lobe beam. Other practical advantages of the H_{01} wave include the lowest critical or cut-off frequency for a given section of guide and negligible attenuation which decreases with increase in frequency. Furthermore, its use calls for a minimum of material in the construction of the guide, as will presently be shown.

The excitor electrode is positioned at the closed end of the tube to coincide with a line of electric intensity in the field pattern and the optimum position can best be obtained by making the closed end in the form of a movable piston reflector which maintains a high conductivity joint around its periphery. The length of the excitor electrode should also be capable of adjustment so as to provide a correct impedance match between the guide, excitor and concentric feeder connecting with the source.

For a rectangular hollow tube wave guide, it can be shown that the critical wavelength (λ_o) is given by the simple relation:

$$\lambda_o = 2b \quad \ldots\ldots\ldots\ldots \quad (1)$$

and the cut-off frequency (f_o) by

$$f_o = c/2b \quad \ldots\ldots\ldots\ldots \quad (2)$$

where c is the free space-wave velocity = 3×10^{10} cm/sec.

In terms of the free space excitation wavelength (λ_e), the wavelength in the tube (λ_t) is given by

$$\lambda_t = \lambda_o/M \quad \ldots\ldots\ldots\ldots \quad (3)$$

where

$$M = \left[1 - \left(\frac{\lambda_e}{2b}\right)^2\right]^{\frac{1}{2}} \quad \ldots\ldots \quad (4)$$

The interesting point to note is that the critical wavelength is not dependent on the dimension a which is parallel to the electric vector E_y and so the tube may be made of small cross-sectional area provided only that Equation (1) is satisfied and that adequate space is available for the insertion of a suitable excitor electrode. For a given operational wavelength the H_{01} wave thus requires less material in the guide construction than would be the case for a circular or square section tube required to transmit any of the possible wave types.

From Equation (3) it is evident that $\lambda_t > \lambda_e$ and thus the phase velocity in an air-filled tube is always greater than that in free space. The value of the phase velocity is given by

$$v_p = c/M \quad (5)$$

and this approaches the value c when λ_e becomes small compared with $2b$ or λ_0.

In transmission line practice it is customary to express the general property of the line in terms of its characteristic impedance, and appropriate impedance expressions may be derived on a power or a current-voltage basis for a hollow tube wave guide. In problems associated with radiation, where the essential quantity is field intensity, a quantity (Z_0), symbolic of impedance, is given by

$$Z_0 = \mu c/M \quad (6)$$

where μ is the magnetic permeability of the medium within the tube, and in the case of air this has a value $4\pi \times 10^{-9}$ henry/cm.

For a plane wave in free space the corresponding value is

$Z_0 = \mu c = 377$ ohms, and it can be seen that this value is approached in Equation (6) as b becomes considerably greater than the excitation wavelength λ_e. Thus by flaring out the end of the tube in the direction of the z-axis, it is possible to approach an impedance match between the guide and the external medium. The horn structure, apart from directivity considerations, may thus be regarded as a non-uniform hollow tube guide with impedance matching properties in the same manner as the non-uniform transmission line.

Rectangular Tube Guide Radiation

The H_{01} wave launched by the excitor electrode (Fig. 1) will travel along the tube to the open end when the greater part of the wave energy will be radiated into free space: only a small part of the energy will be reflected back along the tube.

The properties of this simple form of radiator have been investigated both theoretically and practically by Barrow and Greene[4] who derive expressions for the horizontal and vertical field characteristics for a fundamental transverse electric wave of any order (H_{0m}). The equations here given are simplified in virtue of the fact that only the first order wave is being considered, and the co-ordinate system adopted is shown in Fig. 2.

The relative magnitude of the electric intensity normal to the radius vector r, which is large compared with the excitation wavelength (λ_e) and with the guide dimensions, in terms of the angle θ (referred to the x-axis or direction of propagation) is given by the following two equations:

(a) Vertical characteristic (xy-plane for points P_{xy}).

$$E_\theta(xy) = C\left|(\cos\theta + M).\frac{\sin A}{A}\cos\theta\right| \quad (7)$$

(b) Horizontal characteristic (xz-plane for points P_{xz}).

$$E_\theta(xz) = C\left|(\cos\theta + M).\frac{\cos B}{B^2 - [\frac{1}{2}\pi]^2}\right| \quad (8)$$

where

$$\left.\begin{array}{l} A = \pi W_v \sin\theta \\ B = \pi W_h \sin\theta \\ W_v = \text{vertical aperture} = a/\lambda_e \\ W_h = \text{horizontal aperture} = b/\lambda_e \end{array}\right\} \quad (9)$$

and M is given in Equation (4).

The quantity C is a comprehensive constant taking into account the excitor current and frequency, the size of the tube and the value chosen for the radius vector about which the field intensity is being explored; in short, C does not influence the relative field distribution provided the factors just cited do not vary.

From Equations (7) and (8) the first minima are found to occur when

$$\theta_{xy} = \sin^{-1}\frac{1}{W_v} \text{ and } \theta_{xz} = \sin^{-1}\left(\frac{3}{2W_h}\right)$$

and so the vertical and horizontal beam angles are given by

$$\left.\begin{array}{l} \theta_v = 2\sin^{-1}\dfrac{1}{W_v} \\ \theta_h = 2\sin^{-1}\dfrac{3}{2W_h} \end{array}\right\} \quad (10)$$

since the field configurations are symmetrical about the x-axis.

For equal apertures the beam will thus always be sharper in the vertical plane than in the horizontal, being in ratio of 2:3. In general, any values of beam angle may be provided for by suitable choice of W_v and W_h, that is to say, of a and b.

In the operational limit when the tube is functioning at its critical wavelength, then $\lambda_e = 2b$, hence $W_h = \frac{1}{2}$ and $B = \frac{1}{2}\pi.\sin\theta$; this Equation (8) reduces to:

$$E_\theta(xz) = C'\left|\frac{\cos(\frac{1}{2}\pi.\sin\theta)}{\cos\theta}\right| \quad (11)$$

which is almost a circle possessing a major axis in the direction of propagation.

Again, when $a \to 0$, then $W_v \to 0$ and so $A \to 0$, giving rise to a limiting value for the vertical characteristic in the form

$$E_\theta(xy) = C\,|\,(\cos\theta + M)\cos\theta\,| \quad (12)$$

and if in addition the critical wavelength is also reached, then $M = 0$, and so in the double limit

$$E_\theta(xy) = C.\cos^2\theta \quad (13)$$

Such an examination of the basic equations given at (7) and (8) reveals the manner in which the directive radiation pattern is dependent not only on the physical dimensions of the guide orifice but also on the operational wavelength. In general, it may be stated that for a sharp beam in the horizontal plane (the usual practical requirement), the operational wavelength should be considerably less than the cut-off wavelength, which is another way of stating that the horizontal width of the guide orifice should be large compared with the operating wavelength.

In the previous section, impedance match was seen to be approached by flaring the horizontal tube dimension, and in the present section such flaring also indicates a sharpening of the horizontal beam characteristic. It is now necessary to see how these qualities are achieved by the fitting of an actual horn structure to the end of the hollow tube guide or of the use of a finite length of non-uniform hollow tube guide.

The Sectoral Horn

The relevant dimensions of a sectoral horn, together with the axes of reference, are shown in Fig. 3. The material of the horn, like that of its parent tubular guide, is of high conductivity, at any rate as far as the inner surface is concerned.

The horizontal and vertical apertures are defined in terms of the wavelength and mouth dimensions in accordance with Equations (9), but in addition there exists a relative radial "length" (x_1) and cut-off "length" (x_0) defined by the equations.

$$\left.\begin{array}{l} x_1 = r_1/\lambda_e \\ x_0 = r_0/\lambda_e \end{array}\right\} \quad (14)$$

Such a conductive structure may be excited either by attaching a hollow tube-feed to the throat or by direct excitation when the excitor electrode, backed by an adjustable reflector, is inserted into the throat region. For wavelengths of the order of 20 cm. or less the former method is recommended, while the latter is reserved for the longer wavelengths; in either method of excitation substantially the same radiation field characteristics prevail subject to certain dimensional requirements dependent on horn-wave propagation. For purposes of radiation analysis, the field distribution across the mouth is taken to be the same as that across the appropriate section of a similarly flared horn of infinite radial length when end effects are absent; the ideal mouth distribution is thus the same as that produced by the H_{01} wave in the guide radiator.

In the tubular guide the wavelength (λ_t) was greater than that in free space (λ_e) and, as is to be expected in the case of horn-wave propagation, the wavelength at the throat end is much greater than that at the mouth end, and there thus exists a crowding of the H-lines with attendant high field intensity in the vicinity of the throat. In the throat region the waves suffer a high degree of attenuation, while further along the horn they encounter little or no attenuation, and it is customary to think in terms of an attenuation region and a transmission region through which the waves must pass. The horn, in effect, acts as a specialised form of guide for electromagnetic energy, allowing it to spread out in such a manner as to create a transverse wave across the relatively large boundary surface at the mouth.

In the attenuation region (small r), the phase constant β is very small compared with its free space value of $2\pi/\lambda_e$, while in the transmission region (large r) β is practically equal to the free space value.

For a fundamental transverse electric wave of any order (H_{om}) the attenuation constant (α) and the phase constant (β) for the attenuation region are given approximately by [5]

$$\left.\begin{aligned} \alpha &= \frac{m\pi}{\phi_o r} \\ \beta &= \frac{2\pi}{\lambda_e}\left\{\pi\left[\left(\frac{m\pi}{\phi_o} - 1\right)!\right]^{-2} \left(\frac{\pi r}{\lambda_e}\right)^{2\pi m/\phi_o - 1}\right\} \end{aligned}\right\} \quad \ldots\ldots \quad (15)$$

where r is the radial distance measured from the apex or origin in the xz-plane.

Similarly, for the transmission region the approximate relations are:

$$\left.\begin{aligned} \alpha &= 1/2r \\ \beta &= 2\pi/\lambda_e \end{aligned}\right\} \quad \ldots\ldots \quad (16)$$

The line of demarcation between the attenuation and transmission regions is not well defined, but it is evident from the first of Equations (15) that the radial distance to which the attenuation region extends increases with wave order and with decrease in flare angle. For a given flare angle the horn therefore presents the properties of a wave-order filter tending to suppress the higher order in favour of the lower order waves.

The phase velocity (v_p) and wavelength (λ_h) within the horn are given by

$$\left.\begin{aligned} v_p &= \omega/\beta \\ \lambda_h &= 2\pi/\beta \end{aligned}\right\} \quad \ldots\ldots \quad (17)$$

The group velocity (v_g) in the case of any wave propagation in air or vacuo is given in terms of the phase velocity in accordance with the equation

$$v_g = c^2/v_p \quad \ldots\ldots \quad (18)$$

Thus, since the phase velocity in the throat is larger than c it follows that the throat group velocity is less than c. As the horn wave progresses radially, the phase velocity decreases, while the group velocity increases, until at the mouth they are both equal to the free space wave velocity c.

The above theory applies generally to a horn which extends radially to infinity, but in practice it may also be taken to apply to a horn of finite length. For purposes of radiation, the mouth is taken to be several wavelengths beyond the attenuation region, thus calling for an overall relative "length" (x_r) of the order of about 8 to 10; in addition the flare angle is limited to a maximum value of 90°.

In calculating the field distribution, the radiation is taken to originate from the displacement current sheet across the mouth in precisely the same manner as was done in the case of the guide radiator. As far as the vertical characteristic (xy-plane) is concerned, the radiation conforms with the configuration given in Equation (7), being independent of the flare angle. The rigorous mathematical analysis for the horizontal characteristic (xz-plane) is distinctly involved and can be found elsewhere,[5] but for flare angles not greater than 50° the expression already given in Equation (8) may be employed to a high degree of practical accuracy provided the horizontal aperture is of the order of 3. For flare angles greater than 50° the experimentally observed lobes are broader than those obtained theoretically by the use of Equation (8) and the discrepancy increases rapidly with increase in flare angle. Thus within the 50° limit, the beam angle (θ_h) may also be computed as for a tube radiator.

In assessing the behaviour of a horn as a radiator, apart from its directive qualities, the relative power gain is taken as a measure of its effectiveness. By relative power gain is meant the ratio of the power radiated by a simple dipole to that radiated by the horn to produce the same E-field strength at a fixed point on the principal axis (x-axis) distant many wavelengths from the origin. The power gain is found to be dependent on the flare angle for a given fixed radial length and is also proportional to the vertical aperture (W_v) and relative radial "length" (x_r).

(To be continued)

References

[1] Heaviside, "Electric Papers," p. 443 (1892). "Electromagnetic Theory," vol. 1, p. 399 (1893) Rayleigh, "On the Passage of Electromagnetic Waves through Tubes or the Vibrations of Dielectric Cylinders," *Phil. Mag.*, **43**, 125 (1897). "Scientific Papers," vol. 4, p. 227 (Oxford 1897) Thomson, "Recent Researches in Electricity and Magnetism," p. 344 (Oxford, 1893).

[2] Adams & Page, "Electromagnetic Waves in Conducting Tubes," *Phys. Rev.*, **52**, 647 (1937). Barrow, "Transmission of Electromagnetic Waves in Hollow Tubes of Metal," *Proc.I.R.E.*, **24**, 1298 (1936). Carson, Mead & Schelkunoff, "Hyper-frequency Wave Guides—Mathematical Theory," *B.S.T.J.*, **15**, 310 (1936). Clavier, "Theory of Cylindrical Dielectric Wave Guides and Coaxial Cables," *Bull. Soc. des Elec.*, **8**, 255. (1938). Southworth, "Hyper-frequency Wave Guides—General Considerations and Experimental Results." *B.S.T.J.*, **15**, 284 (1936). "Some Fundamental Experiments with Wave Guides," *Proc. I.R.E.*, **25**, 807 (1937). "New Experimental Methods Applicable to Ultra-Short Waves," *Jour. App. Phys.*, **8**, 660 1937).

[3] Barrow & Chu, "Electromagnetic Waves in Hollow Metal Tubes of Rectangular Cross-section." *Proc. I.R.E.*, **26**, 1520 (1938).

[4] Barrow & Greene, "Rectangular Hollow Pipe Radiators," *Proc.I.R.E.* **26**, 1498 (1938).

[5] Barrow & Chu, "Theory of the Electromagnetic Horn," *Proc. I.R.E.*, **27**, 51 (1939).

Panoramic Display — Design Considerations*

By DONALD W. THOMASSON†

"PANORAMIC Display" is the general name covering a very useful type of oscilloscope. Whereas, in the ordinary way, one of the dimensions of the diagram produced is in a scale of time, in a panoramic display, the corresponding dimension is in a scale of frequency. The variation of the second variable may therefore be observed over a wide range of frequency, as in a "panorama" of the range.

Without the use of panoramic technique, the observation would entail a large number of separate measurements at different frequencies, the results being plotted as a graph. This is, at best, a laborious process, and has other disadvantages.

In the panoramic display, the frequency of measurement is swept continually through the required range, and the motion of the spot on the C.R. Tube screen in one axis is related to the variation of frequency. Each point on that axis is therefore corresponding to a certain frequency.

The second variable is made to control the motion of the spot in the other axis, so that the graph obtained by the "static" technique, mentioned above, is continuously visible on the screen.

Types of Display

There are two basic types of display. In the passive type (Fig. 1), the second variable is an externally generated signal, or signals, and the voltage and frequency of the various components are displayed as vertical lines whose position indicates frequency, and whose height indicates voltage. Examples of the passive type include the panoramic receiver and harmonic analyser.

The active type (Fig. 2), generates the observed signal itself, and displays the effect of an external circuit on the signal. This produces a "response curve" of the circuit, as in the "Wobulator" type of alignment generator.

Essential Features

The essential features of the apparatus required for producing a panoramic display are: the oscilloscope unit, the variable frequency oscillator and a circuit having a finite acceptance band.

In the passive display, the "circuit with a finite acceptance band" is generally in the form of an I.F. amplifier. In the active display, it is the circuit under test, with special reference to any peaks in the response of that circuit.

Whatever the circuit is, the frequency of the input signal fed to it will sweep across the acceptance band. It is this fact that gives rise to the inherent limitations of the technique.

Limitations

General Basis.

"If the frequency of the input to a circuit having a finite pass band is varied across that pass band, distortion of the output will occur if the time taken to cross the pass band is less than the reciprocal of half the band-width."

This is fundamental, and no proof will be given here. The basis of the rule can be seen if the response is assumed to cause amplitude modulation of the applied signal. In practice, the results are in close agreement with the rule.

It may be expressed:

$$w = \sqrt{\tfrac{1}{2}\frac{df}{dt}} \quad \text{(1)}$$

Where the width of the acceptance band is $2w$ c/s., and $\frac{df}{dt}$ is the rate of change of frequency.

Linear Scale.

If the motion of the spot in the frequency axis follows the usual saw-tooth form, with negligible fly-back time, and the change of frequency within a given time is proportional to the movement of the spot, a linear frequency scale will be produced.

If the sweep repetition frequency is s c/s., and the band swept is b c/s. wide, $\frac{df}{dt} = sb$, and:

$$w = \sqrt{\frac{sb}{2}} \quad \text{(2)}$$

Resolution.

The "electrical resolution" (r) of the display is defined as $2w/b$, and is a measure of the degree of accuracy (see Fig. 3). A small resolution indicates high accuracy. Values between 0.03 and 0.003 are satisfactory for most purposes. Substitution of the definition in

* Based a paper presented before the Brit.I.R.E. (*J.Brit.I.R.E.* May-June 1948).

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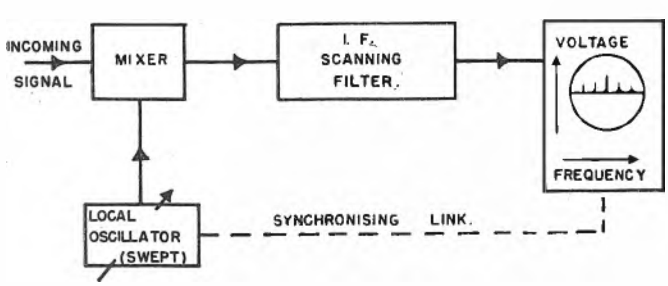


Fig. 1. Schematic of passive display

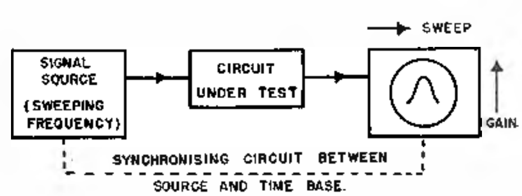


Fig. 2. Schematic of active display

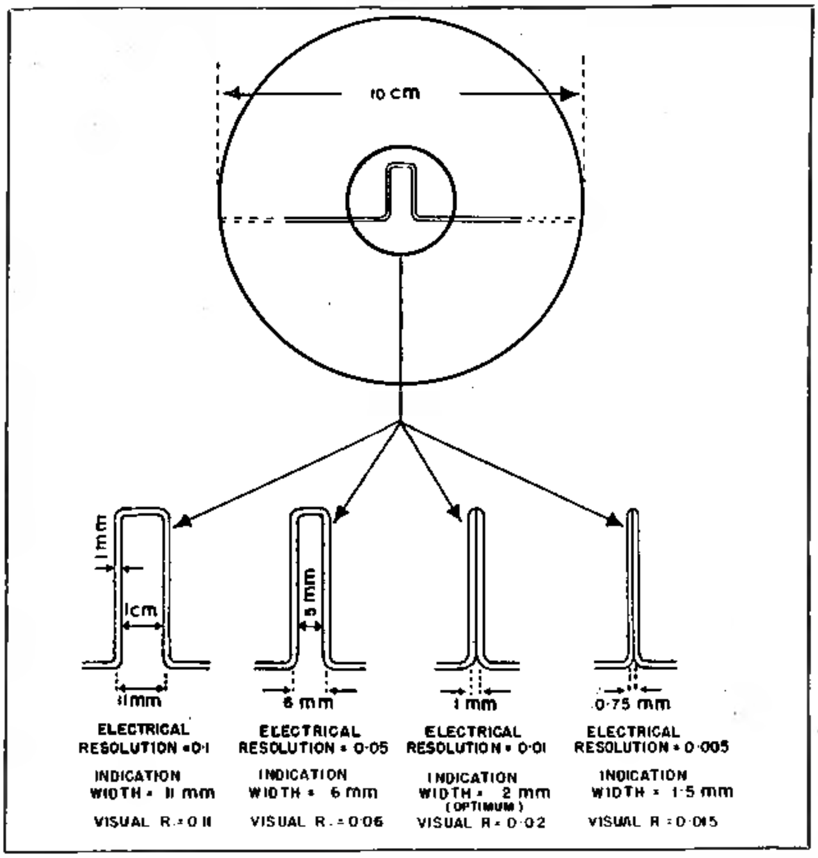


Fig. 3. Examples showing the meaning of the resolution factor

Equation 2 gives:

$$r = \sqrt{\frac{2s}{b}} \quad \ldots\ldots\ldots\ldots \quad (3)$$

An improvement in resolution therefore implies a reduction of sweep frequency or an increase in the swept band.

Selectivity.

The "selectivity factor" (n) is defined as $2w/f$, and is a measure of the degree of accuracy in respect of frequency. From Equation 2:

$$n = \frac{\sqrt{2sb}}{f} \quad \ldots\ldots\ldots\ldots \quad (4)$$

This implies a maximum swept band limit, whereas Equation 3 implied a minimum limit. Together, they imply a minimum frequency limit to the sweep:

$$f_0 = \frac{2s}{nr} \quad \ldots\ldots\ldots\ldots \quad (5)$$

This should be compared with the following form of Equation 3:

$$b = \frac{2s}{r^2} \quad \ldots\ldots\ldots\ldots \quad (3a)$$

Practice.

In practice, s is limited by the nature of the screen. With an ordinary high-speed screen, s must not be less than 25 c/s., or flicker will appear. With after-glow screens, s may be reduced to 0.2 c/s.

It has been stated that r should normally lie between 0.03 and 0.003, and similar values are desirable for n. Combining these requirements with those for s, it is seen that the minimum bandwidth and the minimum frequency of the sweep are both 55.5 Kc/s. With the after-glow screen, both may be reduced to 450 c/s.

These, however, apply only when the worst usable values of r and n are employed. A resolution of 0.03 corresponds to the reading accuracy obtainable with a C.R. Tube having a screen 3 cm. in diameter and a spot 1 mm. in diameter. It should be noted that 0.03 is the electrical resolution, and that the visual resolution would be 0.06 if this size of tube were used, giving a 2 mm. indication width.

With a more useful resolution $r = 0.01$ (10 cm. screen, 1 mm. spot) the limit frequencies increase to 500 Kc/s. and 4 Kc/s.

Evading the Limitations.

These inherent limitations cannot be avoided, but they can be evaded. One possible solution for low frequency sweeps, or where very good resolution is required, is the use of logarithmic frequency sweep. In this, the rate of change of frequency is proportional to frequency, and the optimum value of w varies with frequency.

In the case of the passive type of display, where w is the width of the pass band of a tuned circuit, it is difficult to obtain the full advantage of logarithmic sweep. A recent American design actually varies the bandwidth of the circuit by a control voltage during the sweep, but this is a complex and difficult procedure.

For the passive display, however, another method is available. This involves "shifting" the observed band to a less restricted region by hetrodyning. The technique has been applied with success in recent experiments on vibration analysis.

Frequency Relating Circuits

The heart of any panoramic apparatus is the circuit used to relate the C.R. Tube deflexion voltage and the observation frequency. Some possible circuits will be described.

Reactance Valve.

The most familiar circuit for relating voltage and frequency is the reactance valve (Fig. 4). In this, the signal across the oscillator coil is applied across the anode and cathode of a valve, while a voltage which is 90° out of phase with this signal is fed to the grid. The anode-cathode impedance is thus substantially reactive, the magnitude of the reactance, and hence the oscillator frequency, being controlled by altering the standing bias of the valve.

The reactance valve has a limited sweep range, and the relation between voltage and frequency tends to become non-linear when large sweeps are used. It is, nevertheless, a very useful circuit.

It can be used with advantage in a beat-frequency circuit, when the controlled oscillator can operate at a frequency much higher than that required at the output. In this case, an automatic drift correcting circuit is desirable.

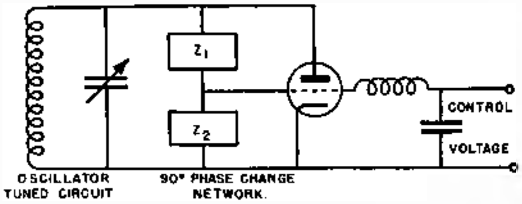


Fig. 4. Reactance valve circuit

A typical production model

For very wide sweeps, two klystrons have been used in such a circuit, the sweep being obtained by variation of the reflector voltage of one of the valves.

Resistance Valve.

Both the input and output impedance of a cathode follower depend on the mutual conductance of the valve, and can be used to control the frequency of an *R-C* tuned oscillator. It is usual to employ the output impedance, but the input resistance can be made to give a wider sweep.

The negative input resistance condition of a cathode follower can be used to couple a reactance vale to the oscillator. This avoids the resistive loading which is mainly responsible for the limitation of reactance valve performance.

Mechanical Sweep.

It is possible to control the sweep by mechanical means, such as a motor-driven tuning capacitor, but there are several disadvantages, and the method should only be used as a last resort.

If mechanical sweep is used, it is necessary to derive the deflexion sweep voltage from the frequency variation. This can be done by use of circuits of the "cycle counting" type, or by using filters with a varying attenuation over the sweep range, so that the output voltage varies with frequency.

When difficulty is experienced in obtaining a linear sweep with ordinary methods the technique of making the voltage dependent on the frequency can be used to advantage in conjunction with the reactance valve and other circuits.

Auxiliary Circuits

Marker Circuits.

Like all forms of oscilloscopes, panoramic display apparatus is best used for comparison rather than measurement. The provision of marking points on the display are valuable for comparison purposes.

In general, the marker circuits should be independent from the main display circuit, and marks in the form of bright spots are then possible. A system which has been found very useful is the provision of a number of crystal controlled spot frequencies, and a variable frequency for interpolation.

Constant Output Circuits.

The variable frequency oscillator is required to give a constant output over the whole sweep. Some form of constant output device is therefore desirable. Many circuits used for this in the normal way cannot be applied here, owing to the rapidity of the frequency variation.

The circuit which has been found of greatest use is that in which a control signal derived from the output voltage is made to control the oscillator amplitude. The selection of time constants requires considerable care.

Video Amplifier.

If amplification is used after the detector, it must respond to all frequencies between *s* and *w* c/s. In cases where this gives rise to difficulty, it is possible to avoid post-detector amplification by using a high-level detector feeding the C.R. tube directly.

Applications

Passive Types.

The panoramic receiver is fairly well known, and has especial advantages when it is necessary to monitor the signals present within a given frequency band. It is also of value for frequency comparison work.

The audio frequency equivalent is the panoramic analyser. This displays the harmonic components of the input signal, and permits very rapid assessment of amplifier performance in terms of the distortion of a square wave input. It has also been used to analyse musical notes.

Active Types.

The use of active displays for aligning band-pass tuned circuits is well known, and this technique has also been applied to the alignment of peaked circuits with success. The method is of especial value in aligning television receivers, and a variation used in this connection is to sweep the video modulation frequency of a 45 Mc/s. carrier, so that the overall video response is observed. This is the only method of aligning television receivers that does not necessitate subsequent adjustment for good picture quality.

In the audio-frequency field, active displays have been used to measure the frequency response of amplifiers, rooms, loudspeakers, microphones, etc.

Conclusion

This brief, and necessary incomplete, survey has shown something of the virtues and vices of the panoramic technique. If the design is carried out in a proper manner, panoramic display apparatus can be of great value in many branches of electronic work.

Unfortunately, many commercial products in this field are badly designed, and their failures and shortcomings are blamed on the basic technique. It is hoped that those responsible will see the error of their ways, and modify their designs to function correctly.

Grateful acknowledgments are due to the Brit.I.R.E. for permission to publish this summary of "The Principles and Practice of Panoramic Display," and for the drawings and circuits, which have been supplied by them.

Dr. J. T. Randall, Wheatstone Professor of Physics, King's College, London

Dr. J. Sayers, Professor of Electron Physics, Birmingham University

Dr. H. R. H. Boot won conducting further magnetron research for the Ministry of Supply

Magnetron Awards

READERS of this Journal will have seen with satisfaction the announcement in the Press of May 20 that the Royal Commission on Awards to Inventors has awarded £36,000 to Professor J. T. Randall, Dr. H. A. H. Boot and Professor J. Sayers, the inventors of the cavity magnetron.

Dr. Randall and Dr. Boot were members of a team under the inspiring leadership of Professor M. L. Oliphant at Birmingham University, where the original development work on the magnetron was carried out; and Dr. Sayers, also at Birmingham, initiated the strapping of the magnetron anodes.

Dr. Randall is now Wheatstone Professor of Physics at King's College, London, Dr. Boot is with a Government Research Laboratory engaged on further magnetron work, and Dr. Sayers is now Professor of Electron Physics at Birmingham University.

It is not an overstatement to say that no single contribution to the war effort changed the fortunes so profoundly as did the invention of the magnetron in the early days of 1940. At that time, the Battle of the Atlantic was at its bleakest, and shipping losses were mounting, the Germans having developed suitable counter measures to our radio detecting methods.

Almost overnight, however, the tide turned, and from then on Britain maintained a commanding lead in the detection of enemy ships and aircraft by the now familiar Radar technique. From the early magnetron-equipped radar apparatus came the host of other devices such as Gee, H$_2$S, Oboe and Rebecca, which conquered the submarine menace and provided the wonderful navigational devices for the R.A.F.

In these days £36,000 tax free is a lot of money, but the award is still not over generous. We join with Mrs. Randall, who is reported to have said "The award is not a surprise. We have been waiting nine years for it."

So have we! H.G.F.

NOTES FROM THE INDUSTRY

"British Trade Week" in Manitoba and Saskatchewan

The United Kingdom Trade Commissioner at Winnipeg (Mr. W. G. Coventry) has reported that the Provincial Legislatures of Manitoba and Saskatchewan have both passed resolutions calling upon the Lieutenant-Governor of each province to proclaim the week of September 26 to October 1, 1949, to be designated "British Trade Week," and requesting all traders to feature and further the sale of British goods during that week.

These actions and similar arrangements from time to time in other parts of Canada constitute most favourable conditions for United Kingdom exporters, particularly (in these instances) for consumer goods of all kinds likely to be saleable to the population of predominantly agricultural areas.

For United Kingdom firms who wish to test the market for specified products, the department will be pleased to supply the names of Canadian buyers of similar goods on application. The names of recommended agents can also be supplied (as a longer term undertaking) after consultation with the Trade Commissioners in the areas concerned.

BBC Engineering Division Changes

After 25 years service, of which the last 13 years have been spent as Head of Overseas and Engineering Information Department, Mr. L. W. Hayes, O.B.E., M.I.E.E., F.I.R.E., has resigned from the Corporation to take up the post of Vice-Director of the Comité Consultatif International des Radiocommunications in Geneva. Mr. Hayes will be chiefly concerned with the activities of the C.C.I.R. in the broadcasting and allied fields. During his service Mr. Hayes has represented the B.B.C. at nearly a hundred International Radio Conferences in all parts of the world.

The following changes in the Engineering Division of the Corporation have been made as a result.—

The Overseas and Engineering Information Department, the Engineering Secretariat and the Engineering Training Department have been formed into the Engineering Services Group. Mr. F. C. McLean, M.B.E., B.Sc., M.I.E.E., S.M.I.R.E. and Mr. E. L. E. Pawley, M.Sc., M.I.E.E., have been appointed Head and Assistant Head respectively of this Group. Mr. H. Wilkinson, B.Sc., becomes Head of Overseas and Engineering Information Department, and Mr. F. Williams, B.Sc., M.I.E.E., Head of Engineering Secretariat. Dr. K. R. Sturley, M.I.E.E., continues as Head of the Engineering Training Department.

Change of Address

Solartron Laboratory Instruments, Ltd., have removed to larger and more convenient premises at 22 High Street, Kingston-on-Thames, where they are concentrating on the research, design and manufacture of electronic instruments and test gear for research Laboratory use.

Opening of Branch Office

Air Control Installation, Ltd., announce that they are opening a branch office in Manchester and have appointed Mr. F. Wright, A.M.I.E.E., A.M.I.H.V.E., as Branch Manager. Inquiries should for the present be addressed to Mr. Wright at 1 Vale Drive, Prestwich, Manchester. Telephone: Prestwich 1653.

Cinema-Television—Dawe Instruments

The Electronics Centre, a combined showroom for Cinema-Television and Dawe Instruments, was opened on June 1. Instruments on show include atomic equipment, measuring instruments, stroboscopes, industrial counters, oscilloscopes, communications equipment, metal detectors photographic flash units, photo-electric cells and cathode-ray tubes.

Visitors will be welcome between the hours of 9 a.m. to 12.30 p.m. and 1.30 p.m. to 5.30 p.m. Monday to Friday.

The address of the Electronics Centre is 88 Piccadilly, London, W.1.

British Standard for Capacitors for Intrinsically-safe Circuits (B.S. 1551 : 1949.)

In response to a request by the Ministry of Fuel and Power, the British Standards Institution has just issued a British Standard for the construction of capacitors primarily intended for incorporation in intrinsically-safe circuits.

At the time that the Ministry of Fuel and Power's request was made, small capacitors were chiefly used as a means of spark suppression in remote control circuits which were designed to be intrinsically safe in accordance with the definition of that term given in B.S. 1259, Intrinsically-safe Electrical Apparatus and Circuits.

As an outcome of recent research, however, alternative methods of spark suppression have been found for such circuits, but there are other applications such as the coupling of an intrinsically-safe telephone circuit to the G.P.O. system. The capacitors for such a use are covered by this new standard, which deals with the dimensions of the containers and gives full details of tests.

Copies of this standard may be obtained from the British Standards Institution, Sales Department, 24 Victoria Street, S.W.1, price 2s.

Publications Received

Mullard Instruments for Research and Industry.

A list of instruments for the electrical laboratory and electrochemical and industrial equipment.

Obtainable from *Mullard Electronic Products, Ltd., Aboyne Works, Aboyne Road, London, S.W.17.*

Redifon 5-7½ KW Transmitter Type G.41.

Full particulars of a medium power short wave transmitter for telephony, telegraphy or broadcast services. Booklet available from *Rediffusion, Ltd., Broomhill Road, Wandsworth, London, S.W.18.*

The Ether Conqueror Radiogramophone.

Description of the series of radiograms and accessories manufactured by *Dynatron Radio, Ltd., Raylea Road, Maidenhead, Berks.*

Electrical Connectors.

A leaflet describing their products, distributed by *Films and Equipment, Ltd., 138 Wardour Street, London, W.1.*

Electronic Co-ax Cables (Publication No. 27).

A brochure describing air-spaced articulated co-axial cables for radio frequencies has been received from *Messrs. Transradio, Ltd., 138a Cromwell Road, London, S.W.7.*

Siemens' Engineering Bulletins No. 237 and 238/9.

A description of the Lisbon-Vila Franka trunk telephone cable, and power cable short circuit data respectively. Received from *Messrs. Siemens Bros. and Co., Ltd., Woolwich, London, S.E.18.*

The Twenty-ninth Annual Report of the Board, 1948.

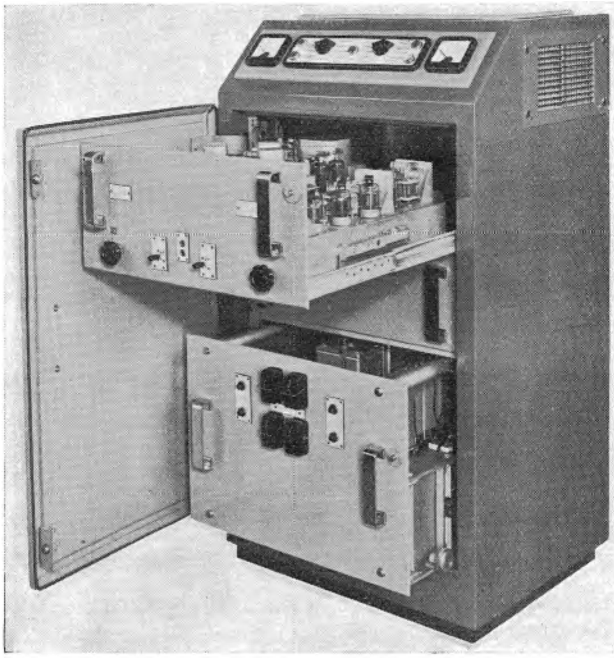
Published by the *Institute of Physics, 47 Belgrave Square, London, S.W.1.*

Latest catalogue of Silvered Mica Capacitors manufactured by: Stability Radio Components, Ltd., 14 Norman's Buildings, Central Street, London, E.C.1.

"PERA and Your Production."

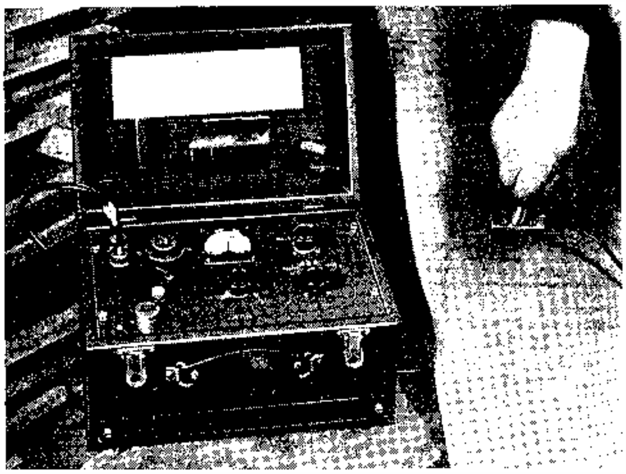
A 44 page brochure, well illustrated, giving information on the objects and achievements of the *Production Engineering Research Association of Great Britain, Staveley Lodge, Melton Mowbray.*

Acru Electric Tool Manufacturers, Co., Ltd., 123 Hyde Road, Ardwick, Manchester, 12.—A leaflet describing their new "ACRU 24" electric soldering iron.



Electronic

A monthly record of British electronic apparatus, components and accessories, compiled from information supplied by the manufacturers.



A New 50-watt V.H.F. Transmitter

(Photo above)

STANDARD Telephones and Cables Limited have produced a 50-watt V.H.F. transmitter especially suited for ground-to-air communication. The frequency range of the first models is 115-135 Mc/s., but since many other uses are envisaged for this transmitter, provision has been made to supply models to operate on a number of bands within the range of 70-150 Mc/s.

It was found that one of the features required at airports was the ability to speak through the same microphone to aircraft listening on two different frequencies, and arrangements have therefore been made whereby the operator can select at will transmission on either one or both of two frequencies. To make this possible the R.F. equipment is duplicated and the power supply equipment and modulator are designed so that they can drive both R.F. units at once. A V.O.G.A.D. (Voice-operated Gain Adjustment Device), incorporated in the speech amplifier ensures a substantially constant depth of modulation, irrespective of wide variations of input level.

The transmitter is housed in a single cabinet as shown in the photograph. It measures 3 ft. 8 in. by 2 ft. by 1 ft. 9 in., and weighs 350 lb. The equipment incorporates a meter panel which gives indications of the operating conditions and enables meter readings to be taken without the necessity for access to any of the units. Changing frequency has been made extremely simple, involving only changing a crystal and adjusting one control.

Standard Telephones & Cables, Ltd.
Connaught House, Aldwych, London, W.C.2.

Ekcovision Table Model TS105

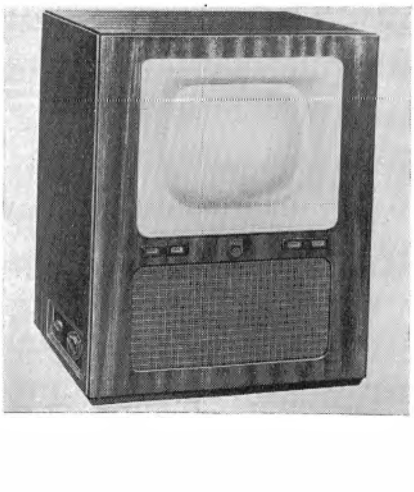
(Photo below)

THE lowest-priced combined television and broadcast receiver has just been marketed by E. K. Cole, Ltd. It is the Model TS105, of which the Midlands version (TS1105) will shortly be available. The makers claim high sensitivity and efficient interference suppression for the television receiver, which uses a 9-inch diameter tube.

The radio section is a superhet circuit with four pre-set station positions, the selected station being shown on one of the four illuminated indicators on the front of the cabinet. The total weight is less than 45 lb.

Price: 45 gns., plus £10 15s. 0 tax.

E. K. Cole, Ltd.,
Southend-on-Sea, Essex.



Moisture-in-Timber Meter

(Photo above)

ALTHOUGH it is well recognised that the drying-oven method is the only way of obtaining precise measurements of the moisture content of timber, there has long been a need for an instrument that would give the moisture content to a reasonable degree of accuracy within minutes instead of the hours required by a drying-oven test. Such an instrument can be of immense value in the quick examination of timber, in the forest, in the yard or during kilning.

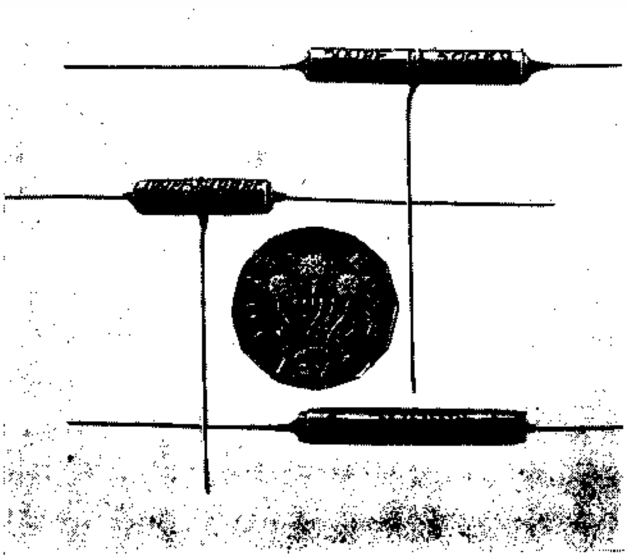
The new Moisture-in-Timber Meter, developed by The General Electric Co., Ltd., provides exactly what is needed for unskilled personnel to carry out rapid tests on timber. All that is necessary is for the instrument to be "set" from a built-in standard and it is then ready for indicating the percentage moisture directly in terms of the dry weight, merely by pushing a small electrode fitted with four prods into the sample.

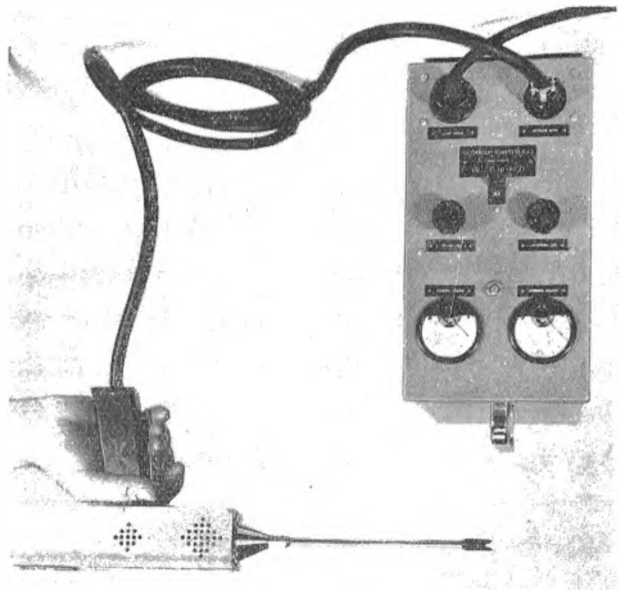
One thermionic valve is incorporated, of a type that is widely stocked by radio dealers, and the calibration of the instrument is unaffected by its replacement, should the existing one be damaged.

The tester weighs 13 lb. and is operated from self-contained dry batteries of a type that can be purchased at all large electrical dealers.

General Electric Co., Ltd.
Magnet House, Kingsway, London, W.C.2.

Equipment





Erie Capacitor-Resistor Units

(Photo above)

THESE are combinations of capacitor and resistor elements arranged in compact mechanical form and which have various electrical combinations frequently used in modern radio and television circuits. They have the advantages of saving in chassis space, and assembly time, and the improved screening which is possible when the resistor element is enclosed by the "earthy" capacitor electrode. In addition, the concentric method of construction makes it possible to keep the inductance associated with the capacitor elements to very small values so that efficient by-passing is obtained at high frequencies.

Diode Filter

This comprises two capacitors and a resistor arranged in the form of a π filter, and has its chief function as an R.F. filter in diode demodulator circuits, and similar applications.

Values available are: 33Ω to 10MΩ and up to 100pF+100pF.

Anode and Grid Decoupler

This is an L-type filter intended for use in decoupling anode or screen-grid circuits at H.F. It may also be used as a combined coupling capacitor and grid leak by the choice of suitable values, in which case it may be advisable for the designer to consider the question of temperature co-efficient where frequency stability of the circuit is important.

Values available are: 33Ω to 10MΩ and up to 5000 pF.

Cathode Decoupler

A parallel combination of capacitor and resistor which has obvious applications as a combined cathode resistor and by-passing capacitor in the H.F. applications.

Values available are: 33Ω to 10MΩ and up to 5000pF.

Erie Resistor Ltd., Milloro Works, South Denes, Gt. Yarmouth.

Mains Connector

(Photo below)

A NEW 2-pole 5-amp. rated mains connector is announced by A. F. Bulgin & Co., Ltd. Having the list number F.461, it may be used at 10 amps. on 6-12 volts, or 1 amp. on 500 volts. 3-pole and 6-pole varieties can also be supplied. The plug is non-reversible.

A. F. Bulgin & Co., Ltd. Bye Pass Road, Barking, Essex.

The B.T.H. Leak Detector—Type H

(Photo above)

THE Leak Detector, Type H, detects the presence of vapours of halogen compounds (those containing chlorine, bromine, iodine and fluorine) and is applied in locating small leaks in pressure or vacuum systems. It can detect freon issuing from a container through a leak at the rate of 1/10 to 1/20 ounces per year.

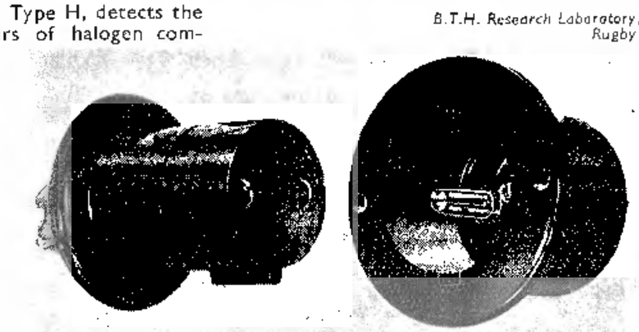
This instrument is suitable for the production testing of refrigerators, freezers and air-conditioning equipment, where the apparatus under test contains a halogen-bearing compound. It is applicable also for the pressure testing of tanks, pipes, joints and welds, etc.

The Type H Leak Detector consists of the detector unit, control unit and the necessary leads. The detector unit is a hand-held probe with a convenient grip and a metal nozzle with plastic tip. It contains an element which is sensitive to halogen compound vapours and a blower which draws air into the detector unit.

Built into the detector is a small loudspeaker which emits a succession of clicks, of which a change in the frequency is an indication of the presence of halogen compound within the detector head. A length of cable is supplied to connect the detector unit to the control unit.

The control unit is a self-contained portable unit containing the power supply, amplifier, voltage stabilising transformer, indicating instrument and other necessary controls. A 20 ft. lead is supplied for connecting a 190 to 260 volt A.C. power supply to the control unit.

B.T.H. Research Laboratory, Rugby



BOOK

Cybernetics

by Norbert Wiener. John Wiley, 1948. Price 18s.

IN many ways this is a book to gladden the heart of an electronic engineer, for it pursues variations on the theme of feedback through all the great range of subjects for which " one has always felt " that a unifying treatment was possible. The somewhat inharmonious title of the new field is derived from the Greek for " helmsman," and will alone doubtless guarantee the work a mixed reception, particularly from those to whom its forms of thought are new and of uncertain value.[1] But the more courageous will find that the elegance of Professor Wiener's mathematical approach compensates both for the title and the highly condensed form in which it is presented. Essentially his thesis is that " the study of sensitive automata, whether in the metal or in the flesh, is a branch of communication engineering," for which the appropriate methods are those of statistical mechanics and group theory.

What gives *direction* to the arrow of time? Wiener answers that in the " Bergsonian " time of statistical mechanics there is a unidirectional flux of *information*. This quantity is defined, apart from sign, in the same way as thermodynamic entropy, and the association of the two is not new. What the author has done, however, is to set forth its fundamental role in widely-differing cybernetic processes.

Chapters III and IV come perhaps nearest to the home ground of the electronic engineer. They include the fruit of some years of war work on filter design and prediction, but make difficult reading for the non-specialist. Particularly important contributions are made to the central practical problem of identifying the " degrees of freedom " of a time series of reducing it to canonical form. Quantal aspects of information do not, however, receive much explicit notice.[2] Some familiarity with recent papers such as Shannon's on Communication Theory[3] may be found an aid to the digestion of this important section.

In Chapter V, "Computing Machines and the Nervous System," the author outlines the principles on which numerical and logical data can be manipulated by automata. The problems of simulating behaviouristic aspects of logical reasoning, memory, conditioned reflexes and learning, and so on, can be met in principle by the joint application of mathematical logic and feedback to the organisation of machines operating on a binary scale, and including retentive and other devices familiar in the field of electronic computation. It is explicitly and wisely denied that anything more than *possible* models of physiological mechanisms are being described. The argument that a mechanistic account of cerebral activity would prove that thought was "nothing but" a physicochemical process, would be too naïve when stated in that form to carry conviction; but in various guises it has never lacked its devotees, and it is perhaps relevant to remark that no fundamentally new philosophical issue appears to be raised by the present volume. The construction of an autonomous artefact would, in the opinion of the present reviewer, be of immense value and interest, to philosophers among others; but the result would be to clarify, rather than to resolve, the outstanding issues.

In this connection it also appears to the reviewer that the behaviouristic significance of internal noise (artificially induced or otherwise) would repay further study. In the main logical " mill " of such a device it would merely predispose to vulgar errors. But in controlled amounts at other points its effects would tend to increase the resemblances between human characteristics and those of the machine in much more interesting ways. In conjunction with analogue techniques, a number of concepts such as *probability*, *preference*, *prejudice* and so on could find especially simple analogues.

It would be churlish to accuse a professedly introductory volume of naïveté, but one wonders whether some of the space devoted to a long and chatty introduction could not have been saved for more detail in exposition. As one example of a communication channel, this, of all books, ought in its structure to be statistically matched to its intended public; and one wonders whether in its present form it represents an optimum design. Its task is made harder by the lack of an index, and the presence of numerous misprints in this first edition.

Less than justice has here been done to the scope and significance of Professor Wiener's subject, bearing as it

References

1 *Book of Acts*, 17: 32.

2 *Gabor D.*, J. Inst. Elec. Engrs., 93, III, 429-458, 1946.

3 *Shannon C. E.*, Bell System Tech. Journal, Vol. XXVII, July and Oct., 1948.

REVIEWS

does on almost every branch of knowledge. In many respects the book will invite and perhaps deserve criticism; but it is important that it, and much more on the same subject, should become widely read.

D. M. MacKay

The Theory and Use of Complex Variable

by S. L. Green, M.Sc. Pitman 2nd Edition 1948. 12s. 6d.

THIS small book on the theory of the complex variable has already proved a valuable and readable introduction to the subject. To the engineer it is valuable, since it includes in the text many details of manipulation which can hardly be called mathematical methods, yet are useful time and time again. Moreover, the examples are printed in large type and seem to be chosen with possible applications in mind.

The last two chapters (8 and 9) discuss briefly applications in potential theory and alternating current theory. The electrical engineer may regret that they are not much longer, but in such a short all-round introduction any intensive investigation in one field is not possible. A more serious criticism is that the discussion of the integration of complex variables in Chapter 4 is very short. Far more examples could well be included in view of the importance of this method of dealing with complicated integrals in radio work or elasticity, and in Laplace transforms.

In Chapters 1 and 2 complex numbers are introduced in a consistent way using the Argand diagram, and the important theorem of De Moivre is discussed and applied to integration and series summation. Chapter 3, on series, is entirely concerned with the exponential function and has many useful formulæ. Chapter 4 deals with complex functions and methods of examining them and plotting them, besides integration and Cauchy's theorem. Chapter 5 on conformal transformations is very long for this book, but is especially relevant to applications of complex variables, as it contains a detailed discussion of some important transformations. The Schwartz-Christoffel transform which transforms a polygon into a half-plane, is dealt with separately in Chapter 7.

There is no mention in the preface of any changes from or additions to the first edition.

G. J. Kynch

New Advances on Printed Circuits

United States Department of Commerce. National Bureau of Standards. Miscellaneous Publication 192, 73 pages, 43 illustrations 6 tables. Price 40 cents.

LIKE all publications by the National Bureau of Standards, Washington, this booklet is well set out with clear and relevant illustrations, and full of interesting subject matter. It has often been said that British industry must look to America for a lead as far as production methods are concerned. This booklet certainly deserves close attention from designers, engineers and management in the radio and electronic industry.

The Editor is Dr. Cledo Brunetti whose publication on the same subject in 1947 was widely read in this country and caused unusual interest. This publication shows that American industry has taken full advantage of the information published then and has forged ahead not only in the development of new methods and collection of data but also in turning this technique to a useful purpose in construction and production.

The book contains 22 papers read by representatives of American industry and Government Laboratories at a Convention on the subject in November, 1948. Dr. Brunetti himself starts by surveying the existing methods impartially and giving some useful hints on design to users, as well as a list of available components and details of performance. Methods of depositing printed wiring on high temperature material and in particular ceramics are presented by representatives of the Centralab Division of Globe Union, Du Pont de Nemours and Continental Carbon. Methods on low temperature materials are described by representatives of Metaplast, Altair Machinery Corporation, Spraywire Laboratories, Franklin Airloop and Kenyon Instrument Co. All these companies give their methods in detail with useful figures on performance. Thus it is claimed that silkscreen printed conductors 1 in. long by 0.03 in. wide have a resistance of 0.1 ohm, a surprisingly high figure which can be bettered in this country.

Stress is put on the value of subassemblies and composite components. Much, however, depends on the availability of high K ceramics in the construction of these. Messrs. Centralab's article ends with an interesting comparison of cost between ordinary wiring and a printed assembly. It is not surprising that this company which has so well understood the value of this

BOOK REVIEWS *(continued)*

technique stands supreme in the market.

Messrs. Du Pont's defence of the silk screen method and of subsequent plating, especially on plastics, is one with which few experts in this country will agree. The list of applications and details of economics are, however, worth studying.

The low temperature techniques show only disadvantages over methods developed in this country and most lecturers are very frank about these. Apart from the method given by the Franklin Airloop Co. which includes valuable data particularly on heavy duty wiring, there is little new in this section. Perhaps the most valuable part of the booklet is the descriptions of components either manufactured by these methods or specially suitable for incorporation in printed circuits. These are by representatives of International Resistance Co., who have thoroughly studied the question of laminated resistors, bulk produced, and adjusted by area, and Remington Arms Co., who give full details of the vitreous enamel capacitor about which we have heard so much recently.

Other interesting contributions on the subject are made by Corning Glass Co., *et al.* An outstanding contribution comes from Balco Research Laboratories, who give a particularly interesting description of resistors and coils. The latter are printed on quartz or glass ready for insertion. Also discussed are capacitors on plastic film and high K ceramics. An interesting paragraph on assembly technique is a valuable contribution.

The papers most worthy of note to British readers are those given by users of printed circuits describing articles already on the market and those planned. Outstanding is a contribution by B. V. Blom, of the Signal Corps, describing how printed circuits help in design of constructions used for military purposes, particularly as regards miniaturisation; unitised construction; increased frequency coverage; number of pre-set channels and reliability; lower operating voltage: operation at higher frequencies, and over extreme climatic conditions. Lastly, it promises increased mass production capabilities. Representatives of various companies describe their printed products which may be summarised in the words of Al Gross, of the Citizens Radio Co. "Printed circuit techniques are here to stay, for they are a boon to the radio and electronic industry." A paper on fundamentals by L. Marton, of the N.B.S., is further worthy of mention.

The booklet ends with a summary on a questionnaire filled in by 527 representatives of American industry which represents a testimony of faith in the method and a vote of confidence in the future of printed circuit technique in general. Of special interest is a list of equipment to which the technique can be applied giving the percentage of those present who are interested in the particular application. It is remarkable that Home Receiving Equipment (AM and FM) top the poll with 35 per cent. Aircraft equipment and television receivers are next. Altogether 20 subjects are listed.

It is regretted that this book, unlike its predecessor, contains no bibliography, and it is even more to be regretted that like its predecessor it will not be readily available to all engineers in this country who might profit by its study.

P. P. HOPF.

Theorie et Applications des Tubes Electroniques

D. G. Fink, Dunod. Paris, 1948.

THIS is a French translation of Mr. D. G. Fink's well-known book in the McGraw-Hill series, and the anonymous translator has done his work well. The problems at the end of each chapter have been included, and an appendix gives definitions of the A.I.E.E. electronic terms. The best summary of the book is given in the phrase on the cover band, which is far more expressive in the original French: "Sans mathématiques supérieures ni vulgarisation élémentaire."

G. PARR

Proceedings of B.T.H. Summer School in Electronic Engineering

Published privately by the B.T.H. Co. Ltd., Rugby.

IN the summer of 1948 the British Thomson-Houston Company held a unique meeting for professors of electrical engineering at their Rugby works, at which the company's staff gave lectures and demonstrations of some of the latest developments in electrical and allied science. These lectures have been issued in book form for private circulation, and should prove of great value to all engaged in teaching the advanced aspects of the subject. A limited number of copies are obtainable by executive engineers and senior officials on application to the Publicity Department at Rugby.

Basic Technical Electricity Cleaver-Hume Electrical Series

No. I by H. Cotton, M.B.E., D.Sc., M.I.E.E. Cleaver-Hume Press, Ltd., 238 pages, 74 figs Price 8s. 6d. net.

PROFESSOR COTTON has a wide reputation as an author of electrical engineering textbooks. He is the general editor of a new series of nine volumes, the Cleaver-Hume Electrical Series, but it is not clear whether or not he is to write them himself. His avowed intention is to provide electrical knowledge for daily work or pastime, and in the preface he claims that this volume contains the minimum of theory as well as such fundamentals as will be required in reading the later volumes. While he mentions electronics in the preface, he does not introduce the subject in this volume. We must therefore assume that the later volumes will not be concerned with applications of thermionics.

Writers of books on technical electricity have in the past evaded the purely scientific issue, and adopted the attitude that if the reader does not already know the fundamental physics of the subject it is no part of that particular writer to remedy the omission. The fields of theoretical physics and applied electrical science overlap to such an extent that the overlap cannot be ignored and employing the electronic theory from the beginning, as this book does, is most helpful.

The presentation is that normally used, the production of an electric current, followed by the effects of current, that difficult subject "Work Power and Energy", then magnetism and electromagnetism and lastly units and measurements. The reviewer would have been pleased if Professor Cotton had adopted the optimistic conception of a conductor and used conductance and mhos straightaway on p. 26, where we are introduced to resistance but perhaps it was venturesome enough to mention it on p. 34 for future employment.

The numerical examples in the text are a great help in understanding quantities, especially electrical units, and the test questions at the end are valuable to the reader who wishes to check his grasp of the subject.

The plates of large power plant are somewhat premature and though they are interesting to the beginner their place is more properly the later volumes.

H. CLARKE

Made in America

Being a selection of American electronic equipment and products, with notes compiled from the manufacturers' data.

New 5-KW FM Transmitter

A NEW R.C.A. 5-KW FM transmitter designed for broadcasters who require up to 60 KW effective radiated power has been announced by the R.C.A. Engineering Products Department. High efficiency and low tube and operating costs are claimed for the new Model BTF-5A transmitter. It is particularly adapted for use with a four-section Pylon antenna with a gain of six to obtain 20 KW radiated power.

This transmitter, combining the "Direct FM" circuits common to previous R.C.A. transmitters with the power saving grounded grid circuit, is capable of furnishing power output of from 1,000 to 5,000 watts to the transmission line, and when used with the R.C.A. high-gain Pylon antenna, can provide radiated power up to 60 kilowatts.

Structurally, the 5 KW FM transmitter consists of three standard transmitter cabinets. The exciter (and a spare, if used) and its power supply are located in the centre cabinet. The R.F. amplifier circuits are housed in the left-hand cabinet, and the high-voltage power supply and control circuits in the right-hand cabinet. Cabinet styling and appearance are the same as that of all unit enclosures of other R.C.A. FM transmitters of both lower and higher power.

A variety of R.C.A. Pylon antennas may be used with the new transmitter including the standard and heavy duty types. By adding from one to eight sections, radiated power of from 7.5 kilowatts to 60 kilowatts is possible.

RCA 5794 Triode *(Photo on left)*

THE 5794 is a fixed-tuned U.H.F. oscillator triode with two integral resonators for use in radiosonde transmitters operating at 1,680 megacycles. One of the resonators is fixed-tuned and is attached between grid and cathode; the other is tunable over a narrow range about 1,680 megacycles and is attached between grid and plate. The latter resonator is loop-coupled to a coaxial R.F.-output terminal. The 5794 has a useful power output in the order of 500 milliwatts.

Features contributing to the usefulness of this valve in radiosonde service include its compact metal construction, low battery drain and small frequency drift.

R.C.A. Photophone, Ltd.,
43 Berkeley Square,
London, W.1.

Rahm Medical Equipment

THE following electro-medical equipment is described in brochures issued by Rahm Instruments Inc.

All-mains electro-encephalograph gives smudge-proof, inkless recording "Duratape." The amplified uses miniature valves to give a maximum gain of ten million (1 mm. deflexion per microvolt).

A fixed- and a variable-frequency stimulator. For neurosurgical use in determining Motor-Cortex areas and locating sensory pathways.

Two electro-shock monitors; a comprehensive model with variable shock voltage and duration (from 0.1 to 1 second), and a smaller and lighter type with only the essential features of the more expensive model incorporated. Both monitors, however, are fully safeguarded.

Rahm Instruments Inc.,
12 West Broadway,
New York 7.

THE Fourth National Instrument Exhibition is to be held in the St. Louis Municipal Auditorium from September 12 to 16, 1949. It is anticipated that upwards of 10,000 people will inspect the exhibits, which will include scientific and industrial instruments and devices for measurement, inspection, testing and control.

Technical sessions of the Instrument Society of America, American Institute of Physics, Industrial Instruments and Regulators Division of the American Society of Mechanical Engineers, and the Instruments and Measurements Committee of the American Institute of Electrical Engineers, the Institute of Radio Engineers, the American the National Telemetering Forum, will be held in the Auditorium while the exhibition is in progress.

United Kingdom firms wishing to participate should apply to the Executive Secretary of the Instrument Society of America, 1117 Wolfendale Street, Pittsburgh, 12, Pa.

Inquiries about this exhibition should be addressed to the Department's Exhibitions and Fairs Division, Horseferry House, Thorney Street, London, S.W.1. (Telephone: Victoria 6800 Ext. 253).

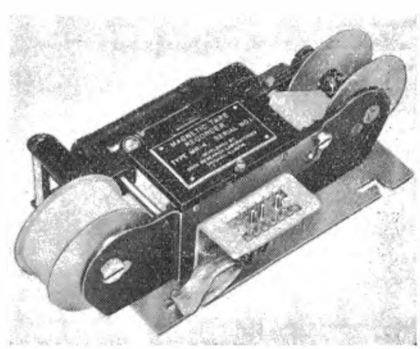
Data Recorder *(See below)*

A NEW addition to the standard line of data recorder mechanisms produced by Cook Laboratories has been announced. This unit is designated Type MR-4 and is designed for use with suitable coupling equipment and sensing instruments as a complete recording system. It is fully capable of withstanding high shock accelerations up to 75 G.

The Type MR-4 recording mechanism is a miniature 13-channel unit weighing 24 ounces. It includes one reference frequency oscillator plus 12 information channels and has a recording time of $2\frac{1}{2}$ minutes. Its small size of $8 \times 3\frac{5}{8} \times 2\frac{1}{4}$ in. and light weight make it suitable for applications requiring the measurement of such factors as accelerations, stresses, temperatures, pressures, vibrations, etc., in airborne equipment, flight testing and guided missile work.

This new unit, like other Cook recorders, uses magnetic tape to store variable or transient data under conditions of severe shock acceleration for later analysis.

Cook Research Laboratories,
1457 Diversey Parkway,
Chicago 14, Illinois.



CORRESPONDENCE

R-C Oscillators

DEAR SIR,—In Mr. F. Butler's article "Variable Frequency *R-C* Oscillators,"[1] there are inaccuracies in the table giving attenuation ratio and operating frequency for various stages of the *R-C* uniform ladder, which is used as the feedback network. From a cursory inspection of the literature on the subject, it appears that no one has yet published a carefully checked list of attenuation and frequency coefficients for the *R-C* and *C-R* uniform ladder networks of n steps (Fig. 1). In fact, there seems to have been errors in several of the early articles. As examples, (*a*) Ginzton and Hollingsworth[2] give a wrong expression for the attenuation of a non-uniform 4-step *C-R* ladder, and a wrong attenuation coefficient for a 3-step uniform *R-C* ladder; (*b*) Whitehead,[3] for a 3-step uniform *R-C* ladder gives a quite erroneous table of attenuation and frequency coefficients, (these having been deduced by neglecting the shunting effects of subsequent steps on any one section, thus he gives an attenuation factor of 8, which should be 29); and finally (*c*) Bacon,[4] who makes the same simplification as Whitehead.

Table 1 herewith has therefore been produced to meet this need; the number of steps is probably beyond the range of practical interest, although it may serve to show the surprising result that less amplification is required, the larger the number of steps used.

Comparing this Table 1 with the table given by Butler, it will be seen that for the *R-C* uniform ladder, the two attenuation coefficients he gives for 5- and 6-steps, namely 16.15 and 13.72, should be 15.43 and 14.12 respectively. A more serious error occurs in the frequency coefficients which he gives; they are all about twice the correct values. Consequently the range of 250-5,000 c/s., which he states for the 4-step *R-C* oscillator of his Fig. 3, should I think, be 125-2,500 c/s.

Regarding the more detailed 25-17,000 c/s. *R-C* oscillator given in his Fig. 4 and the table referring to the frequency range on each of its six positions, from the description and figure it is difficult to decide if the feedback *R-C* ladder has 3, 4 or 5 steps. Assuming the oscillator to have a 4-step *R-C* ladder, the variable capacitor to change between the values 100-500 pF, and neglecting the phase shift occasioned by the 0.1 µF coupling capacitor and the 1-MΩ shunt, then Table 2 herewith gives the theoretical frequency ranges which would be obtained. It can be seen that these are, very roughly, about twice those given by Butler. This difference could not be occasioned by the coupling, the effect of which would be negligible at the top of the range, and at the bottom would cause the frequencies stated to be about 25 per cent too low. It would be very informative to know if the figures given by Mr. Butler are experimental or theoretical, and if experimental, how he would account for such large differences.

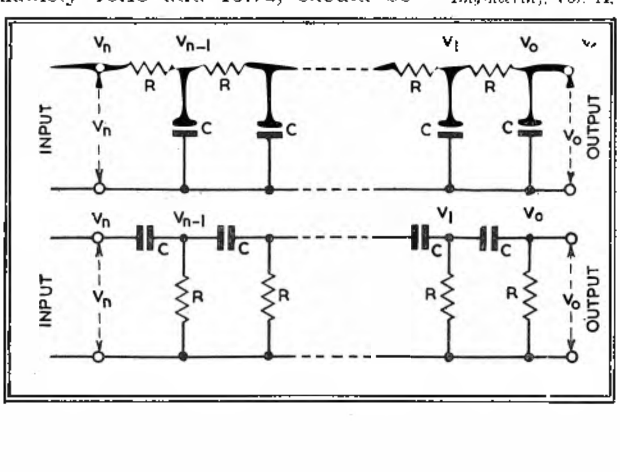
References

[1] F. Butler, "Variable Frequency *R-C* Oscillators," *Electronic Engineering*, Vol. 21, No. 254, pp. 140-142. April, 1949.

[2] E. L. Ginzton and L. M. Hollingsworth, "Phase Shift Oscillators," *Proc. I.R.E.*, Vol. 29, pp. 43-49, February, 1941.

[3] R. C. Whitehead "Resistance-Capacity Oscillator," *Wireless World*, Vol. 48, pp. 278-281, December, 1942.

[4] W. Bacon, "A simple *R-C* Oscillator," *Electronic Engineering*, Vol. 14, p. 707, April, 1942.



R-C and C-R uniform ladder networks
(See letter, above, from J. Parton)

Table 1

Attenuation and Frequency Coefficients for R-C and C-R Uniform-Ladder Networks of n Steps

Steps n	Attenuation Coefficient α for both *R-C* and *C-R* ladders	Frequency Coefficient β *R-C*	*C-R*
3	—29	0.390	0.0650
4	—18.39	0.1905	0.1352
5	—15.43	0.1178	0.2155
6	—14.12	0.0812	0.3135
7	—13.43	0.0593	0.427
8	—12.97	0.0457	0.556
9	—12.66	0.0363	0.702
10	—12.58	0.0296	0.858
∞	—11.57	0	∞

Table 2

Range	Frequency c/s
1	34.5— 54.5
2	47.7— 95.5
3	76.2— 381
4	381 — 1905
5	1905 — 9520
6	7620 —38100

JOHN E. PARTON,
Electrical Engineering Dept.,
Glasgow University.

DEAR SIR,—The contribution about "Variable Frequency *R-C* Oscillators" by F. Butler in the April issue, 1949, of ELECTRONIC ENGINEERING contains on page 140 a table giving the attenuation of an operating frequency by different *R-C* ladder networks according to Fig. 2. The operating frequencies given in the table, do not agree with my calculations nor with the data published by Ginston and Hollingsworth in the February issue, 1941, of the *Proc. I.R.E.* The data for f, given by Butler, are about twice too high. Accordingly the frequency ranges given for the oscillators shown in Fig. 3 and Fig. 4 do not seem to be correct.

In order to give Mr. Butler opportunity to check my calculations and eventually to point out the fault in my calculation, I give you an extract of the way I tackled the problem.

In the figure below, I pictured a general ladder-network of series-impedances Z_1 and shunt-impedances Z_2. Applying Kirchoff's laws we can write down the following equations:

$$\begin{aligned}
& i_1(Z_1 + Z_2) - i_2 Z_2 = E_1 \\
& - i_1 Z_2 + i_2(Z_1 + 2Z_2) - i_3 Z_2 = 0 \\
& - i_2 Z_2 + i_3(Z_1 + 2Z_2) - i_4 Z_2 = 0 \\
& - i_{n-2} Z_2 + i_{n-1}(Z_1 + 2Z_2) - i_n Z_2 = 0 \\
& - i_{n-1} Z_2 + i_n(Z_1 + 2Z_2) = 0 \\
& i_n = E_o / Z_2.
\end{aligned}$$

From these equations we can find the relation E_i/E_o by eliminating $i_1, i_2 \dots i_{n-1}, i_n$. This I have done in the following way. Putting $Z_1/Z_2 = a$ we can rewrite the equations as follows:

$$i_1(1+a) - i_2 = E_i/Z_2$$
$$-i_1 + i_2(2+a) - i_3 = 0$$
$$-i_2 + i_3(2+a) - i_4 = 0$$
$$\overline{-i_{n-2} + i_{n-1}(2+a) - i_n = 0}$$
$$-i_{n-1} + i_n(2+a) = 0$$
$$i_n = \frac{E_o}{Z_2}$$

From these we find:

$$i_n = \frac{E_o}{Z_2}, \quad i_{n-1} = i_n(2+a),$$
$$i_{n-2} = i_n(2+a)^2 - i_n$$
$$i_{n-3} = i_n(2+a)^3 - 2i_n(2+a),$$
$$i_{n-4} = i_n(2+a)^4 - 3i_n(2+a)^2 + i_n$$
$$i_{n-5} = i_n(2+a)^5 - 4i_n(2+a)^3 + 3i_n(2+a), \text{ etc., etc.}$$

For $n = 3$ we find therefore:

$$i_3 = \frac{E_o}{Z_2};\ i_2 = (2+a)\frac{E_o}{Z_2};$$
$$i_1 = (2+a)^2\frac{E_o}{Z_2} - \frac{E_o}{Z_2}$$

and finally:

$$\frac{E_o}{Z_2}\left\{(1+a)(2+a)^2 - (1+a) - (2+a)\right\} = \frac{E_i}{Z_2}$$

giving:

$$\frac{E_i}{E_o} = (1+a)(2+a)^2 - (3+2a)$$

In the case under consideration

$$Z_1 = R;\ Z_2 = \frac{1}{j\omega C};\ \frac{Z_1}{Z_2} = j\omega RC = j\alpha$$

yielding:

$$\frac{E_i}{E_o} = 1 - 5\alpha^2 + j(6\alpha - \alpha^3)$$

For a phase difference of 180° between E_o and E_i, the imaginary part must equal zero. This gives $6 - \alpha^2 = 0$; $\alpha^2 = 6$. The real part of the expression for E_i/E_o then works out to $E_i/E_o = 1 - 30 = -29$, showing that the phase difference is really 180° and the attenuation ratio is 29. The operating frequency works out to

$$f = \frac{\alpha}{2\pi RC} = \frac{\sqrt{6}}{2\pi RC} = \frac{0.391}{CR}$$

For $n = 4$ and working along the same lines, I find:

$$\frac{E_i}{E_o} = 1 + 10a + 15a^2 + 7a^3 + a^4,$$

giving

$$\frac{E_i}{E_o} = 1 - 15\alpha^2 + \alpha^4 + j(10\alpha - 7\alpha^3)$$

This yields for 180° phase difference between E_i and E_o: $\alpha^2 = 10/7$,

$$\frac{E_i}{E_o} = -18.4,\ f = \frac{\alpha}{2\pi RC} = \frac{\sqrt{(10/7)}}{2\pi RC} = \frac{0.191}{CR}$$

$n = 5$ gives:

$$\frac{E_i}{E_o} = -15.83;\ f = \frac{0.118}{CR}$$

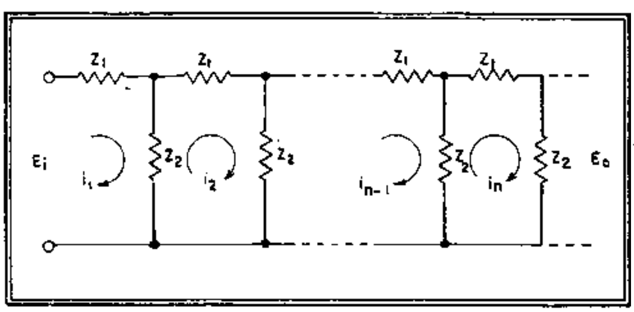
and $n = 6$ gives:

$$\frac{E_i}{E_o} = -14.09;\ f = \frac{0.081}{CR}$$

If my calculations are correct, it seems to me in the interest of the readers of ELECTRONIC ENGINEERING to have the data published by Mr. Butler corrected. If there might be a hidden fault in my reasoning, I should be glad to be corrected by Mr. Butler.

J. ROORDA.

Hofwyckstraat 57, Voorburg,
Holland.



Series- and shunt-impedance network
(See letter from J. Roorda)

Sealed Transformers

DEAR SIR,– In reference to the article "Hermetically Sealed Transformers" in the June issue we submit the following elementary comments on the principles of manufacture.

The testing o fcontainers for leaks

Under-water tests with some 20/30 lb. of internal pressure is of little value, however frequently repeated, for revealing the extremely small holes through which oil may escape. The surface tension of water is too great for this purpose and sets a limit on the size of the hole it is possible to detect. Still more important, a hole will most certainly be obstructed by the resin flux used when soldering. There is also the dangerous possibility that the cold water may be at a lower temperature than the transformer as it arrives from the preceding hot soldering process and water may be sucked through by air contraction before the pressure is applied. Again the very presence of water at any stage during manufacture is in complete disregard to the condition so strictly enforced in transformer or capacitor production of absolute dryness of surroundings.

The pressure process of testing containers for leaks is normally made under oil of low surface tension raised to a sufficient temperature to soften adequately any obstructing resin deposit. Ultra-violet light tests are often defeated by the presence of trichlorethylene used for degreasing.

Steel or tin plate containers v. copper or brass

Both iron and tin plate offer rustable edges. All iron pieces need to be resin dipped soon after shaping and in consequence become inconvenient to handle and difficult to fit tightly together. The meagre degree of magnetic screening that thin iron may provide is a doubtful merit. Iron is less costly than copper, but the latter metal is always clean and unrustable and will not corrode under paint when in use. The consideration that iron is less heavy is insignificant, a typical transformer consisting of a 1½ in. stack of No. 4 stampings being only ⅔ per cent heavier with copper container..

Terminal sealing by R.F. heating

This often suggested process is not favoured. The small metallised ring around many a bush may suffer immediate destruction, resting as it does on an insulating surface of resin flux and the metal terminal heads all become overheated. Nothing is easier, if electrical heating is intended, than the passing of a current, regulated by foot switch control, across the terminal carrying section of the box, from copper or carbon faced clamps, particularly as the current density increases around the holes. Ceramic bushes so fixed can be smashed off on the face of an anvil, but the silver to copper seal, carrying a coating of sharp ceramic particles, will always remain.

Metal flanged glass bushes

These are far more easily damaged by heat, transit and use than those of hard ceramic. The

CORRESPONDENCE *(continued)*

centre conductor is usually sharp ended and inadequate, while the seals themselves take up too much space.

Filling Materials

Reference is made to the difficulty of injecting petroleum jelly or other media into the container. The commonly used methods of vacuum impregnation by which all canned devices are filled presents no problem. In any event the filling fluid is best kept adequately heated and under vacuum to ensure dryness, and any air subsequently admitted must be drawn through a drying source. The adoption of such special insulating fillings as have been recently introduced in respect of small high voltage capacitors offers enormous advantages.

The first transformers built to this general principle of total sealing in lapped seam copper containers and fitted with soldered-in insulating terminal bushings were developed by ourselves. The system was later taken up by a number of contemporary producers to meet the war demands of the services. We have made no substantial change from the original productions using horizontal core stack so as to afford flexibility of can size with the fixing centres standardised on lamination corner holes, features that are appreciated by your contributor.

Small canned transformers are undoubtedly useful in certain applications, but respect may be paid in design to the lack of ventilation. Specific heat and the latent heat of melting of the filling give some measure of cooling in intermittent use. The canned unit is no more costly to produce than the overall dipped open type, where the general construction can be seen and judged. The open type is to be preferred for many purposes and insulation weaknesses so often criticised usually arise from inferior terminal plate design.

HUGH F. HAYNES
Haynes Radio, Ltd.

Mr. Jones replies:

I appreciate that there are several methods of manufacturing hermetically sealed transformers, and the method each individual manufacturer chooses is no doubt to some extent dictated by the equipment available. The points raised by Mr. Haynes seem to suggest only a different method of arriving at a similar result. I wish to emphasise that the ultimate test of sealing is the final heat run of four hours at 110° C. mentioned in my article, the immersion of the container in a fluid after inflation being only a preliminary eliminating test.

I make no claims that mounting the laminations horizontally is unique, as this construction seems only logical if some measure of standardisation is to be achieved within the industry. I cannot agree, however, that with the present materials available the hermetically sealed transformer need be more costly than its open counterpart. The total cost of material per transformer is considerably greater, and more time is involved in the prolonged additional tests necessary to check the efficacy of the sealing, as unless this is complete the transformer may well be inferior to the open type.

Combined Current and Voltage Feedback

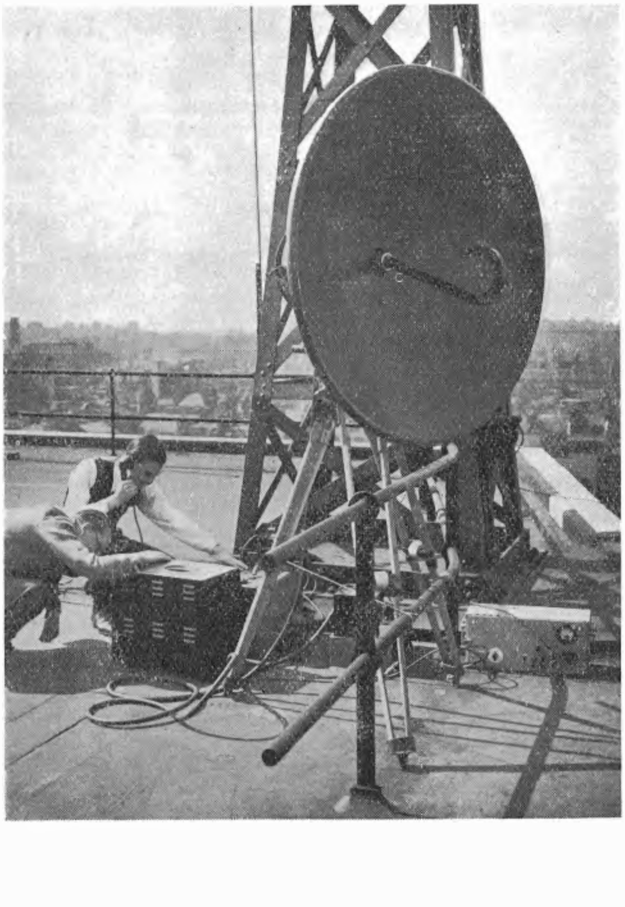
DEAR SIR,—The amplifier described in Dr. Sturley's article in your May issue is a simple case of a multiple-path feedback amplifier. It is true that the local feedback occurring in the input stage of an amplifier can usually be neglected, but considerable use can be made of such feedback mainly to improve the stability margin of the amplifier. An example where the local feedback has been deliberately employed can be found in an article "A Miniature Audio-frequency Amplifier" in the *Post Office Electrical Engineer's Journal 41* p. 228, January '49.

The use of multiple-feedback paths in amplifiers is described in a paper entitled "Some Consideration in the Design of Negative Feedback Amplifiers," early copies of which are available from the Institution of Electrical Engineers.

W. T. DUERDOTH,
B.Sc., A.M.I.E.E.

Microwave Radio Link for Television Outside Broadcasts

B.B.C. engineers are investigating the possibilities of microwave radio links for transmitting television pictures from outside broadcast points to Alexandra Palace.



The transmitting equipment being used in these tests consists of a klystron oscillator operating on a wavelength of 4.5 cm., which is frequency modulated by the vision signals, and a 4-ft. diameter paraboloid reflector with waveguide feed. The transmitter power is about 100 mW and the aerial gain is 5,000. A similar aerial system is used at the receiving end. The transmitter and the receiver are built into the back of the paraboloid reflectors, and the rest is constructed in "suitcase" form.