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CONTENTS

EXHIBITIONS

TWO exhibitions of considerable importance to the electronic engineering industry as a whole have been held in London during April. The first, the Physical Society's Annual Exhibition of Instruments and Apparatus at Imperial College, South Kensington, was the thirty-fourth of the series and the fifth to be held since the war.

Although its aims have remained fundamentally unchanged since 1905, the exhibition has, year by year, grown steadily in scope and importance, and this year some 120 firms and research organisations took part.

The Exhibition covered a wide range of instrumentation. Only a casual inspection of the exhibits is necessary to show the extraordinary growth in the application of electronics to the technique of measurement.

Like its predecessors, it has achieved an admirable balance between displays by commercial firms and research exhibits by Government departments, universities and other research organisations; and though it is not housed to its best advantage, the exhibition clearly demonstrates the strength of the British instrument manufacturing industry.

With perhaps a freer hand than their opposite numbers in commercial firms, scientists in universities and Government departments displayed an array of apparatus using a wealth of new techniques for the solution of long standing problems. It is significant that in the research section the Ministry of Supply was by far the largest single exhibitor, with displays and demonstrations from its Atomic Energy, Chemical Defence, Radar, Signals, Armament, Telecommunications Research and Development Establishments. The Royal Aircraft Establishment, the Royal Navy Scientific Service and the Department of Scientific and Industrial Research also had important contributions.

The growth of the British instrument-making industry to its present state largely depends on the supply of accurate, reliable components of all kinds, and the opportunity for the component industry to display its products occurred later in the month at the private exhibition at Grosvenor House organised by the Radio and Electronic Component Manufacturers Federation.

The R.E.C.M.F. Exhibition (of later origin than the Physical Society's Exhibition) is the outcome of an exhibition held during the war. It was in the nature of a "hush-hush" display promoted exclusively for the benefit of the Service Establishments and the Armed Forces.

The success of that exhibition and a second which followed in 1945 influenced the Radio Component Manufacturers Federation, as it then was, to hold annual exhibitions, to acquaint engineers and manufacturers with the latest advances in the design and development of the multitudinous components required for the radio, electric, communication and allied industries.

At this year's three-day exhibition there were over one hundred exhibitors whose products covered all types of materials, components, valves and measuring apparatus, and ranging from thimble-sized vales and miniature components for hearing aids to heavy duty equivalents for huge power television transmitters.

The resources of the British component industry are worthy of note. Before the war, the industry consisted of about 40 firms with an annual output of approximately 50 million major components of comparatively simple design. Today, over 130 firms are producing annually nearly six times as many major components, the majority of which involve intricate manufacturing and assembly techniques and methodical testing, selecting and grading.

MARCONI MARINE JUBILEE, 1900 - 1950

In February, 1896, Gugliemo Marconi arrived in England and successfully demonstrated his wireless transmissions to Sir William H. Preece, Chief Electrical Engineer of the Post Office.

Four years later on Marconi's 26th birthday the Marconi International Marine Communications Company was formed, with offices in London and Brussels, "for the purpose of developing for the safety and convenience of all those at sea" Marconi's discoveries.

From these early beginnings have developed the radio, radar and television as we know them today.

On April 25th this year the first fifty years of the Company's service to shipping have been successfully concluded and an item of the Jubilee programme was an exhibition at the Baltic Exchange, London.

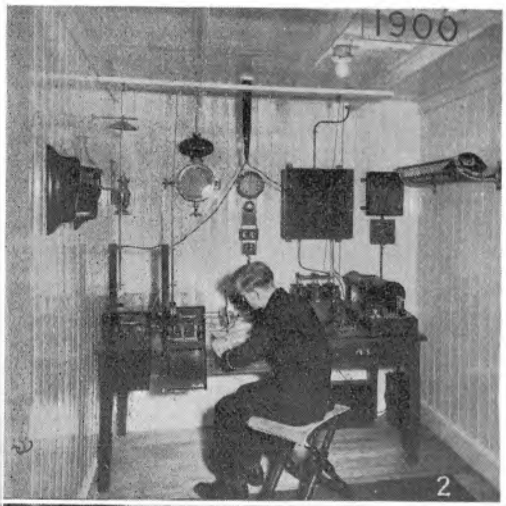
Here were equipped a number of ships' wireless cabins typical of the period from 1900 to 1950 and marking the progress made in ten-yearly decades.

Among the historic exhibits were the first valve receiver made in 1904 and employing the Fleming Diode ; a magnetic detector made in a cigar box by Marconi himself, and an early experimental spark transmitter incorporating the now famous tuned circuit patent No. 7777.

With the co-operation of the General Post Office a large map of the world was shown indicating the daily position of actual ships at sea, similar to that at Burnham, the radio station which handles all Britain's long-distance marine traffic.

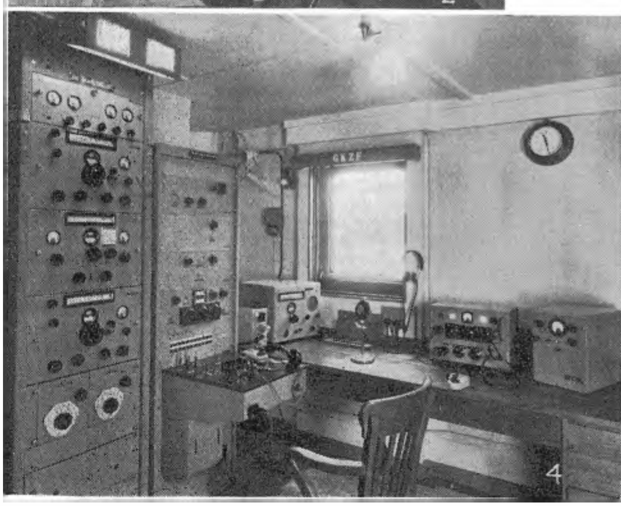
The accompanying illustrations show :—

1. *Marchese Marconi, G.C.V.O., Ll.D., D.Sc., born April 25, 1874, died July 19, 1937*



2. *A ship's wireless cabin of 1900 equipped with a battery operated spark transmitter using an inductor coil and Leyden jar condensers.*
3. *The actual magnetic detector made by Marconi. This exhibit is preserved in the Marconi Company's museum in Rome and was specially flown to London for the occasion*
4. *The long range radiotelephony transmitting and receiving equipment on board R.M.S. "Queen of Bermuda"*

The radio equipped cabin of the Orient liner "Orcades" showing similar modern long-range transmitting, receiving and direction finding equipment



The Nyquist Criterion of Stability

By J. C. WEST, B.Sc., A.M.I.E.E.*

THE principles of feedback have been known for a long time. If the output of an amplifying circuit is fed back to the input through a suitable network it is possible to alter the amplifier characteristic considerably. The overall gain may be reduced and decrease the amount of all forms of distortion.[1] The gain may even be reduced to unity as in the majority of servo-mechanisms or like the Cathode Follower.

Positive and Negative Feedback

Consider first of all a feedback system represented by Fig. 1 that is stable and which produces a sinusoidal signal output e_o for an input e_i. The gain G of the whole circuit is the ratio of output to input

$$G = e_o / e_i \quad \text{......} \quad (1)$$

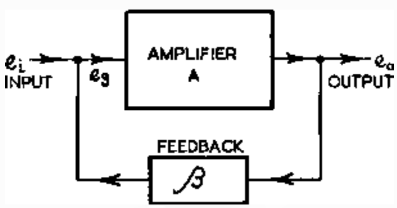


Fig. 1. Simple feedback loop

The amplifier alone has a gain A so that if e_g is the input signal at the amplifier terminals then:

$$A = e_o / e_g \quad \text{......} \quad (2)$$

The feedback circuit connected to the output e_o feeds back a signal βe_o to the amplifier, so that the total input signal is now:

$$e_g = e_i + \beta e_o \quad \text{......} \quad (3)$$

These three relations can be combined to give the overall gain in terms of A and β

$$G = A / (1 - A\beta) \quad \text{......} \quad (4)$$

Now A, β and hence G will, in general, be complex for phase changes take place as well as amplitude changes in amplifiers and networks. If the absolute magnitude or modulus of the denominator, usually written $|1 - A\beta|$, is less than unity then the gain G with feedback is greater than the gain A without feedback and if $|1 - A\beta|$ is greater than unity then G is less than A. In the first case where the effect of feedback is to increase the gain the system is said to have positive feedback, and in the second case with reduced gain, negative feedback.

Suppose an amplifier introduces no phase change and the gain is a real number, say 100, and that the feedback system also has no phase change at the frequency considered, but is only an attenuator where β can be represented as a fraction, say 1/200. Suppose that it is possible to reverse the connexions of the feedback path so that 180° phase change takes place, i.e., β is now $-1/200$.

When the feedback β is positive, the product $A\beta$ is equal to $\frac{1}{2}$ and $|1 - A\beta|$ is less than unity. The gain G is doubled. When the feedback β is negative $|1 - A\beta|$ is greater than unity, being in fact $1\frac{1}{2}$ and the overall gain G is reduced by a factor of $\frac{2}{3}$. Thus positive or negative feedback depends on the sign of $A\beta$, whether it is positive or negative. However, when A and β are complex, i.e., the phase changes are not zero or multiples of 180°, it is more difficult to say whether positive or negative feedback is taking place.

Stability

If $A\beta$ were made exactly equal to unity for a certain frequency, then as seen from Equation (4), the overall gain G would be infinite and the system would definitely be unstable. The condition $A\beta = 1$ is sufficient to ensure instability, but it is not a necessary condition for it is possible to have an unstable circuit for which $A\beta$ is not equal to unity for any frequency from zero to infinity. The reason that Equation (4) does not produce the complete stability conditions is that the feedback system of Fig. 1 is assumed to be stable initially in order to derive the equation. Thus it is only valid when the system is stable and it is inherently impossible to derive the conditions for instability from it.

The root of the trouble lies in considering only steady state conditions. When the input is initially applied there is a transient condition, normally for a very short period, before the output has reached the steady state. Under appropriate conditions, however, this transient state may not die away rapidly, but instead build up continuously so that a steady state condition is never reached. Thus it is inevitable that a study of the stability leads to a study of the transient conditions.

Transient Response

If any signal whose instantaneous voltage at a time t is represented by $E_i(t)$, is applied to the input of a four terminal network, then the corresponding output $E_o(t)$ can be obtained by a differential equation. If the network consists only of lumped parameters, i.e., resistors, capacitors and inductors and possibly valves, then the relationship is a linear differential equation with constant coefficients.

As a simple example, consider the circuit of Fig. 2. The differential equation is:

$$RC \frac{dE_o(t)}{dt} + E_o(t) = E_i(t)$$

and if the input is a sine wave applied at time $t = 0$, i.e., $E_i(t) = E \sin \omega t$ then the differential equation gives the output as:

$$E_o(t) = 1/RC\, \epsilon^{-t/RC} + E\left\{\sin(\omega t + \phi)\right\} / \left\{(1 + R^2C^2\omega^2)\right\}^{\frac{1}{2}}$$

where ϕ is given by $\arctan 1/RC\omega$.

The second term is the steady state output remaining when the transient given by the first term has decreased to negligible size. It must be noted that the transient term is independent of the form of the

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input signal. It can be shown that this term is the response of the network to a unit impulse applied at time $t = 0$ if the network is initially in a state of rest. This solution is often referred to as the weighting function.

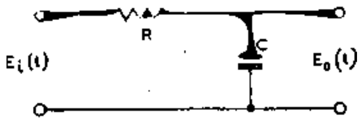


Fig. 2. (See Text)

In the general case the differential equation becomes:

$$a_n \frac{d^n E_o}{dt^n} - a_{n-1} \frac{d^{n-1} E_o}{dt^{n-1}} + \ldots + a_o =$$
$$b_m \frac{d^m E_i}{dt^m} - b_{m-1} \frac{d^{m-1} E_i}{dt^{m-1}} + \ldots b_o \quad \ldots\ldots\ldots\ldots (5)$$

where $m \leqslant n$

and $a_n \ldots a_o$, $b_m \ldots b_o$ are constants determined by the components of the network and by the initial starting conditions. To obtain the transient solution only, E_i is made zero and the right-hand side of Equation (5) becomes zero. This solution is made up of a sum of terms each of which has an exponential factor of the type ε^{pt} where p is in general complex. The values of p can be obtained by substituting ε^{pt} for E_o in the left-hand side of Equation (5) and equating to zero. This becomes:

$$\left\{ a_n p^n + a_{n-1} p^{n-1} + \ldots - a_o \right\} \varepsilon^{pt} = 0 \quad \ldots\ldots (6)$$

Thus ε^{pt} is a solution if

$$a_n p^n + a_{n-1} p^{n-1} + \ldots + a_o = 0 \quad \ldots\ldots\ldots\ldots (7)$$

The roots of this equation give the required values of p.

If any of these values are complex and take the form

$$p_r = \sigma_r + j\omega_r$$

where σ_r and ω_r are real, then the conjugate values

$$p_r^* = \sigma_r - j\omega_r$$

will also be roots of the equation, and it will then be possible to combine a root with its conjugate to form solutions with factors $\varepsilon^{\sigma_r t} \cos \omega t$ and $\varepsilon^{\sigma_r t} \sin \omega t$.

Thus the transient solution is made up in linear combination of a sum of terms with exponential factors, each of which will take one of the following forms depending on the particular value of the root p_r.

(a) p_r real and negative ………………… $\varepsilon^{-\sigma_r t}$

(b) $\begin{cases} p_r \text{ complex with negative real part} \\ p_r^* \text{ conjugate of above} \end{cases}$ … … $\varepsilon^{-\sigma_r t} \begin{cases} \text{Cos}\,\omega_r t \\ \text{Sin}\,\omega_r t \end{cases}$

(c) $\begin{cases} p_r \text{ purely imaginary} \\ p_r^* = -p_r \end{cases}$ … … … $\begin{cases} \text{Cos}\,\omega_r t \\ \text{Sin}\,\omega_r t \end{cases}$

(d) $\begin{cases} p_r \text{ complex with positive real part} \\ p_r^* \text{ conjugate of above} \end{cases}$ … … $\varepsilon^{\sigma_r t} \begin{cases} \text{Cos}\,\omega_r t \\ \text{Sin}\,\omega_r t \end{cases}$

(e) p_r real and positive ………………… $\varepsilon^{\sigma_r t}$

The first two types approach zero rapidly as t increases, while (c) oscillates continuously, (d) oscillates with ever increasing amplitude and (e) increases rapidly without oscillation. Thus considering a linear combination of these types, only when *all* the p's have negative real parts (as in a and b) will the transient solution approach zero as t increases. If one or more of the p's have a zero or a positive real part, then the transient solution will not approach zero and the steady state will never be attained. Under these conditions the network is unstable and it is seen that the criterion for stability rests solely on whether any of the roots of Equation (7) have zero or positive real parts, in which case it is unstable, or whether all the roots have negative real parts forming a stable network. In practice it is not desirable to have to find the roots of an equation such as (7) to determine the stability, especially as n may be quite large. This can be avoided by the use of the Hurwitz criterion[2] which gives the conditions that a polynomial shall have roots with negative real parts. These same conditions also form the basis of Routh's[3] criteria of stability in linear dynamical systems. However, these methods of stability determination have little value for the electronic engineer for if it turns out that the network is unstable the criteria give no information to enable the designer to modify the network in the right manner to gain complete stability.

There is another stability criterion, first shown and proved by Nyquist[4] specially for feedback systems, which does give some indication of the necessary modifications to make an unstable system stable and also shows how near to instability is a given stable network. Several alternative ways of proving the theorem have been developed[5,6,7] but the following account will be developed graphically from the preceding argument.

The Frequency Response Locus

If the network is stable and the input consists of a sinusoidal voltage, then the output will become sinusoidal of the same frequency after a certain time has elapsed from the application of the input signal, i.e., after the transient effect has decreased to zero for all practical purposes. The ratio of the steady state output to the input function is termed the "Steady State Response Function," or the "Frequency Response Function." If the input function is written:

$$E_i(t) = \varepsilon^{j\omega t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

then the output function becomes:

$$E_o(t) = \Phi(j\omega) \,.\, E_i(t)$$

where $\Phi(j\omega)$, a complex function of frequency independent of time, is the frequency response function. For the general linear network this function can be obtained from Equation (5) by the substitution of Equation (8) and (9). Hence:

$$\left\{ a_n(j\omega)^n + a_{n-1}(j\omega)^{n-1} + \ldots + a_o \right\} \Phi(j\omega) = \left\{ b_m(j\omega)^m + b_{m-1}(j\omega)^{m-1} + \ldots + b_o \right\}$$

from which is obtained:

$$\Phi(j\omega) = \left\{ b_m(j\omega)^m + \ldots + b_o \right\} / \left\{ a_n(j\omega)^n + \ldots + a_o \right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

If the complex function $\Phi(j\omega)$ is separated into real and imaginary parts so that:

$$\Phi(j\omega) = \Phi_1(j\omega) + \Phi_2(j\omega) \quad \ldots\ldots\ldots\ldots (11)$$

where Φ_1 and Φ_2 are both real, then for a particular frequency, $\Phi(j\omega)$ can be represented vectorially as in Fig. 3, where the absolute magnitude OP and the phase angle θ are given by:

$$OP = |\Phi(j\omega)| = \left\{\Phi_1^2 + \Phi_2^2\right\}^{\frac{1}{2}}$$

and

$$\theta = \arctan \Phi_2/\Phi_1$$

If ω is varied from 0 to $+\infty$ then OP and θ vary and the point P will trace a contour, a typical one being shown in Fig. 4, and if the locus is continued for negative frequencies from 0 to $-\infty$ (a purely mathematical

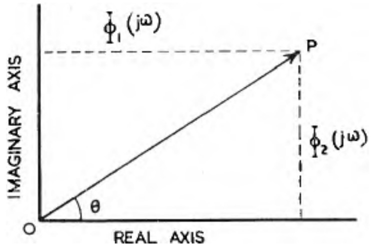


Fig. 3. The response vector

fiction) it is found to be the exact image of the positive frequency contours about the real axis. This is shown dotted in Fig. 4. The complete plot from $-\infty$ to $+\infty$ is the "Frequency Response Locus." In practice it can be obtained, for a given network, by direct measurement of gain and phase change without any of the constants of Equation (5) being known.

The Generalised Frequency Response Function

It is essential for the development of the proof to consider, not a simple sinusoidal input signal $\epsilon^{j\omega t}$ as in the last section, but an input function of the form ϵ^{pt} where p, as before, is complex with real and imaginary parts $p = \sigma + j\omega$. The frequency response function now becomes:

$$\Phi(p) = \left\{b_m(p)^m + b_{m-1}(p)^{m-1} + \ldots + b_o\right\} / \left\{a_n(p)^n + a_{n-1}(p)^{n-1} + \ldots + a_o\right\} \quad \ldots\ldots\ldots \text{(12)}$$

$$= \Phi_1(p) + j\Phi_2(p)$$

This generalized frequency response function $\Phi(p)$ has two main properties. First, if $p = \sigma + j\omega$ is replaced by $(j\omega)$ that is σ made zero, then the function degenerates into the steady state response $\Phi(j\omega)$ discussed previously. Second, if the denominator of Equation (12) is taken on its own and equated to zero, the values of p satisfying the equation are those required to find the solution of the transient function and determine whether the network is stable or unstable.

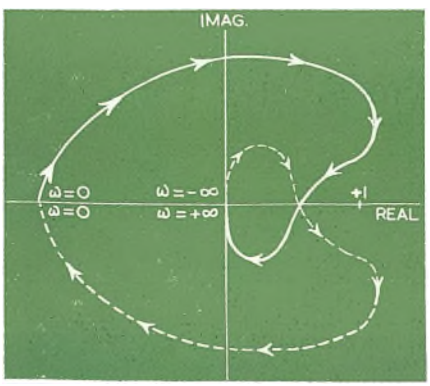


Fig. 4 (left). The frequency response locus

The frequency response locus (Fig. 4) is a plot of the steady state frequency response to sinusoidal input for frequencies $-\infty$ to $+\infty$. It is a special case of $\Phi(p)$ when $\sigma = 0$, i.e., $\Phi(j\omega)$. Hence a complete set of curves could be drawn each for varying ω from $-\infty$ to $+\infty$, but having different constant values of σ. A section of such a series of curves is shown in Fig. 5 where the full line is part of the steady state frequency response locus where $\sigma = 0$ and the broken lines indicate loci with various values or σ. It can be proved[10] that all the loci with values of σ positive and greater than zero are to the right of the frequency response locus for $\sigma = 0$ as the contour is traced in the direction of increasing frequency. If the frequency response locus forms a closed loop as in Fig. 4 then the loci of positive σ all lie inside the closed loop.

Networks with a Feedback Loop

Consider now the feedback system of Fig. 1, and let A and β now be functions of p for an input of the form ϵ^{pt} defined in the same manner as Equation (12).

If the feedback loop is broken, as shown in Fig. 6, then an input $e_i = \epsilon^{pt}$ will produce an output $e_o = A(p)\epsilon^{pt}$ and fed back through the β network would become:

$$e_{f.b.} = A(p) \,.\, \beta(p) \,.\, \epsilon^{pt}$$

$$= \Phi_o(p) \,.\, \epsilon^{pt}$$

where $\Phi_o(p) = A(p) \,.\, \beta(p)$ is the open loop gain of generalized frequency response.

Reconnecting the feedback loop, the overall gain or frequency response will be given, in a similar manner to Equation 4, by the following:

$$G(p) = A(p)/1 - A(p)\beta(p) \quad \ldots\ldots\ldots \text{(13)}$$

$$= A(p)/1 - \Phi_o(p)$$

If p is replaced by $(j\omega)$ then Equation (13) becomes identical with Equation (4), but as it stands the equation can be made to determine the stability criterion. For if the denominator is equated to zero, the roots give the required values of p for the transient response and if any of these roots have positive real parts the system is unstable.

$$1 - \Phi_o(p) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(14)}$$

Suppose the open loop gain $\Phi_o(p) = A(p) \,.\, \beta(p)$ is plotted in a series of contours, as in Fig. 7, when $\sigma = 0$ the locus is the steady state frequency response for the open loop $A\beta$. It will be a closed contour, for the frequency response at $\pm\infty$ is always zero, and it is known that all the loci of positive values of σ lie inside the curve. Consider the point $+1$ on the real axis, the contours passing through this point satisfy

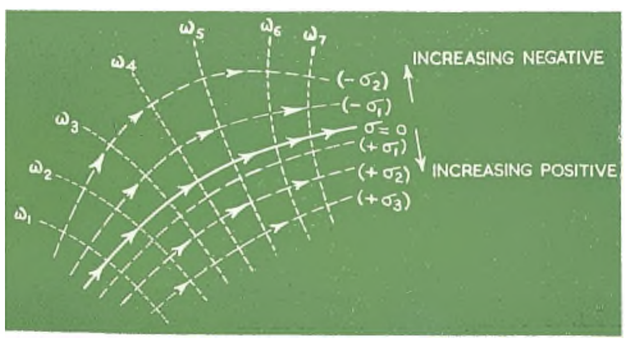


Fig. 5 (right). Section of a generalized frequency response diagram the equation:

$$\Phi_0(p) = 1$$

giving the values of $p = \sigma + j\omega$, but this equation is identical with Equation (14). Therefore these values of p are the ones required to determine the transient response. The system is unstable if any of these values have a real part which is positive and greater than zero. But we have seen that all the positive σ loci lie inside the open loop frequency response curve and therefore the system can only have a positive σ root if the $+1$ point lies inside this contour. If the frequency response curve does not enclose the point $+1$ the system must be stable.

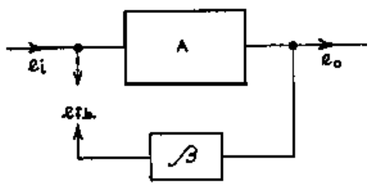
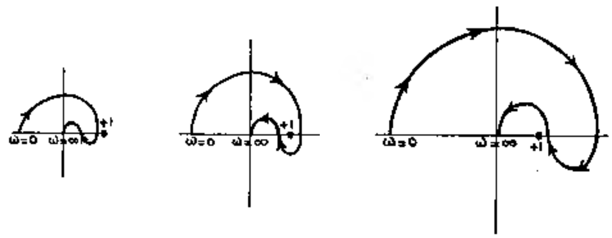


Fig. 6 (*left*). The open-loop gain

Fig. 8 (*right*). Conditional stability



(a) (b) (c)

This is Nyquist's criterion for stability and can be stated as follows:—

Plot the frequency response characteristic of the open loop circuit $A\beta$ as a vector locus of magnitude and phase. This can be done either theoretically by analysing the known networks A and β, or by practical frequency measurements with β disconnected as in Fig. 6. If this plot encircles the point $(+1,0)$ the system is unstable. If the plot does not enclose this point the system is stable and, furthermore, if this point is some distance away from the plot, then minor variations in the operating conditions, i.e., changes in voltages or of the circuit constants, are unlikely to cause any instability.

Frequently the criterion is stated in a modified manner where the plot of $-A\beta$ is taken.[8] This only means that the whole diagram is turned through 180° and the critical point is now $(-1,0)$.

Conditionally Stable Networks

A conditionally stable network is one which is only stable for certain gain conditions of the open loop. For instance, a positive feedback arrangement is stable if the open loop gain is less than unity, but increasing the gain produces instability with ensuing oscillations. If it were possible to come into a stable region again by a further increase in the open loop gain, then the network would be conditionally stable.

According to the Nyquist theory, if the open loop gain contour takes the form shown in Fig. 8a, then it ought to be possible to make this network operate in a conditionally stable state.

In Fig. 8a the circuit will be stable, and if the gain is increased so that the conditions are as shown in Fig. 8b then the circuit will be unstable, but if condition 8c is obtained by a further increase in gain, then the circuit should be conditionally stable.

A successful experiment was carried out in 1934[9] to verify the existence of this conditionally stable case. From the preceding section it is fairly clear how this phenomenon arises. The roots of Equation (14) for the case 8c must all have negative real parts, since the loci corresponding to positive real parts are all inside the closed contour and hence cannot cut the $(+1,0)$ point. With this amount of gain the circuit must be stable and the operation can be studied by the use of the steady state response.

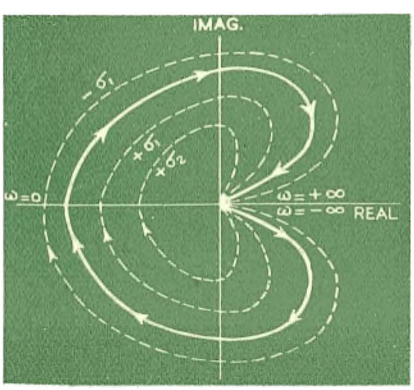


Fig. 7. Regions of positive and negative σ

Appendix

The following restrictions have been assumed:—

1. A valve amplifier can be regarded as composed of a multiplying constant produced by the gain of the valves and independent of frequency and a frequency dependent factor determined by the L.C.R. networks of the circuit.
2. The addition of a β circuit to the output of the amplifier does not modify the operation of the amplifier.
3. When the open loop gain $A\beta$ is measured the disconnecting of β must not upset the loading conditions and alter A or β.
4. The amplifier A and the feedback circuit β must both be stable circuits when isolated.
5. The high frequency response of the amplifier must eventually become zero. This is inevitably true in all realizable networks.
6. All the circuits must consist only of lumped components, i.e., high frequency lines, feeders and aerials are not included in the loop.

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[10] See Ref. 8, Sect. 86, p. 151.

The Dekatron

A New Cold Cathode Counting Tube

By R. C. BACON, B.Sc., A.Inst.P.,* and J. R. POLLARD, M.A., M.I.R.E.*

A general study of the work already carried out in the field of electronic counting and computing, leads inevitably to the impression that, despite considerable ingenuity on the part of circuit engineers, there remains a fundamental need for specialised tubes designed to meet the new problems involved. In this approach to circuit simplification, it is logical to attack the problem by dealing in the first place with speeds that are in the immediate range above that at which mechanical devices can be safely and reliably operated. To fulfil this need a range of 'Dekatron' tubes has been designed which comprises, at present, three types of multi-electrode cold-cathode tubes.

General Principles of Operation

THE three types considered in this article are:

(1) A scale-of-ten tube on an octal base for direct viewing.

(2) A scale-of-ten tube of miniature size on a B7G base for frequency division or gate operation.

(3) A batching tube with multiple outlets, of similar physical dimensions to (1), for the purpose of obtaining any of several scaling factors.

All the above types operate on the same principle. A cathode glow on one of a set of inter-connected cathodes, arranged around a central common anode, is caused to transfer from one position to the next by the application of controlling voltages to intermediate electrodes or "guides." This arrangement will become clear by consideration of Figs. 1 and 2.

Fig. 1 shows, around the central anode disk *A*, a number of equi-spaced rods or wires (on a pitch circle of 20 mm. diameter in the case of GC10A). These wires actually comprise thirty electrodes, of which ten are cathodes, ten are guide 1 electrodes, and ten guide 2 electrodes. Nine of the cathodes are connected internally in the sequence shown in part in Fig. 1. The tenth cathode is isolated and brought out separately, as the output or marking cathode. The ten guide 1 electrodes are connected internally. *g*1, *g*1*a*, etc., and in the same way the ten guide 2 electrodes marked *g*2, *g*2*a*, etc., are internally linked. Hence the tube has five outlets, comprising anode, output cathode, cathode ring, guide 1 ring, and guide 2 ring.

Referring to Fig. 1, together with the simple circuit arrangement of Fig. 2, let it be assumed that a discharge is taking place between the anode *A* and cathode *k*2. If a negative pulse of 120 volts is applied to the group of guide 1 electrodes (*g*1, *g*1*a*, etc.) which were originally at +60 volts with respect to the cathode *k*2, a transfer of the glow will take place in a clockwise direction to electrode *g*1*a*. That is to say the glow discharge will transfer preferentially one position clockwise as opposed to two positions anticlockwise to electrode *g*1. If it be arranged that simultaneously with the restoration of guide 1 to +60 volts, a similar pulse is applied to guide 2, the glow will move clockwise to electrode *g*2*a*. The function of the two guide systems is thus to render certain the direction of motion of the discharge. When guide 2 is restored to its original potential of +60 volts relative to the cathode, the glow moves forward to the next cathode *k*3. This accomplishes one complete cycle of operation: for each such cycle the illumination moves one step in a clockwise direction.

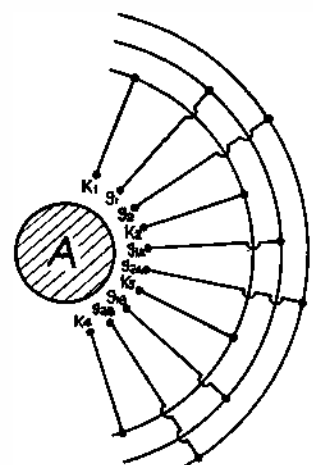


Fig. 1. Interconnexion of the electrical system of the cathode counting tube

It follows from the above argument that by reversing guide 1 and guide 2 connexions the glow can be caused to rotate in an anticlockwise direction.

The action of these tubes as described will no doubt recall a somewhat similar tube of recent American origin.† There are, however, certain interesting points to be noted. In the first place it will be appreciated that the functioning of the tube now being described is essentially a guided *transfer* of the discharge from cathode to cathode, rather than a series of separate striking and extinguishing operations. Thus it is not necessary to raise the potential of the glowing electrode simultaneously with the reduction of potential of the "about-to-glow" electrode in order to effect the transfer of glow. It

* *Research Laboratories, Ericsson Telephones Ltd., Nottingham.*

† "A Polycathode glow discharge tube for counters and calculators." J. J. Lamb, J. A. Bustman, *Electronics*, Vol. 22, No. 11, pp. 92-96, Nov. 1949.

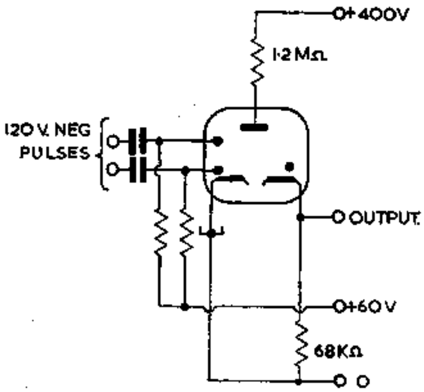


Fig. 2 *(above)*. **Driving and output arrangements**

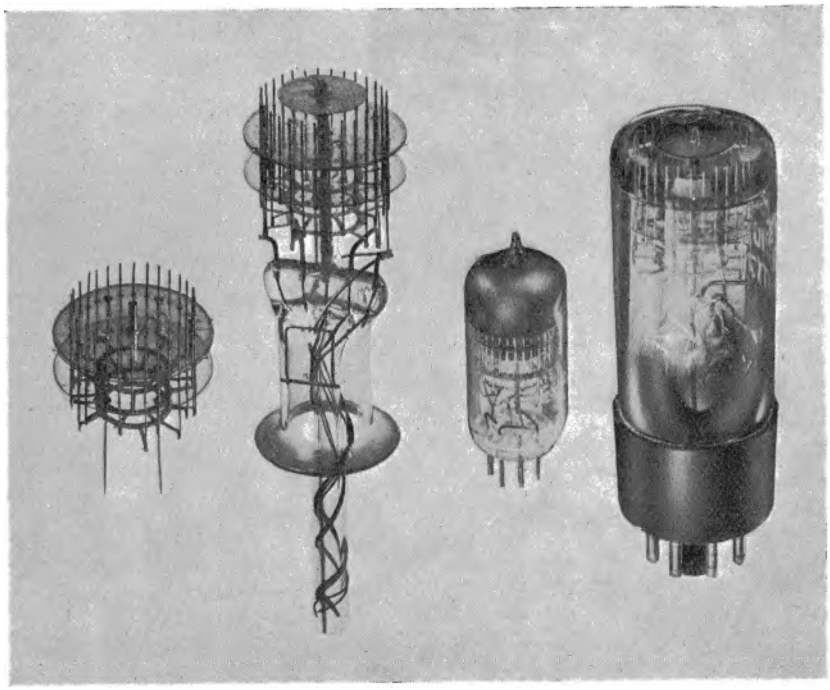


Fig. 3 *(right)*. **Electrode assembly and completed tubes. The GC10A tube is shown on the extreme right**

suffices to cause the potential of the " about-to-glow " electrode to become a few volts negative to that of the glowing electrode.

In addition, it may be pointed out that the GC10A will operate quite satisfactorily at very low current values—of the order of microamps rather than milliamps. It is expected that a reliable life of the order of 10,000 hours will be obtained in view of the life test data already accumulated.

Tube Details and Performance

The major items influencing the satisfactory operation of the tube are:

(1) Mechanical accuracy and uniformity of electrode spacings;

(2) Purity and freedom from contamination of the electrodes;

(3) Purity and accuracy of the gas filling.

In order to fulfil these conditions the tube is completely jig assembled, resulting in an accurate and rigid 30-electrode unit as depicted in Fig. 3. A great deal of attention is paid to the initial and final purity of the electrodes and other components to ensure clean and stable surface conditions that will permit uniform behaviour over a long life.

In the case of the GC10A the recommended maximum counting rate is of the order of six hundred cycles per second and, with applied voltages as shown in Fig. 2, the operating current is 200 microamps with a nominal tube voltage drop of 160 volts.

The GC10A tube is rather less than 100 mm. in length, is fitted with an international octal base and the viewing end of the bulb is approximately 28 mm. in diameter. A metal shield indicator carrying numbers 0 to 9 can be fitted over the bulb as an additional indication of count if required.

The electrical characteristics of the miniature version of this tube are similar to the GC10A. Its application is more appropriate as a gate or frequency division tube rather than as a counter for direct viewing.

In order to cover the probable necessity for scaling factors other than ten, certain " batching " tubes have been considered. A very considerable degree of flexibility can be achieved with this type of tube by dividing the cathode ring on the standard tube and bringing out a number of cathode connexions. It will be appreciated, for example, that in a twelve-cathode system with suitable outlets, division by two, three, four or six would be possible.

Circuit Requirements

In discussing the practical application of these tubes two aspects must be considered: the production of suitable controlling voltages on the guides, and the utilisation of the output current at the separate cathode.

The driving circuit for the tubes must produce the necessary transfer conditions each time an input pulse is applied to it: a typical transfer charac-

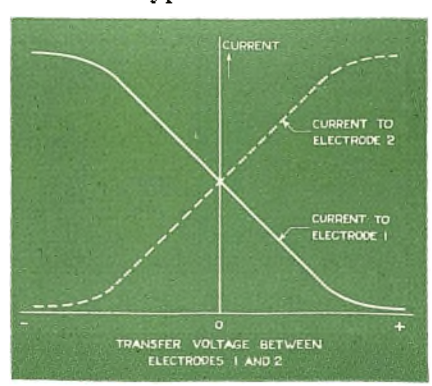


Fig. 4. Transfer characteristics

teristic is shown in **Fig. 4**. The glow transfer takes place over a range of no more than a few volts potential difference between adjacent electrodes. A wide range of voltage waveforms applied to the guides will serve to cause the transference of the glow, but the best, and that which is recommended for use at the highest counting speeds, consists of interlaced or paired rectangular pulses of the form shown in Fig. 5A. From this figure it can be seen that the mark-space ratio of each pulse is approximately one-third, so that at any given speed the maximum possible time is allowed for the discharge to settle on one electrode before the next transfer is initiated.

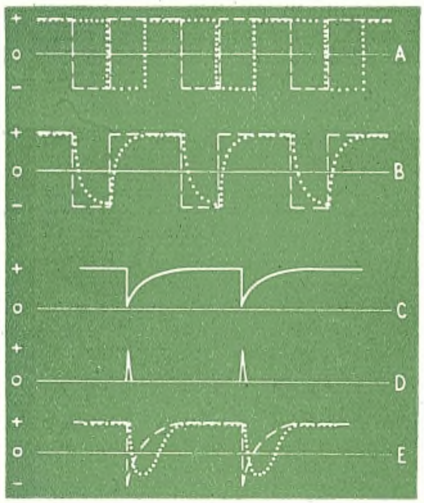
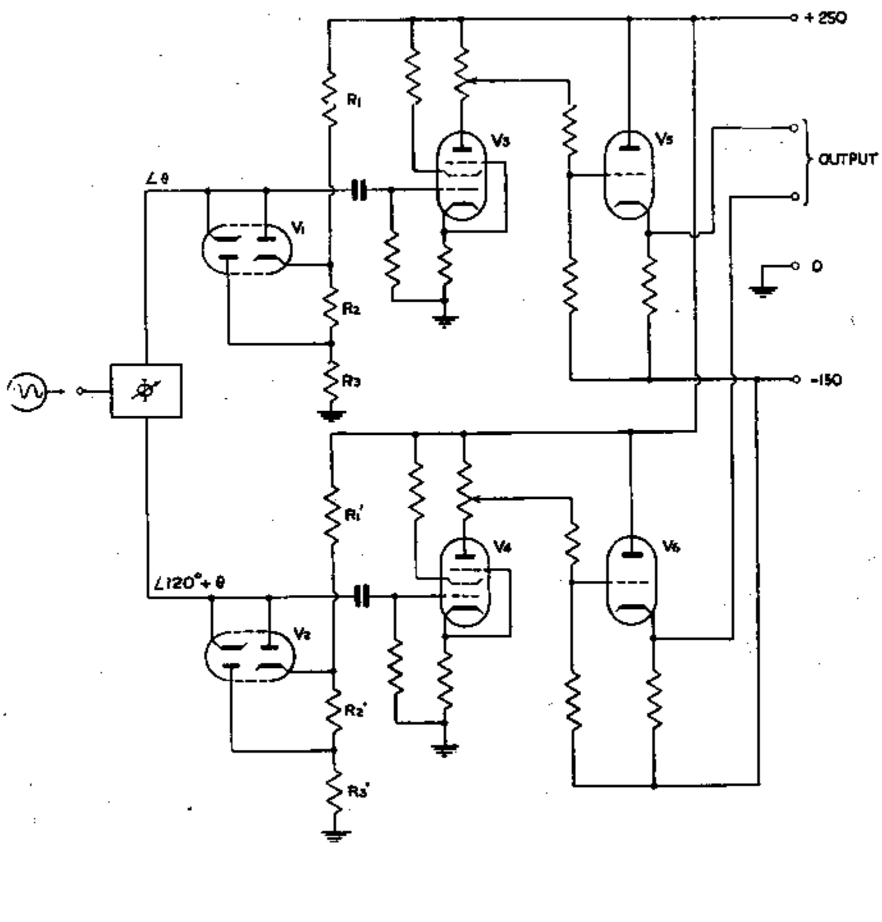


Fig. 5 (*left*). Driving circuit waveforms

Fig. 6 (*below*). Driving circuit producing paired rectangular pulses

One rather elaborate arrangement, which produces extremely satisfactory driving voltages of this type, is shown in Fig. 6. A sine wave input signal is applied to a phase shifting circuit, which provides two outputs differing in phase by 120°. These voltages are applied to diode "slicers" V_1, V_2, which pass only the portion of the waveform between amplitude levels set by the potential divider R_1, R_2, R_3. The resulting pulses, which have the correct base-width and phasing, are then amplified in the limiting amplifier stages V_3, V_4, and applied, by means of the cathode followers V_5, V_6, to the guides of the scaling tube.

Although the types of waveform shown in Fig. 5A represent the ideal for high speed operation, they require rather complex apparatus for their production. Considerable economy in the drive circuits can be obtained if a slight reduction in maximum counting speed is acceptable. For example, Fig. 5B shows a square pulse applied to guide 1; the pulse applied to guide 2 is obtained by the action of an integrating circuit, of suitable time constant, on the guide 1 waveform. A simple circuit which produces this result is shown in Fig. 7. This principle can be made use of in developing the single-valve drive circuit shown in **Fig. 8**. The pentode V_1 is normally biased to cut-off and in consequence its anode potential is that of the H.T. + supply line. One guide signal is derived directly from a potential divider between anode and the negative supply rail, and the other via an RC integrating circuit. When a positive-going pulse is applied to V_1 grid, the anode potential falls, rising again at the end of the pulse. Waveforms like those of Fig. 5B are thus applied to the guides.



It is frequently desirable to operate the scaling tubes from a signal source not producing square pulses, and it has been found that the general method shown in Fig. 7 can be applied to a large variety of input waveforms with satisfactory results. For example, Fig. 9 shows a drive circuit employing a single cold-cathode trigger triode. When triggering pulses, shown in Fig. 5D, are applied, the anode potential waveform will be of the type shown in Fig. 5C. If this output waveform is applied to an

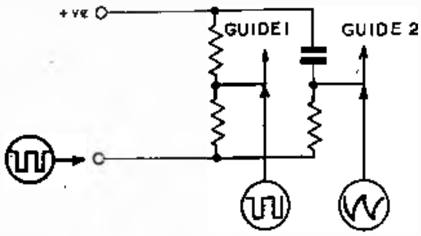


Fig. 7. Integrating circuit for producing drive signals

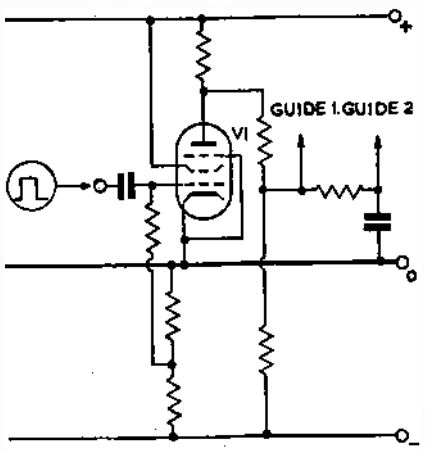


Fig. 8. Simple single-valve drive circuit

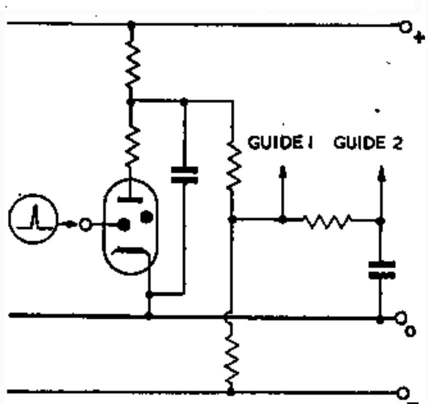


Fig. 9. Trigger-triode drive circuit

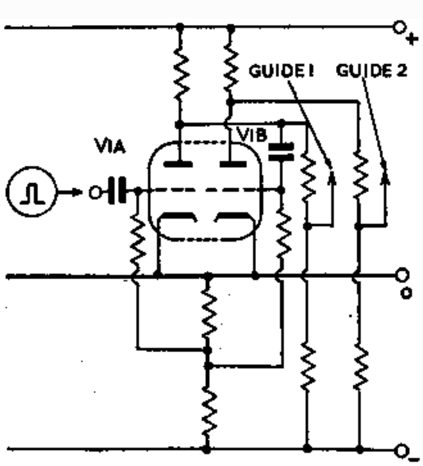


Fig. 10. Double triode drive circuit

arrangement containing one directly-coupled circuit and one integrating circuit of small time constant, then outputs of the form shown in Fig. 5E will be obtained. Although these are very different from the ideal rectangular pulses of Fig. 5A, it will be seen that the voltages developed are still suitable for transferring the discharge. The only effect of the degradation of waveform is to reduce the time allowed on certain electrodes for the discharge to stabilize and, in consequence, there may be some reduction in the maximum obtainable speed. The circuit shown in Fig. 9 is particularly useful since, by appropriate choice of input circuit for the trigger triode, it can be made to operate on single pulses, repeatedly on pulse trains or on step functions.

The circuit shown in Fig. 8 has been found useful in frequency dividing arrangements for coupling between successive stages. Fig. 10 shows a double triode circuit which has been employed for a similar purpose. In this arrangement, both halves of the double triode are normally biased to cut-off. A positive-going pulse applied to the grid of V_{1A} produces a negative rectangular pulse at V_{1A} anode, which is coupled to guide 1. At the end of the input pulse, V_{1A} anode potential rises: this causes V_{1B} to pass anode current and so produces a pulse for guide 2 at V_{1B} anode. By appropriate selection of time constants, the overlap of the pulses and the duration of the pulse applied to guide 2 can be made satisfactory for high speed working.

The circuit arrangements described above and illustrated by Figs. 6-10 represent, of course, only the beginning of the study which is being made of the problems involved. Many other control and driving circuits are possible, and it is hoped to deal with some of these in greater detail at a later date.

Derivation of Outputs

When the discharge rests on the single cathode which is connected to a separate base pin, the current flowing to that cathode will give rise to a potential difference across a series resistor in the cathode lead (see Fig. 2), so that it is possible to obtain an output pulse coincident with every tenth input cycle. The anode current is approximately 200 microamps, so that resistors in the range 50-100 kilohms will give output voltages of approximately 10-20 volts. If larger cathode resistors are used in an attempt to get considerably greater output voltages, it is found that the large rise in potential at the single cathode when the discharge passes on to it is such as to interfere to some extent with satisfactory transfer. This may cause irregular operation, particularly at the higher operating speeds, and so a maximum output of 20 volts is recommended for ordinary use. Normally the cathode is at earth potential, but rises to +20 volts during the time the discharge rests on it. In some circuits it is more convenient to have the cathode at -20 volts while quiescent, rising to earth potential for the pulse period. This can easily be effected by the addition of a resistance from cathode to the negative supply rail, as shown in Fig. 11. With this modification the control of subsequent control-grid or suppressor-grid gated stages (for example, in adding and calculating circuits) is extremely convenient, as it is then possible to earth the cathode of the controlled valve, the cut-

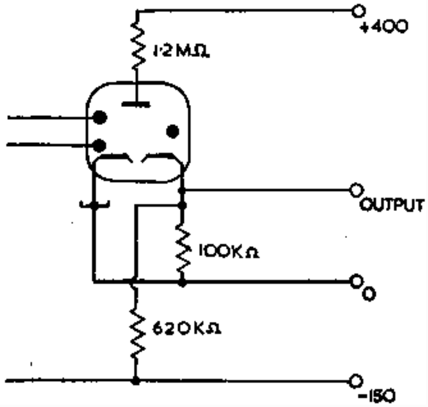


Fig. 11. Output circuit

off bias normally required being inherent in the output arrangement of Fig. 11.

Conclusions

It will be apparent that the design of these tubes has evident flexibility in digital scaling and also that in general terms the tubes are non-critical as regards operating conditions. An additional advantage is the possibility of adding or subtracting at will by reversal of the connexions to guides 1 and 2.

A considerable future is envisaged for these tubes in view of the possibility of greatly increased operating speeds (20 kc/s. is certainly possible), the small size and low power consumption, the potentially very long life, and the reduction in ancillary valves and circuits in counting and computing work.

Acknowledgments

The authors would like to record the original design work of Mr. J. R. Acton on these tubes and also their sincere appreciation of his continued interest and collaboration.

Our special thanks are due to Dr. J. H. Mitchell, Head of the Research Laboratories of Ericsson Telephones, Limited, for his interest and encouragement which have made this work possible.

Finally we would like to acknowledge our appreciation to the Directors of Ericsson Telephones, Limited, for permission to publish this paper.

A Single Valve Magnetic Time Base

By C. H. BANTHORPE
*(Central Equipment Ltd.)**
and B. HOPENGARTON

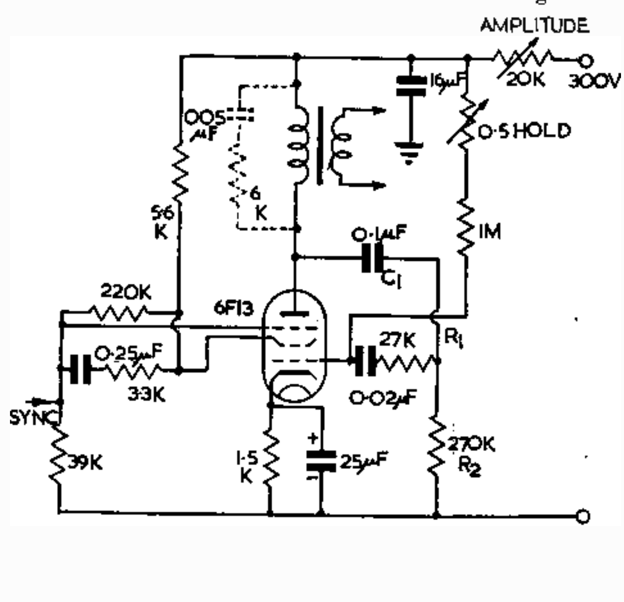
THERE have been a number of attempts to make a single valve time base for magnetic deflexion, but generally the circuits have some disadvantage. They need (i) a considerable amount of sync. voltage or power, or (ii) work valves on parts of their characteristics which may not be similar from valve to valve, or, much worse, (iii) subject valves to great strain where normally little strain exists, e.g., high grid current, or high voltage between electrodes. A magnetic time base with none of these faults and which, in addition, is extremely linear and economical has been developed and it has given satisfactory results as the frame time base in television receivers.

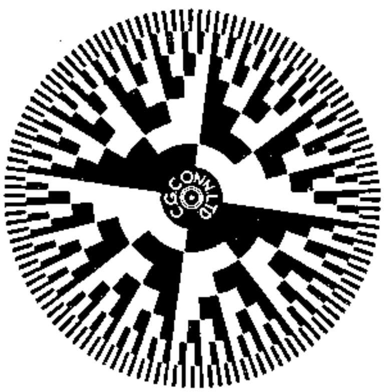
The circuit shows it to be of the transitron type with feedback between anode and $G1$ for the purpose of linearising as in the Blumlein or Miller Integrator. As it is secondary current which is required to be linear the feedback path includes the time constant $R2$, $C1$ which is adjusted to correct for the distortion of the output transformer. If the anode load of the valve is too low, the current will be excessive for a given power output, while if it is too high the anode voltage will fall too far during the scan unless the H.T. supply is very high. An H.T. supply of up to 300 volts and an anode current of 5 mA has been found to be a good compromise and the valve is then well within the makers ratings, $V_a = 230$ V $i_a = 5$ mA, $V_{g2} = 230$ V $i_{g2} = 3$ mA.

The output transformer has to present a rather higher impedance than usual and has a primary inductance of 90 henries, and a ratio of 20 : 1. The scanning coils are standard and have 500 turns on the frame windings. Due to the method of linearizing, the output transformer can have cheap iron laminations and the output is almost unchanged from valve to valve. With the values given there is more than enough sweep amplitude to scan a 9 in. or 12 in. C.R.T. with 7 kV E.H.T. and a suitable amplitude control can be as shown. The components drawn dotted can be added to increase still further the efficiency of the circuit.

The controls are somewhat interdependent which is unfortunate, but over reasonable limits can be considered independent. In practice, if different components to those shown are used, $R2$ may be adjusted to make the linearity good over most of the scan and $R1$ may be adjusted to make the first part of the trace linear.

Negative sync. pulses may be applied to $G3$ for locking purposes, or other methods may be used. The Mazda 6F13 is shown in the diagram but, of course, almost any similar valve should be able to give satisfactory results and the "normal" sized valves would be even more within their ratings.





A Stroboscopic Tuner

For Musical Instruments

By ALAN DOUGLAS

THE increasing use of electronic musical instruments makes it desirable to provide a means of accurately checking the constancy of tuning, especially where there are independent pitch generators. While, of course, tuning can be carried out by normal aural methods, there are some types of instrument in which a higher degree of accuracy is required.

The Stroboconn provides a rapid means of ascertaining the exact frequency of any pitch note, and at the same time indicates the presence of harmonics which may exist in the note. It also indicates the departure from exact tune as a percentage of the nearest semitone; this is read directly from a scale calibrated to 12 per cent of one-hundredth of a semitone. This degree of accuracy is about 25 times greater than any departure which can be detected by the most critical human ear.

The tuning unit consists basically of a series of twelve rotating transparent disks, printed as shown above. Each disk carries seven rows of alternate light and dark segments, and each ring has twice the number of segments of the adjacent ring. Thus the compass of the instrument is 7 by 12 or 84 semitones. This covers from 31.772 to 4066.8 cycles per second.

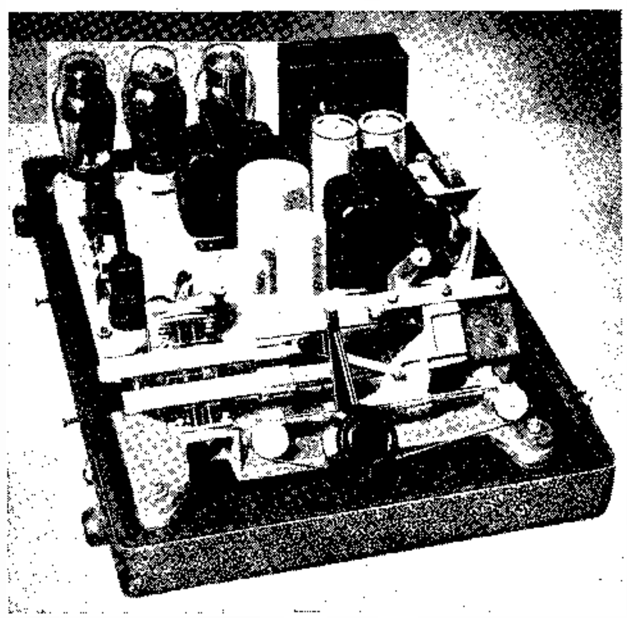


Fig. 2.
Fork drive amplifier section

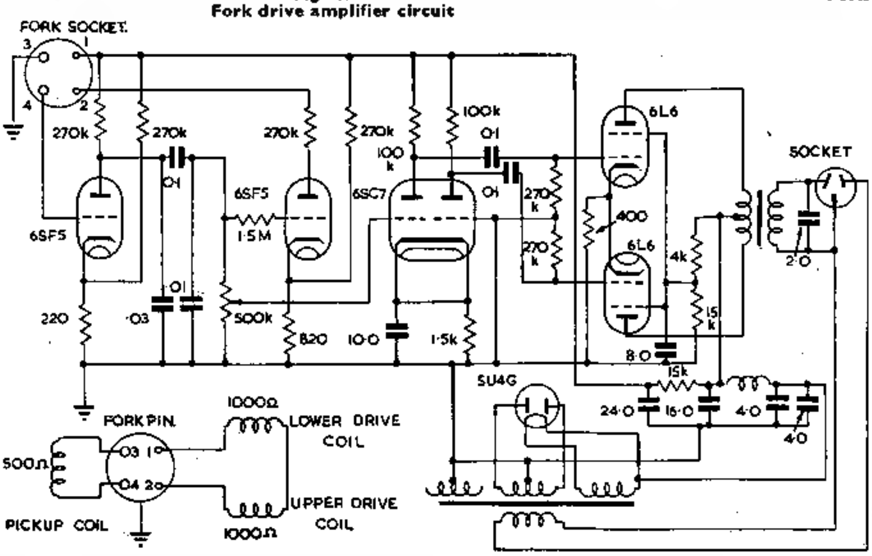


Fig 1.
Fork drive amplifier circuit

All of the 12 disks are permanently geared together and driven by a common motor. Since the frequency ratio of successive semitones in the equally tempered scale is the twelfth root of two, it is impossible to gear the disks so as to obtain absolutely perfect intervals. However, by using two different gear ratios (89/84 and 107/101) it is possible to keep the maximum error to 12 per cent of one-hundredth of a semitone, as stated.

The motor driving the gearbox is supplied with power by the drive amplifier, Fig. 1, in which a variable frequency is derived from the adjustable tuning fork. This fork, made from one of the Invar classes of steel, has an adjustable sliding weight on both tines. These weights can be moved by the control knob seen in Fig. 2, and the adjustment provided alters the fork frequency by one semitone. The central position of the knob causes the fork to vibrate at 55 c/s., and the frequency can be increased or decreased over the range mentioned by turning the knob in one direction or the other.

The Stroboscope neon tubes, which are fitted behind each disk (Fig. 3) are energised from the flashing amplifier, Fig. 4. This circuit is fed from a crystal microphone, which causes the neon tubes (N2) to flash at a speed corresponding to the pitch of the note picked up by this microphone. When the disks rotate, bands of light will appear in one or more of the windows covering the disks. The fundamental tone of the received sound will appear as a dark band nearest to the apex of one window, and the harmonics of the tone will appear as lighter bands in the same window, or perhaps in other windows as well (Fig. 5).

Since each window is provided with an index showing the name of the note it represents, then if a pattern remains stationary in the appropriate window, that note is in tune to within 0.01 semitone. If the pattern drifts to the right, the tone is sharper; if to the left, flatter. By turning the fork control knob the pitch may be restored and the percentage departure noted. Thus, when tuning an instrument, the effect of getting into more correct tune can be observed very exactly.

The foregoing explanation is based on the use of the key of C and, also, A = 440 c/s. For tuning in other keys, a transposing slide is provided which indicates the correct windows to be used for the key signature required.

For tuning at some other frequency, say A = 435, it is only necessary to adjust the fork frequency so that the A(440) ring image is brought to a standstill

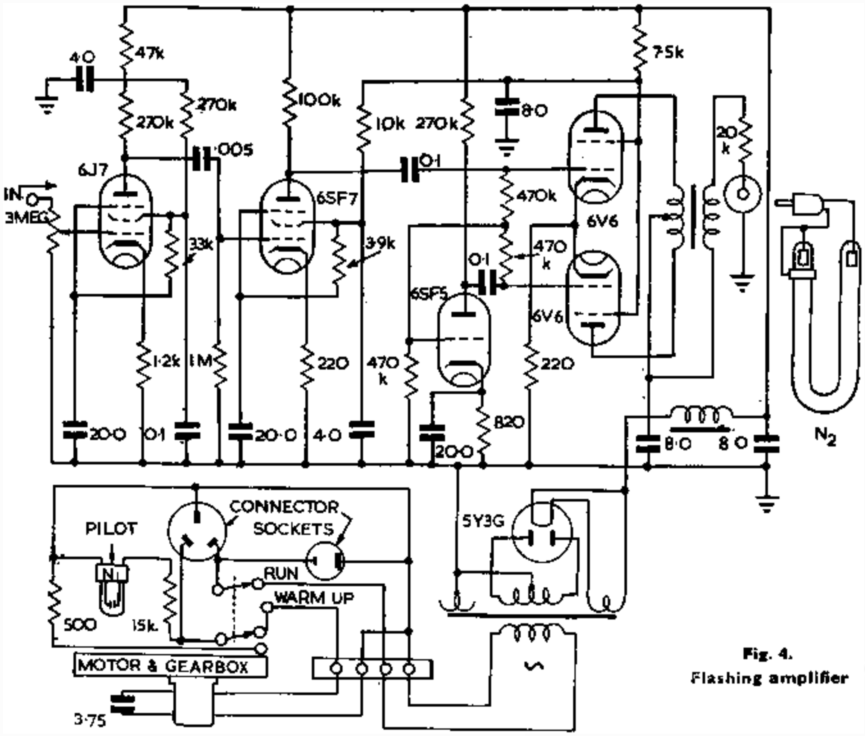


Fig. 4.
Flashing amplifier

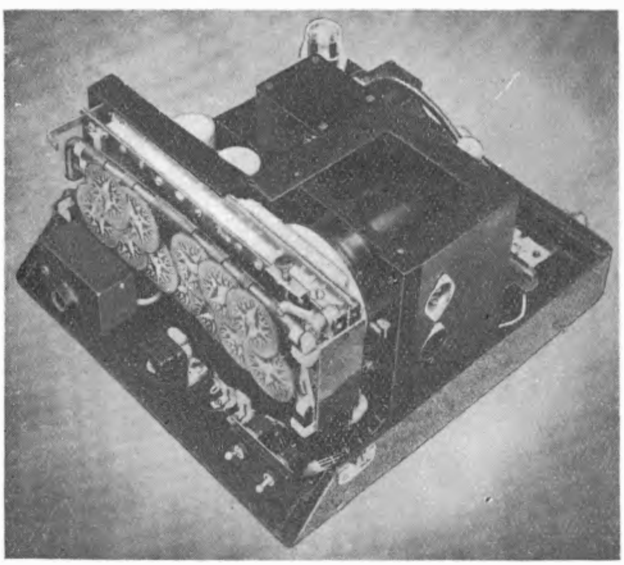
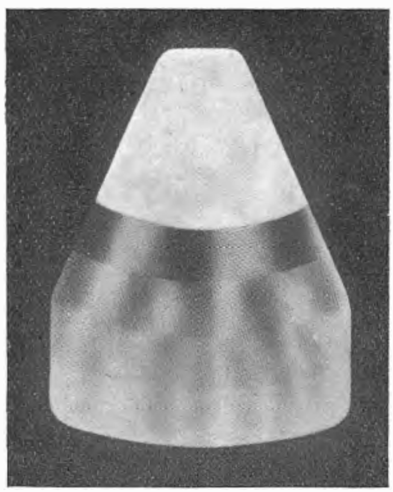


Fig. 3 (*left*).
Flashing amplifiers and disk drive unit

Fig. 5 (*right*).
Appearance of relevant aperture when the microphone is picking up a note



at A = 435. The relative intervals for all other notes in the scale will then be correct.

It is clear that in the case of many electronic musical instruments it will not be necessary or desirable to use the microphone to collect the sound, since this would pass on any harmonic distortion which might be present in the amplifiers or loudspeakers. In such cases, the signal outlet from the generators or mixing circuits may be directly connected to the input of the flashing amplifier.

This very ingenious device could profitably form an integral part of a comprehensive electronic musical instrument, since many of these are known to contain up to 200 independent frequency generators, and several have been made with more than 1,400.

The author wishes to acknowledge the courtesy of C. G. Conn, Ltd., of Elkhart, Indiana, U.S.A., who invented and developed this device, for kindly permitting publication of the details.

Delaying the Release of Relays

by R. Townsend, B.Sc. (Eng.), A.M.I.E.E.

WHEN it is desired to delay the release of a relay more than about half a second it is not practicable to use a relay provided with a copper "slug," and it is common practice to shunt the relay coil with a high capacitance, low voltage electrolytic capacitor, which discharges through the coil when the energising voltage is removed. It is possible, under certain conditions, to increase the delay with a given relay and capacitor by inserting a resistor in series with the capacitor as shown in Fig. 1. As a resistor is a far smaller component than an electrolytic capacitor, both space and economic considerations merit the use of an optimum combination of resistance and capacitance. In order to simplify the calculations the effect of the inductance of the relay has been neglected and it has been treated as a pure resistance.

Referring again to Fig. 1, the working current of the relay $= E/R1 = I$. Let the release current $= KI = KE/R1$, where K is a fraction giving the ratio of the release current to the working current.

When the switch S is opened the current flowing in the relay coil is given by

$$i = \frac{E}{R1 + R2} \cdot e^{-\frac{t}{C(R1+R2)}}$$

At the moment of release

$$i = \frac{KE}{R1} = \frac{E}{R1 + R2} \cdot e^{-\frac{t}{C(R1+R2)}}$$

$$\text{whence } t = C(R1 + R2) \log_e \frac{R1}{K(R1 + R2)} \quad \ldots\ldots\ldots (1)$$

Differentiating to find the maximum value of t when $R2$ is varied

$$\frac{dt}{dR2} = C\left[\log_e \frac{R1}{K(R1 + R2)} - 1\right]$$

which is zero when t is a maximum.

$$\text{Thus } \log_e \frac{R1}{K(R1 + R2)} = 1$$

$$\frac{R1}{K(R1 + R2)} = e$$

$$\text{and } R2 = R1 \frac{(1 - eK)}{eK} \quad \ldots\ldots\ldots (2)$$

Substituting this value in the equation for time delay we have

$$t_R = CR1/eK \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

This may be compared with the time delay when no resistance is used which is

$$t_0 = CR1 \log_e 1/K \quad \ldots\ldots\ldots\ldots\ldots (4)$$

The increase of time delay obtained is shown by the ratio

$$\frac{t_R}{t_0} = \frac{1}{eK \log_e 1/K}$$

From Equation (2)

$$\frac{R2}{R1} = \frac{1 - eK}{eK}$$

The factors $1/eK$, $R2/R1$ and t_R/t_0 are plotted in the curves of Fig. 2. From these can be found the time delay, the optimum resistance, and the increase in time delay obtained by the use of the resistance.

The following conclusions may be drawn:

(a) From Equation (2), if $R2$ is to be positive, K must be less than $1/e$. In this case t_R is increased as shown by Equation (3).

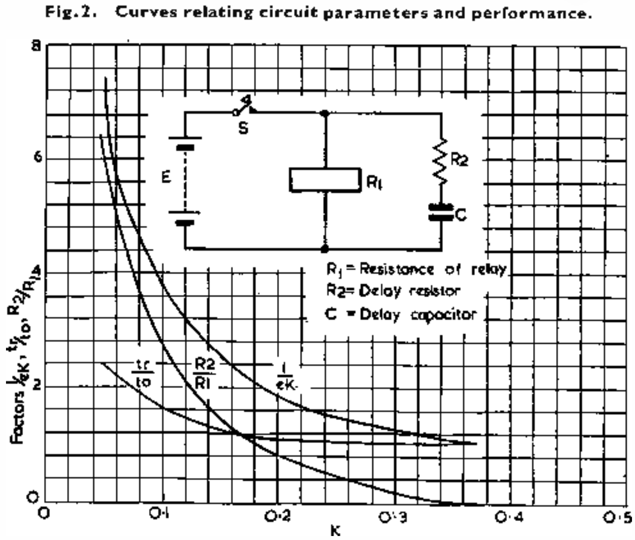
(b) If $K = 1/e$, $R2$ becomes zero.

(c) If K is greater than $1/e$, $R2$ becomes negative, and therefore is of no practical significance, and no improvement in the delay time can be achieved by the use of a resistance.

It is clear that in order to get the longest delay, K should be made as small as possible, by choosing a relay which has a considerable difference between its operate and release currents, and by working the relay with as high a current as is practicable from other considerations.

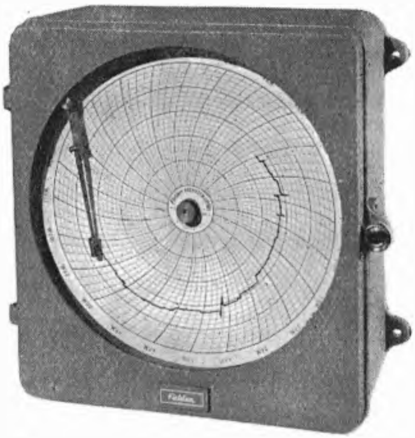
Fig. 1 (inset). Circuit arrangement.

Fig. 2. Curves relating circuit parameters and performance.



The Servograph

A New Electrical Graph Recorder



A NEW development which is of interest to all branches of the electrical engineering industry has recently been introduced by Fielden (Electronics) Ltd., of Manchester. In all sections of the light current engineering world light current indicators have found commonplace use, and modern improved magnetic alloys have made available a range of robust indicating instruments which will operate on the smallest current and which, as they consume only a very small amount of power, can be used in almost any circuit. Unfortunately, however, for many industrial and laboratory processes, an indication is not sufficient and a graphical record is required. There are several well-known solutions to the problem, but most of the existing systems suffer from limitations, most of which are associated with the difficulty of operating a pen over a paper surface with the small power available from low current circuits. It is claimed that the new instrument overcomes these difficulties and provides a robust and accurate recorder which will operate in any circuit where an indicating instrument can be used.

The instrument consists of a servo-operated mechanism which is positionally controlled by a moving coil, moving iron or dynamometer movement. The indicator of the normal instrument is replaced by a light vane which acts as one plate of a variable capacitor, another similar vane, arranged to be turned by the servo mechanism, moves in the same arc as the meter-operated vane, and the two are maintained at a constant spacing by an electronic capacitance relay which controls the servo motor. The current to be measured has to provide only enough energy to deflect a normal indicating meter movement and the servo mechanism locates the pen arm with precision at the resting place of this movement.

The equipment has been developed in rotary disk chart form and is available in several ranges of current and voltage. It is understood, however, that a further model providing a band chart is under development which will be available in due course.

The capacitance relay employed consists of a valve oscillator in which the feed back circuit is arranged as a capacitance dividing network, of which the meter capacitor forms one arm and an internal preset capacitor another. When one capacitor is larger than the other the feed back is positive, and when one is smaller than the other the feed back is negative. The circuit is so arranged that it is in oscillation when the meter capacitor is the smaller, and any conditions which cause the meter-operated vane and the servo-operated vane to close up together put the circuit out of oscillation.

The capacitance relay controls the direction of rotation of the servo motor, which is suitably geared to the pen arm of the recorder, and to the servo-operated vane in the instrument. The whole arrangement thus provides a system which maintains the two capacitor plates at constant spacing and where any electrostatic attraction between two vanes has no effect on calibration accuracy.

To consider the equipment in operation: Let it be assumed that some increment in current has changed the position of the indicating movement. If its movement is downwards its vane leaves the servo-operated vane, conversely, if its movement is upwards it moves up to and rests against the servo-operated vane. In either event the motor starts to rotate in one direction or the other, moving the servo vane to the new position. The circuit is so adjusted that when the two plates are positioned one-hundredth of an inch from one another the voltage present at the servo vane pulls the meter vane towards it, but in doing so switches off the oscillator and the electrostatic attraction. The meter vane starts to return to its original position, but in doing so switches on the oscillator, and the cycle is repeated. The result is that the meter vane is maintained in oscillation at several cycles per second in a very small arc of about a thousandth of an inch at its periphery and the servo vane remains stationary. The meter vane takes up a mean position slightly towards the servo vane, but this disturbance is constant over the whole scale and, consequently, does not affect calibration accuracy. The fact that the meter movement is in oscillation overcomes any tendency to pivot sticking, and the accuracy is equal to that of a movement which is being very gently tapped throughout the readings.

An important feature of this new development is its stability. By arranging the capacitor plates in the vertical plane the circuit operates on a change of spacing of a capacitor with a very narrow gap, and the increment in capacitance is relatively large. This factor enables the equipment to be pre-set at the works, and external controls are unnecessary. It is interesting to note that any slight change in the performance of the capacitance relay due to valve ageing or renewal appears as a minute change in the operational distance of the capacitor gap, which, if readable at all, would be taken up by the natural re-adjustment of the set zero on the pen of the graph recorder. The accuracy of the completed device is well within B.S.I. meter standard; in fact, it is just as good as the basic meter movement used for its construction.

It will be obvious that this device is equally applicable to moving coil, moving iron, or dynamometer movements, and such developments are already in hand. It also opens up quite a new field of application in many branches of research and industry. Even on heavy current where, at present, moving coil recorders are used, this instrument offers considerable advantage, as it does away with light, flimsy pen movements with their attendant constant ink troubles. Further, all inaccuracies due to change in pen weight as the ink pot level changes are completely eliminated. Another feature is the fact that owing to the servo-operated mechanism there is no tendency for the pen to stick, and vertical transients are recorded with accuracy. The instrument also offers a new equipment to the marine and aeronautical world as it requires no levelling screws and will operate in any position under conditions of vibration.

The equipment is operationally very similar to quite a number of existing potentiometer recorders, but while it is only capable of reproducing meter accuracy, it does away with any need for maintaining a constant slide wire current, and will have the same long-term calibration stability as the indicating instrument.

Another valuable feature is the fact that the instrument will be available not only as a graph recorder, but as a graph recorder controller. The servo-operated mechanism provides ample power for the operation of cam switches which can be set to operate at any level, and, for special applications, instruments will be available with several switching levels for performing a sequence of operations at any series of specific circuit values. Due to the instrument's capability of responding to the most minute change in current, it is capable of giving a control switching action on a differential of 0.1 per cent of scale reading which, in the case of a 0-50 microamp. movement allows a control switching action on 0.05 microamp.

The equipment described in this article forms the subject matter of several British and foreign provisional patents.

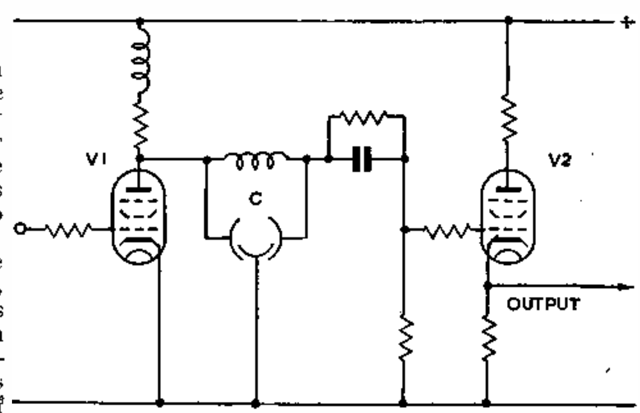
Wide-Band Amplifier Circuits

THE anode circuit peaking coil is a well-known device in television amplifiers and by its use the drop in response at higher frequencies, due to stray capacitance present at the anode of the amplifier valve, may be largely offset. For most purposes the increase in bandwidth so obtained is sufficient. This is usually true in receiver circuits and very often so in transmitting equipment.

The requirements, however, in transmitting, where so many amplifier stages may be employed in cascade, are, of course, particularly stringent and it sometimes happens that a circuit having better qualities than the single peaking coil circuit is called for. In these circumstances a device to which it is convenient to turn is the so-called "two-coil filter" circuit. A circuit of this type is shown in the diagram and it will be seen that not only is there a peaking coil in the anode circuit of the amplifier valve $V1$, but a further coil is included in the connexion between the anode of $V1$ and the grid of the subsequent valve $V2$. By the appropriate choice of inductance values and suitable adjustment of the circuit capacitances a bandwidth may be obtained which is practically double that given by the simple peaking coil circuit.

The two-coil circuit, however, suffers a certain disadvantage as compared with the single coil circuit in its increased complexity. This disadvantage is most apparent when the circuit has to be set up, and practical experience shows that setting up involves a long process of tedious and exacting measurement.

The main difficulty of the setting up procedure arises from the necessity of two capacitance adjustments, namely the adjustment of capacitance associated with the anode of $V1$ and that associated with the grid of $V2$. Accordingly it is convenient to use for these capacitance adjustments not two separate capacitors but a single capacitor of special differential type. This is shown in the diagram as the differential capacitor C.



Actually the capacitor is such that the rotor portion is not limited to rotation through 180° as in the normal differential capacitor, but is mounted on a screw-thread arrangement so that continuous rotation of the rotor provides a differential capacitor of greater or lesser total capacitance for instance, by altering the overlap of the plates. By this or other suitable expedient it is ensured that successive rotations of the 180° cause the capacitance variations between rotor and stator to occur through a progressively increased or decreased range. As the range adjustment and differential adjustment thereby fall under a single control, the trimming capacitances of the circuit may be correctly set by this one control. If the other constants of the circuit are carefully calculated and adjusted to their required values individually (to aid in this respect the inductances should be of the air-cored variety), the whole circuit may be set up by progressive adjustment of the one capacitance control until the desired frequency response is obtained.

—*Communication from E.M.I., Ltd.*

Microwave Lenses

By J. BROWN, M.A., and S. S. D. JONES, M.A.*

Part II

A KNOWLEDGE of the simple theory of ordinary dielectrics is essential for a full understanding of the way in which a delay dielectric functions and so this article will commence with a brief account of this theory. All bodies contain both positive and negative electric charges and the principal difference between conductors and insulators is that in the former at least one of the kinds of charge (electrons in a metal, ions in an electrolyte) is free to move, whereas in an insulator both charges are more or less fixed. Under the action of an electric field, however, the charges in an insulator, of which dielectrics are special cases, are slightly displaced, the material thus becoming "polarised." The amount of this polarisation or movement of charge is proportional to the strength of the electric field. This polarisation contributes to the electric displacement, a vector quantity D related to the electric field strength E by the equation

$$D = \epsilon E \quad \text{.......................} \quad (12)$$

where ϵ is the permittivity of the dielectric in farads per metre (M.K.S. units are used throughout). It may be shown that the displacement D is also given by

$$D = \epsilon_0 E + N\alpha E \quad \text{................} \quad (13)$$

where ϵ_0 is the permittivity of free space, α is the polarisability of each molecule, and N is the number of molecules per cubic metre in the dielectric. A comparison of Equations 12 and 13 shows that the dielectric constant K (i.e., ϵ/ϵ_0) is given by

$$K = 1 + N\alpha/\epsilon_0 \quad \text{................} \quad (14)$$

Since α is always positive, it follows that K always exceeds unity. A fuller account of the theory of dielectrics may be found in any of the standard text books.[9,10]

Winston E. Kock in his original paper on metallic delay dielectrics, suggested that the action of ordinary dielectrics might be reproduced at centimetric wavelengths by constructing a lattice of metallic elements, which would act in a similar way to the molecules of the dielectric. The simplest structure which suggests itself for this purpose is a cubic lattice of perfectly conducting spheres of radius a and centre to centre spacing s. It may be shown that the polarisability of a single sphere is

$$\alpha = 4\pi\epsilon_0 a^3 \quad \text{......................} \quad (15)$$

and so from Equation 14 the dielectric constant of the delay structure is

$$K = 1 + 4\pi a^3/s^3 \quad \text{..................} \quad (16)$$

since the number of spheres per cubic metre is $1/s^3$.

For such a structure the refractive index is not given by $\sqrt{K}$ as would be supposed from Equation 3. This is because the structure has a permeability different from unity, since there is a magnetic effect similar to the electric effect described above. The result of this distortion of the magnetic field is to make the refractive index

$$n = [(1+4\pi a^3/s^3)(1-2\pi a^3/s^3)]^{\frac{1}{2}} \quad \text{............} \quad (17)$$

It will be seen that n is therefore less than $\sqrt{K}$, an undesirable feature as the refractive index is thereby limited to values lower than those desired. Kock proposed that this limitation be removed by replacing the spheres by metallic disks of the same radius and lying in planes at right angles to the direction of propagation. Such disks would distort the electric field while leaving the magnetic field substantially unaltered. The dielectric constant of the disk structure will therefore exceed unity, but the permeability will be the same as for free space and so Equation 3 will once more apply. Disk structures have been constructed and have shown the expected increase in refractive index.

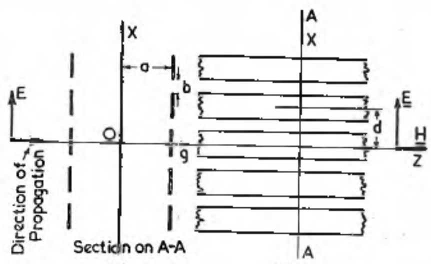


Fig. 7. Strip dielectric

There are many applications for lenses in which operation with only one plane of polarisation is required. For such cases, another delay structure may be employed; this consists of continuous metal strips at right angles to the electric vector and lying in planes at right angles to the direction of propagation as shown in Fig. 7. If the electric vector of an incident wave is parallel to the strips the structure will behave as an almost perfect reflector and might therefore be used as a polarisation filter, as all waves passing through it will have their electric vectors perpendicular to the strips.

Kock has derived formulæ for the refractive indices of both disk and strip dielectrics by making use of Equation 14. Such formulæ are, however, only correct if two conditions are satisfied:

(1) The dimensions and spacings of the metallic elements must be small compared with the free-space wavelength at which the structure is used.

(2) The elements must be sufficiently far apart for

* Radar Research and Development Establishment, Ministry of Supply.

the inter-action between adjacent elements to be negligible.

If condition 1 is satisfied, the refractive index of the dielectric is independent of wavelength: the dielectric thus has a very large band-width. Condition 2 is only satisfied for structures having comparatively small refractive indices; in the case of sphere and disk dielectrics Kock's formulæ are only accurate for values of n up to 1.5 and for strip dielectrics for even smaller values of n. As strip dielectrics are the most widely used, it is important to have an accurate formula for the refractive index. An alternative method of deriving the refractive index which takes into account the most important inter-actions is therefore outlined in the next section.

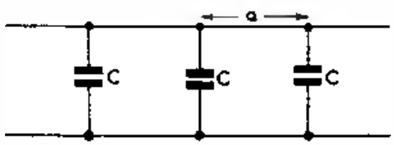


Fig. 8 (above). Transmission line analogy for strip dielectric

Fig. 9 (right). Refractive index of strip dielectric

Theory of Strip Dielectrics

The following theory[11,12] is based on the analogy originally pointed out by Booker[13] between the propagation of plane waves and the propagation of waves on a transmission line. In the particular case shown in Fig. 7 where the perfectly conducting strips are assumed to be of infinite extent in the y-direction this analogy may be very simply derived. A wave of angular frequency ω and free space wavelength λ_0 and having the electric vector perpendicular to the direction of the strips, is propagated in the direction of the z-axis. The electric vector has therefore only the one component E_x and so perfectly conducting sheets may be inserted in the planes $x = 0$ and $x = d$ without anywhere distorting the field. These sheets form the conductors of an infinite strip transmission line of spacing d and characteristic impedance $Z = Z_0 d$ per unit width in the y-direction, where Z_0 is the characteristic impedance of free space (377 ohms). Within the transmission line the strips form irises and Macfarlane[14] has shown that the capacitance of each iris is

$$C = (2/\pi) \log_e (\operatorname{cosec} \pi b/2d) \quad \ldots\ldots\ldots \quad (18)$$

The delay structure is therefore analogous to the loaded transmission line of Fig. 8 and from this analogy the refractive index may be calculated. The refractive index n is a function of the free space wavelength, but for wavelengths exceeding $10a$ it is virtually constant and given by

$$n^2 = 1 + (2d/\pi a) \log_e (\operatorname{cosec} \pi b/2d) \quad \ldots\ldots \quad (19)$$

The meanings of the dimensions a, b, d are clear from Fig. 7. The delay material is effectively opaque for frequencies above a certain value, this value being such that the wavelength within the material is $2a$. The way in which the refractive index of the strip dielectric varies with wavelength is shown in Fig. 9: the curve plotted in this figure is for a material designed to operate at 10 cms. and having the dimensions $a = 0.64$ cms., $b = 1$ mm., $d = 1$ cm. As the wavelength is decreased towards the cut-off value, the refractive index increases but remains finite even at the cut-off value.

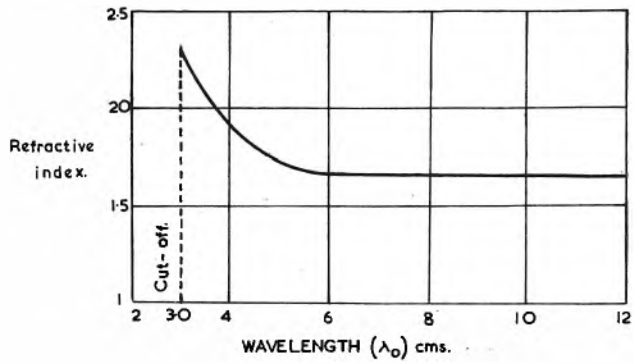
Equation 19 gives a wide choice of the constants a, b, d required to give any desired value of the refractive index. There are, however, certain considerations which limit this choice and the preferred design procedure is as follows:

(1) Select a to be one-tenth of the smallest wavelength at which the material is to be used.

(2) Choose a suitable gap width b as small as is practically convenient.

(3) Evaluate b/a.

(4) From Fig. 10 obtain the value of d/a necessary



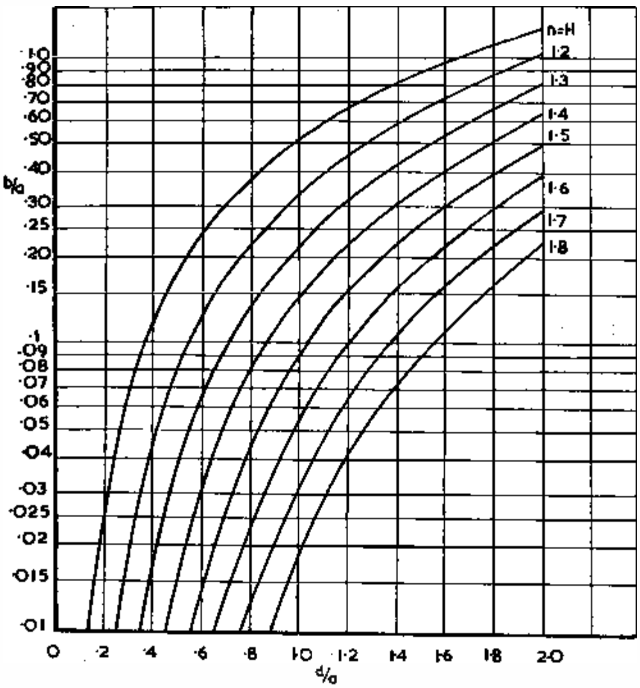
to give the required value of refractive index with the above value of b/a.

It is perfectly feasible to construct strip dielectrics having refractive indices of up to 15: such high values of refractive index are of little practical value for lens construction for reasons which will be seen later. It is unlikely that values exceeding 2 will be used at present.

It should be noted that the theory given in this section is only accurate when the direction of propagation is in the direction of the z-axis (Fig. 7). For lenses having a plane outer face and a curved inner face, as studied in the previous article, this theory is sufficient, as all the ray paths through the lens are in the required direction. If both lens surfaces are curved, however, the ray paths through the lens will not be parallel to the lens axis: if the angle between the ray path and the lens axis is small, Equation 19 may still be used for the refractive index, but as the angle increases the equation will cease to be valid. A full analysis has not yet been made, but it may be shown that in certain directions propagation is not possible, the wave then being exponentially attenuated. This implies that the corresponding incident wave will be totally reflected. In general, this variation of refractive index will only be of importance when lenses are being designed to produce radiation patterns, other than pencil beams, e.g., consecant-squared patterns.

Methods of Construction

Delay lenses are usually constructed from thin insulating sheets, upon which are mounted the conducting elements: these sheets are then spaced apart by light-weight insulators of thickness a and having a refractive index as nearly unity as possible. Kock



used for the spacing material in his original lenses an expanded dielectric, "Styrofoam," made by the Dow Chemical Co. (U.S.A.). Similar materials are not available in quantity in this country and so recourse has been had to either "Onazote," an expanded ebonite produced by the Expanded Rubber Co., or "Dufaylite," a paper honeycomb material made by Dufay-Chromex, Ltd. Although neither ebonite nor paper is a particularly good insulator at microwave frequencies, the cellular structure of both onazote and dufaylite makes their use in delay lenses a practical proposition. The transmission loss through these materials is, however, rather greater than for polystyrene foams (of which styrofoam is an example) as will be seen from Table 2.

There are several ways of obtaining the sheets of conducting strips: the simplest is to spray zinc directly on to sheets of paper through a harp-like wire mask whose dimensions are such that the correct values of b and d are obtained. A similar method

TABLE 2
TRANSMISSION LOSS FOR VARIOUS SPACING MATERIALS

Material	Loss in db. per ft.
Dufaylite	0.53-0.83
Onazote	0.45
Polystyrene Foam	0.07

TABLE 3
TRANSMISSION LOSS FOR COMPLETE ASSEMBLIES

Assembly	Loss in db. per ft.
Dufaylite interleaved with Metal-sprayed Paper	4.29
Onazote sprayed with Zinc	1.72
Onazote interleaved with "Printed Circuit" Strips	0.91

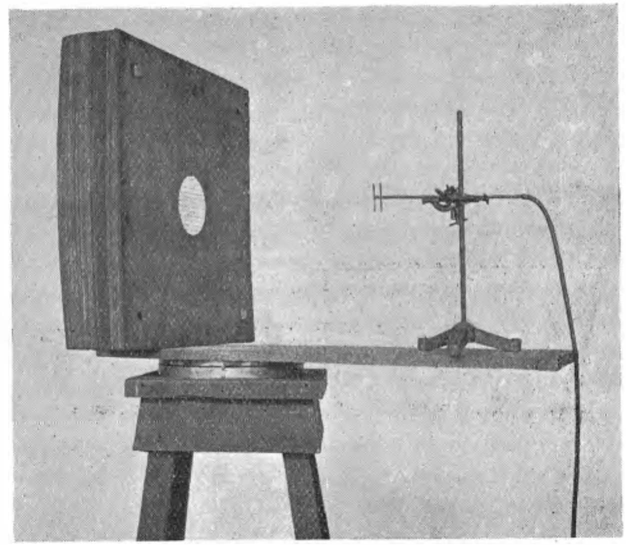


Fig. 10 (*left*). **Dependence of refractive index on strip dimensions**
Fig. 11 (*above*). **Experimental arrangement of delay lens**
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is to spray directly on to the onazote layers which are to serve as the spacers. The most efficient system, however, is to use a "printed circuit" technique to mount strips of aluminium or tin on thin paper or sheets of polythene. The transmission losses for these three assemblies are given in Table 3. It is unusual for a lens to be as much as a foot thick, so that the transmission loss through a complete lens assembly will be less than the figures given in Table 3: even so when the gain of the lens system is of primary importance as, for example, for lenses used as the aerial systems in repeater links, these losses are of such importance that only the combination of printed circuit sheets with onazote spacers is likely to be used. For many laboratory applications, however, the loss is not of any real importance and so any of the forms of construction may be used, the first two being often preferable on the grounds of simplicity.

Mechanical Tolerances

The generally accepted criterion for the mechanical accuracy of a microwave beam radiator is that the phase of the emerging wave be constant to within about 20°. In other words, the optical path length of each ray should be constant to within $\lambda_0/16$, where λ_0 is the free space wavelength.

If x is the thickness of a lens, then the phase retardation through the lens is

$$\phi = 2\pi x/\lambda = 2\pi n x/\lambda_0 \qquad (20)$$

where λ is the wavelength within the lens and equals λ_0/n. The phase retardation of a wave travelling the same distance x in free space is

$$\phi_0 = 2\pi x/\lambda_0 \qquad (21)$$

The differential effect of the lens is therefore

$$\theta = \phi - \phi_0 = 2\pi(n-1)x/\lambda_0 \qquad (22)$$

If there is a small error δx in the thickness of the lens, then the corresponding error in θ, obtained by differentiating Equation 22 is

$$\delta\theta = 2\pi(n-1)\delta x/\lambda_0 \qquad (23)$$

Since the maximum permissible value of $\delta\theta$ is $2\pi/16$, it follows that the tolerance on the lens thickness is

$$\delta x = \lambda_0/16(n-1) \qquad (24)$$

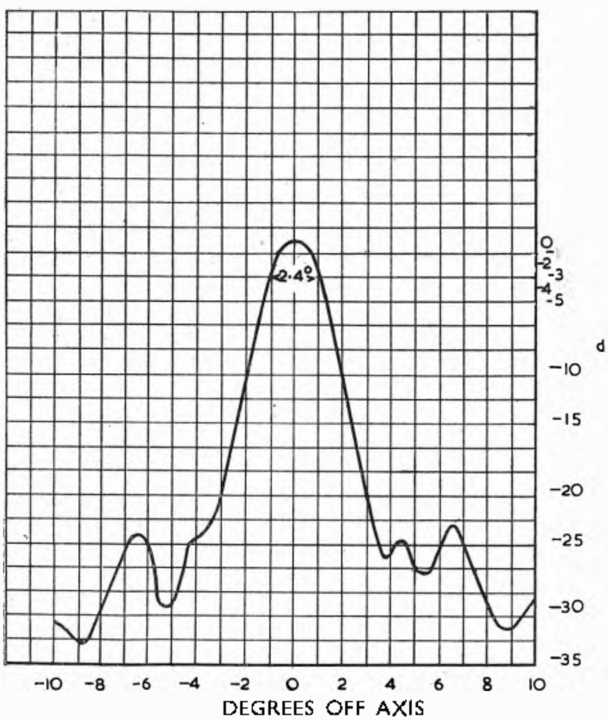
For a lens with a refractive index of 1.7 and operating at 10 cms. the tolerance on the thickness is therefore approximately 9 mm. which may be met without difficulty.

The tolerance on the refractive index, n, may be obtained by a similar method and is

$$\delta n = \lambda_0/16x \qquad (25)$$

The tolerance on refractive index imposes tolerances on the dimensions a, b, d, but it may be shown by a fuller analysis that provided the average values of these quantities are maintained, first order variations in individual spacings produce only second order errors in the refractive index.

It is therefore quite simple to construct delay lenses to the required degree of mechanical accuracy. With use, however, there is a tendency for the spacing layers to bow, thus causing quite considerable errors in the profile of the lens. The thickness of the lens is, however, not appreciably altered by such bowing, and by an analysis similar to the above it may be shown that profile errors of this type do not cause a sufficiently great phase error to affect the lens performance.



Experimental Results

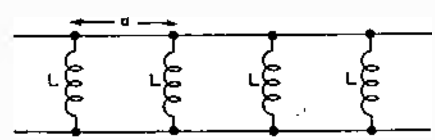
A simple experimental arrangement which may be used to examine the behaviour of a lens is shown in Fig. 11. The lens shown is made by the second method described above, i.e., by spraying zinc directly on the onazote layers which form the spacers. The strip spacings and dimensions are those mentioned in the section under the heading "Theory of Strip Dielectrics," and the lens profile is calculated from Equation 10. The lens primary feed is a half-wave dipole and reflector situated at the focus. By finding the position of best focus, it is possible to deduce a value for the refractive index of the lens material. For the lens shown in Fig. 11, the measured value of refractive index is 1.71 for a wavelength of 10 cms., agreeing well with the theoretical value 1.70, from Equation 19[5]. From Fig. 9 it is seen that the cut-off wavelength should be almost exactly 3.0 cms.; in fact, measurements at 3.0 cms. show the lens to be virtually opaque.

The radiation patterns from delay lenses are essentially as would be predicted from diffraction theory. The lens of Fig. 11, for example, has an aperture of 60 cms., and so for a wavelength of 10 cms. and a uniform amplitude distribution across the aperture the theoretical beam-width to the half-power points is 8°. The measured value of 8.5° is slightly higher than this, because the amplitude distribution falls off towards the edges.

Fig. 12 *(left)*. **Radiation pattern of delay lens**

Fig. 13 *(above)*. **Lattice structure for rodded dielectric**

Fig. 14 *(below)*. **Transmission line analogy for rodded dielectric**



The measured polar diagram of a horn with a correcting delay lens in its aperture is shown in Fig. 12: there is a single broad side-lobe (whose presence is not expected from diffraction theory) at a wide angle on each side of the main beam in the electric plane. These side-lobes are some 25 db. below the level of the main beam and so for most purposes are of no importance: they are, however, larger than the values permitted by the Ministry of Transport specification for civil marine radar. It is believed that these side-lobes are due to reflexion effects within the lens, but the exact mechanism which produces them is not fully understood.

In general, all the properties of delay lenses which are predicted by theory have been observed within the limits of experimental error. The formula for the refractive index, Equation 19, has, in particular, been verified for wavelengths between 3 and 10 cms., and for a wide range of values of the refractive index. This formula may be safely used for the design of delay dielectrics provided the procedure suggested at the end of section 2 on the theory of strip dielectrics is adhered to.

Rodded Lenses

The dielectric for rodded lenses is also a lattice structure, but the elements of the lattice are now perfectly conducting rods. The structure is shown in Fig. 13 and consists of rods lying in the direction of the x-axis, the direction of propagation being along the z-axis. It will only function as a dielectric if the electric vector is parallel to the rods and may be analysed in a similar way to the strip dielectric considered earlier. The transmission line analogy is found to be the inductively loaded line of Fig. 14, where the value of each inductance, L, may be obtained from Macfarlane's results on wire grids.[16] It is apparent from the results of filter theory that

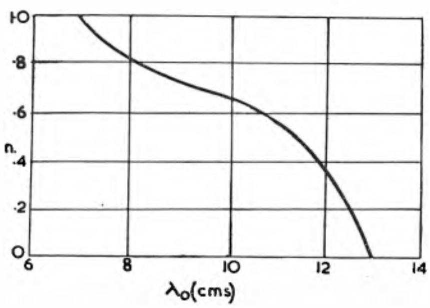


Fig. 15. Refractive index of rodded dielectric

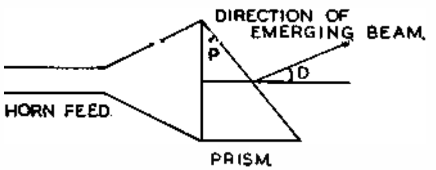


Fig. 16. Experimental arrangement for measurement of refractive index

whereas the loaded line of Fig. 9 is a low-pass circuit, that of Fig. 14, is a band-pass circuit and does not therefore have a range of wavelengths for which the refractive index is constant, i.e., a rodded dielectric is dispersive. The refractive index (n) may be calculated from the equation

$$\cos 2\pi an/\lambda_o = \cos 2\pi a/\lambda_o + \frac{\lambda_o \sin 2\pi a/\lambda_o}{2d \log_e d/2\pi r} \quad \ldots\ldots (26)$$

where a, d are the lattice spacings shown in Fig. 13, and r is the radius of the rods. Equation 26 is obtained by a straightforward analysis of the loaded transmission line.

Unlike delay dielectrics, rodded dielectrics have refractive indices which are always less than unity. There is a wide choice of the parameters, a, d, r which will combine to give any required refractive index at a given wavelength. The radius of the rods should be small compared with the wavelength and the spacings, and a suitable value for wavelengths in the region of 10 cms. is 1/16th inch. A convenient value of refractive index is 0.6 and this value is obtained at a wavelength of 10.7 cms. when a = 3.55 cms. and d = 3.90 cms. The variation of refractive index with wavelength for a rodded dielectric having these values of a, d, r is shown in Fig. 15.

Rodded lenses[17,18] have only recently been suggested and little experimental evidence on their behaviour is yet available. Some preliminary experiments carried out with a prism constructed with the dimensions above, mainly with a view to checking the accuracy of the calculations of refractive index are of interest, however. A prism of this type was placed at the mouth of a horn as shown diagrammatically in Fig. 16. The deviation D undergone by a beam in passing through the prism was measured by noting the position of the maximum of the radiation pattern of the outer face of the prism. The refractive index was then calculated from the equation

$$n = \frac{\sin D}{\sin P} \quad \ldots\ldots\ldots\ldots (27)$$

where P is the angle of the prism. The results for the range of wavelengths 10.0 to 11.5 cms. are shown in Fig. 17, together with the theoretical curve. The agreement is sufficiently good for all practical purposes.

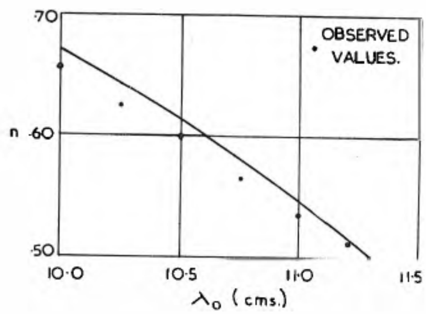


Fig. 17. Experimental results of refractive index

The principal reason for the introduction of rodded dielectrics was to avoid the use of a spacing dielectric, the rods being sufficiently thick to require no support. The principal source of loss of delay dielectrics is thus avoided. A disadvantage of the rodded dielectric is the dependence of the refractive index on wavelength: as will be seen in the next article, this is also the case for metal plate lenses and a fuller discussion will be given then.

(To be continued)

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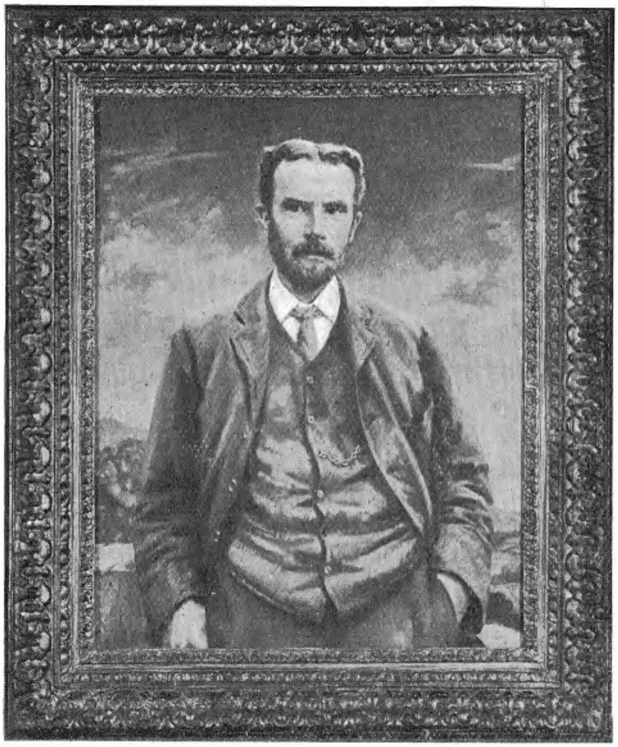

Birth Centenary of Oliver Heaviside — May 18, 1950

This short tribute to the work of Oliver Heaviside was compiled from notes supplied by Professor J. T. MacGregor-Morris, D.Sc.(Eng.)London, M.I.E.E., who, through illness, was unable to write a full appreciation.

The picture was reproduced by kind permission of the Institution of Electrical Engineers, from a portrait in their possession.

OLIVER HEAVISIDE, born May 18, 1850, at 55, King Street, Camden Town, London, was the youngest of four sons of Thomas Heaviside, a wood engraver. Heaviside only had an elementary school education, but had a natural aptitude for learning. He taught himself to play the piano, and later an "Æolian", and by self-training "acquired a remarkable skill in the application of mathematics to electro-dynamics."[1]

He left school in 1870 and then held a post as a telegraph operator in the service of the Great Northern Telegraph Co., Newcastle-on-Tyne, until 1874. There is evidence, in a letter in the collection at the Institution of Electrical Engineers, that he visited Denmark about this time, and a statement made by Heaviside, that he observed phenomena relating to signalling through heterogeneous telegraph circuits at Frederica, substantiates this evidence.[2]

Between the years 1876 and 1889 he pursued his studies in a room in his father's house in Camden Town. He conducted numerous experiments in telegraphy with one of his brothers, who was a divisional engineer of the British Post Office at Newcastle. In 1882 he was experimenting with microphones and carbon blocks, and in 1886 with the Wheatstone Bridge, as well as other measuring apparatus.

In 1847 his mother's sister, Emma West, had married Sir Charles Wheatstone, although so far as is known Wheatstone took no direct interest in shaping Heaviside's career. On the other hand, Charles Heaviside, an elder brother, was employed in Wheatstone's musical instrument shop at 128, Pall Mall, until he moved to Torquay to set up business there. In 1889 Charles Heaviside invited his parents and Oliver to make their home there.

Heaviside's work embraced many aspects of physics; he mainly devoted his mathematical genius to telephone transmission theory, but he was also interested in the problems of the age of the earth, thermo-electricity and electron motion.

It has previously been stated that Heaviside had an aptitude for learning, and evidence of this is provided by an article of his which appeared in the February 1873 issue of *The Philosophical Magazine* on the best arrangement of the Wheatstone Bridge for measuring resistance with a galvanometer and battery. Thus Heaviside must have mastered the Differential Calculus between leaving school and his twenty-third year.

He had achieved a great mastery of mathematics during this time, developing new methods, of which his operational calculus is the best known. He also simplified and gave fresh impetus to the work on vector analysis originated by Gibbs. His contribution to the mathematics of the calculus was the use of "an algebraic quantity (p) with the condition that p^2 signifies differentiating twice, p^3 differentiating three times and $1/p$ the operation of integration."

In the latter part of the nineteenth century, telegraphy was not very far advanced, and telephony could be regarded as a recent development. Heaviside made valuable contributions to the early literature of telecommunication in both volumes of his *Electrical Papers*. His work embraced articles on the Wheatstone Bridge and similar measuring apparatus, telegraph signalling, the expansion of Thomson's theory to include the effect of self-inductance in the wires, and some general electrical theory based on Maxwell's work.

When, in 1887, Hertz's work on the discovery of electric waves was published, Heaviside began to write numerous papers on electric wave propagation in the ether and along wires, dealing with the effects observed, including reflexion of the radio waves from any conducting obstacles (the principle of radar), and he devoted considerable attention to the reflexion caused by impedance irregularities or incorrect terminations.

Heaviside propounded his theory of a conductive layer in the upper atmosphere in *Electromagnetic Theory*, Volume III, shortly after Kenelly in America made a similar suggestion. Following Appleton's proof of the existence of this layer it was named the Kenelly-Heaviside Layer.

Heaviside's main contribution to telephony was his discovery of the benefits of loading by added inductance. He showed that when the four constants of the line—resistance, inductance, capacitance and leakance—were arranged so that $RC = LG$, all frequencies were equally attenuated and propagated at the same velocity.

In 1891 the Royal Society elected Heaviside as a Fellow, as a recognition of his genius, although they failed to appreciate or understand his work. A paper which he sent to the Society was declined by Lord Rayleigh. He wrote: "Both our referees, while reporting favourably upon what they could understand, complain of the exceeding stiffness of your paper."

Heaviside's mother died in 1894 and his father two years later. Heaviside then moved to Newton Abbot, where he lived alone until 1909. In 1905 Heaviside was awarded the degree of Doctor of the University of Göttingen. In 1908 he was elected as an honorary member of the Institution of Electrical Engineers, and in 1918 he was persuaded by Dr. Behrend to accept honorary membership of the American Institution of Electrical Engineers. When he was 50 years of age he accepted a Civil List pension of £120 a year from the Government.

Latterly Heaviside was in poor health, and a Miss Way, a sister-in-law of his brother Charles, offered him accommodation in her house "Homefield", in Torquay.[1] Later Heaviside purchased this house. He died in a nursing home in Torquay on February 2, 1925.

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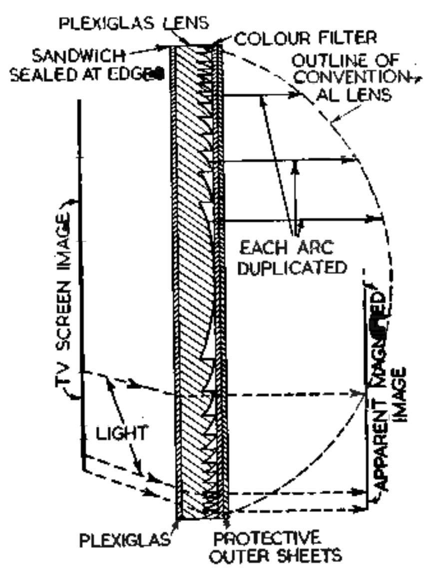
A New Flat Plastic Lens

A NEW thin, flat plastic lens for enlarging the television image on home receivers is the latest accessory for television fans. It operates on the Fresnel principle of magnification and is known as the Magna-Screen. Weighing but a few pounds, it is easily attached to any type of receiver by means of brackets supplied with the lens. It is adjustable and can be quickly changed to give any desired degree of magnification within its scope. The Magna-Screen is free from edge distortion and provides glareless viewing at a reasonably wide angle.

The lens operates on a principle similar to the Fresnel lens used in lighthouses. Its magnifying power is based on the fact that carefully designed optical prisms or ridges are impressed in the plastic from a master die, each prismatic line corresponding to a segment of the curved surface of a thick glass lens of the usual type.

How the rays of light are refracted through the successive ridges or prisms in the lens is shown in the diagram. As the circular ridges or prisms approach the outer edge of the lens their angle becomes steeper, whereas towards the centre of the lens the prismatic ridges flatten out until they are nearly flat. In this manner the lens is able to pick up rays of light from all angles and redirect them beyond the lens to form an enlarged (virtual or apparent) image, which is viewed by the observer.



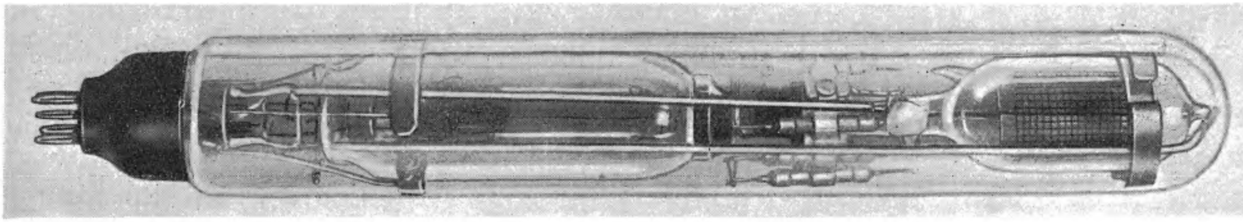
The magnifying element of the screen is formed from a sheet of thin plastic, into which hundreds of the prismatic grooves are pressed. In the assembly there is a green filter which eliminates glare, together with protective outer sheets of plastic (Plexiglas), the whole unit being sealed at the edges. When used with a 10-in. television tube, the image can be enlarged up to the size normally received on a 16-in. diameter tube.

Plastic lenses of this type are made by cutting ridges into a brass or other suitable metal mould, which is heated and pressed into the plastic sheet. The grooves are very fine in some parts of the lens, running as high as 200 or more to the inch. The circular rings or grooves can be seen when looking at the screen; but when placed in front of a television picture tube the lines are not visible because of the smoothing out or resolving effect of the overlapping rays of light.

The Magna-Screen is mounted in a neat wooden frame and comes in three sizes: 8 in. by 10 in. for sets with 7-in. tubes, 9 in. by 12 in. for 7-in. and 10-in. tubes, and 11 in. by 16½ in. for sets with 10-in. and 12-in. tubes. The brackets supplied with the lens permit using it on any table set, and it is available mounted on a floor stand for use with console television receivers.

The Magna-Screen is made by the Willson Camera Co.

—*Radio Electronics*, Jan., 1950.



Electronic Measuring Instruments

A Survey of the Field

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

THE application of electronics to measurement and testing has both widened and deepened the range of useful measurement. Widened by the application of new devices in the electronic field where there is no corresponding existing electro-mechanical device, and deepened by the smallness of the currents required by electronic devices compared with electro-magnetic or electro-mechanical devices.

The total range is very great and in this article will be found a survey of the general effects and the devices using these effects, and a short account of some of their applications to measurements.

Electronic instruments may be grouped into two general types; those using electronic devices auxiliary to measuring instruments, such as amplifying valves and rectifiers, and those using electronic devices directly as instruments, such as the C.R.T. and the stroboscope.

The chart attempts a general form of classification of electronic devices used in measurement, where measurement is meant as quantitative, excluding qualitative or on-off indicators such as some counting devices, burglar alarms, checking articles on conveyor belts and other industrial applications.

Electronic emission devices originated, of course, with the Fleming valve, then the de Forest triode and later multi-electrode valves. These are all thermionic, but later extended to two cold-cathode classes: photo-electric, and impact in a rare gas discharge. All these sub-divisions of electronic emission valves have many applications in measurement, some in combination.

Secondary emission is a phenomenon which is useless and harmful in some cases and most useful in others. The original magnetic-controlled secondary emission tube is now largely replaced by the electrostatically-controlled tube with about ten stages and a stage gain of the order of 5 or 6, or alternatively an output of 5 A per lumen incident light. Secondary-emission tubes then are essentially different in principle from those shown under (1) in the table, but their applications overlap, with, of course, the much higher amplification leading to increased sensitivity and range.

Electron transfer is listed as (3) and generally involves conduction, either unilaterally as in all contact rectifiers, or a gaseous condition produced by incident ionisation, shown as (4).

Another device within the scope of this article is the "electret," discovered some years ago but not yet fully explored. Briefly it comprises a dielectric electrically strained, so that a permanent E.M.F. is produced, somewhat analogous to the permanent magnet. Possible uses include sources of low voltage and no current, but again the possibilities are wide.

It is admitted that the chart reproduced is neither complete nor in a form to satisfy all readers. Many forms are possible with an entirely different layout, as several instruments are on the borderline of inclusion and others could be added.

Considered briefly, but in more detail than above, the various electronic effects can be discussed in relation to one another and to the classes of measuring instruments developed for practical use.

There is, of course, intermingling between the groups; the measurement of distance by radio waves; radar, involving quite a lot of electronic devices in measurement, as well as others, such as gas-discharge switches, in the accessory equipment, but not in themselves strictly measuring instruments. Similarly with the measurement of ionizing radiations, not only is the ionization chamber and Geiger counter used but there may be associated thermionic or ionic valves as amplifiers, and P.E. cells as light integrators with fluorescent screens. Unilateral conduction is found in the rectifier instruments used as indicators.

Electronic analysers, of which many types are now appearing, also form comprehensive stores of electronic measuring devices of many kinds. Electronic counters and timers are similarly composed of various types of unit equipment.

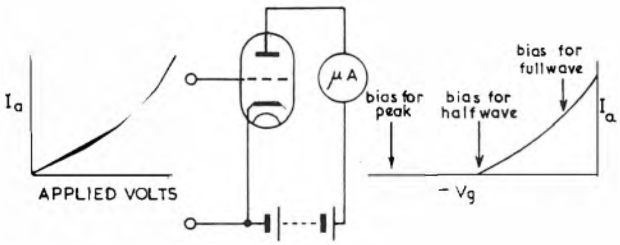
Applications

Electrical measurements, and a number of non-electrical measurements made by electrical means, are usually made with indicating instruments. The types are well known, with the moving-coil type of widest application and the electrostatic type of limited but very useful application to circuits where no power is to be taken by the measurement. Improvements in magnetic materials have progressively lowered the minimum current for full-scale

EFFECT	ELECTRONIC DEVICE or apparatus	APPLICATION	MEASURING INSTRUMENT using the effect
1. ELECTRONIC EMISSION from solid surfaces through the action of:—			
1.1 : **Heat** (thermionic)	Valve diode	Rectifier	Diode valve voltmeter Peak voltmeter, electrostatic
	Valve triode (and multi-electrode)	Amplifier Amplifier generally Waveform, etc. Magnifier	Valve voltmeter Amplifier incorporated in instrument Cathode-ray oscillograph Electron-microscope
	Klystron (and reflex)	Generator of U.H.F. C.W.	Radar receiver, range, etc.
	Magnetron, cavity	Generator of U.H.F. pulses	Radar transmitter, range, etc.
	Gas-filled relay	Relay for amplifier, etc. Frequency measurement	Relay, counter, etc. Frequency meter
	X-ray tube	Measurement of thickness	X-ray thickness gauge
1. 2: **Light** (photo-electric)			
1.21 Photo-emissive 1.22 Photo-voltaic 1.23 Photo-conductive	Vacuum cell Gas-filled cell Rectifier cell (metal) (barrier layer) Selenium cell	Illumination generally, directly and indirectly	Photometers, including comparators, densitometers, reflectometers, colorimeters
		Measurement of X-ray intensity by fluorescent screen	X-ray intensity meter
1. 3: **Impact** (gas-discharge)			
1.31 Solid cathode	Cold cathode diode	Voltage stabilization High-speed light-flash	Voltage reference source High-speed camera
	Cold cathode triode	Definite potential trigger High-speed light-flash	Counter or gauge Repetition stroboscope, high-power
	Cold cathode tetrode	Trigger tube	Ultrasonic depth sounder
	Cold cathode multi-electrode	High-speed light-flash	Low-power stroboscope
1.32 Liquid cathode (Mercury)	Cold cathode triode	Voltage stabilization High-speed light-flash	Instrument power supply Repetition stroboscope, mercury cube
2. SECONDARY EMISSION	Multiplier tube	Amplifier for electron emission current	Photometers, generally as 1.2
3. ELECTRON TRANSFER	Metal rectifier (barrier layer)	Rectifier	Rectifier instrument
Unilateral conductivity	Crystal diode Crystal triode (' transistor ')	Rectifier Amplifier	U.H.F. rectifier instrument Amplifier for instrument
4. CONDUCTION BY IONIZATION (Ion pair production)	Ionization chamber Geiger counter	Measurement of X-rays and other ionizing radiations	α, β, γ and X-ray dose, dose-rate and intensity meters and detectors
5. ELECTRONIC DISPLACEMENT			
Electrically strained semi-conductor	Electret	Provision of D.C. E.M.F.	

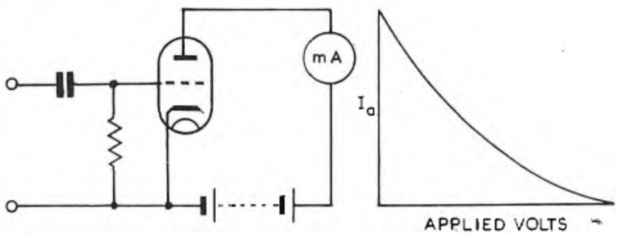
deflexion and now miniature pivoted instruments of 5 μA range are marketed. As voltmeters this corresponds to 200 kΩ per volt, a remarkably high figure, but still much too low for some applications. Here the thermionic valve finds application in two ways; first as a rectifier and second as an amplifier. As a diode rectifier it now has less commercial application due to developments in metal rectifiers, but as an amplifier it is invaluable and by its aid valve voltmeters of megohms instead of ohms resistance are available. The application is not simple; due to the fact that valve characteristics are non-linear the measured current may be proportional to mean, R.M.S. or peak value, and the value may vary from range to range, and even over the scale.

Many such voltmeters are scaled "volts," with no reference to whether peak, R.M.S. or mean. Others are marked "R.M.S." but are dependent on waveform as they actually read peak volts, being calibrated R.M.S. assuming sinusoidal waveform. For correct use it is necessary to know what is actually being measured, and if it is independent of waveform.



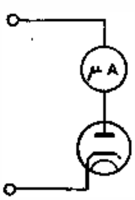
Valve voltmeter (anode type)

Valve voltmeter (grid leak type)

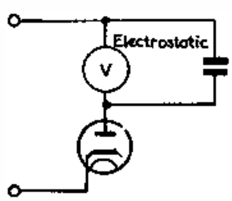


Valve voltmeters are commonly suitable up to a few Mc/s. For higher frequencies it is necessary to mount the valve in a probe or other terminal unit where it can be connected to the H.F. circuit with the minimum of circuit alteration to minimise changes in conditions due to instrument capacitance and inductance.

The electrostatic peak voltmeter should be considered here. Although the indicating instrument is electrostatic and not moving-coil, the rectifier used is thermionic—but may possibly be replaced by a non-thermionic rectifier. The valve is solely a rectifier and its purpose is to charge a capacitor to the peak voltage of the circuit, with either polarity as connected. The capacitor has an electrostatic voltmeter in parallel with it so that the peak voltage is read directly and free from any waveform error. By reversing the polarity of the rectifier either half of an A.C. wave may be measured. It is also possible to extend the instrument to read the ripple on a smoothed unidirectional supply by the use of two rectifiers in a suitable circuit.



Diode peak voltmeter



Electrostatic peak voltmeter

An extension of the simple valve amplifier is in the amplifier embodying one or more valves coupled so that part of the output is fed back to the input in reverse, thus considerably improving stability at the expense of some gain. This is negative feedback and is of wide application both to measurements and electrical processes generally.

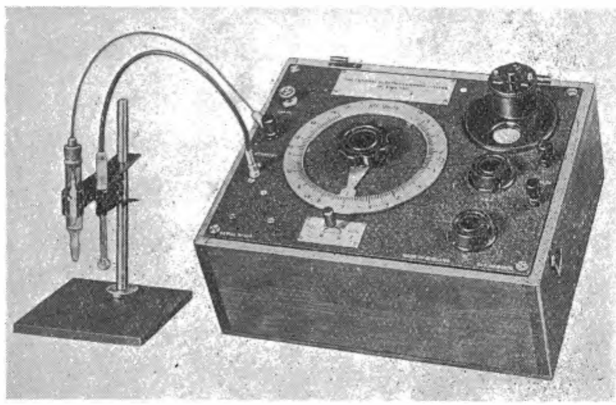
Although the amplifier itself is not a measuring instrument, its application to many types of measuring instrument is so wide that it may properly be considered here. While a simple amplifier embodies a triode, it is commoner to use a pentode or a combination of valves in cascade for any practicable degree of amplification required, the practical limit being due only to circuit and valve imperfections.

Measurements of very small displacements are accomplished by employing two electrodes between which the displacement is to be measured and electronically measuring the very small change of capacitance by any suitable means.

Other methods include change of inductance by varying a coil airgap, and change of resistance by compression or tension, as in the strain gauge. For cyclic variations a transducer may be used in which an E.M.F. is generated and subsequently measured. The piezo-electric pick-up is an example.

Another adaptation of the basic thermionic valve is to the measurement of acceleration. One electrode is rigidly mounted, as usual, and another flexibly mounted so that it will swing or vibrate when the valve is subjected to sudden motion. Thus a change of capacitance, or of the control effect of a grid, causes changes in current in the circuit which may be made proportional to sudden movement or acceleration.

Commercial measurement of acidity and alkalinity, or *p*H measurement, is now carried out on a large scale by a measurement of E.M.F., using a half-cell, with some form of electronic amplifier as an indicator, either reading by deflexion or as a null method for precision use.



Potentiometer-type *p*H meter
(Courtesy G.E.C., Ltd.)

Among the electronic measuring instruments of the "direct" type, the cathode-ray tube used in the cathode-ray oscilloscope is supreme and of nearly universal use. Its main advantages over the earlier electro-magnetic type are two; much higher frequency response and very high impedance requiring practically no power from the circuit on test. In the table the application shown is to the measurement of waveform, but this is only one of a wide range of measurements. Due to its universal scope it is well known and no attempt is made here to mention any of its other multitudinous functions.

Also developed from the cathode-ray tube is the electron microscope, again using an electronic beam directly on a fluorescent screen. While the optical microscope has a magnifying limit of 1,000-2,000 times the electron microscope is now available with magnifications up to about 150,000 times. This also is a complete subject covered by various books and other publications.

The usual construction of thermionic valve is suitable for high frequencies up to Mc/s., but for ultra-high frequencies of the order of kMc/s. a different construction is necessary due to the time of travel of the electrons. Two forms are now available, one the klystron and the other the reflex klystron for generating ultra-high frequency continuous waves, mainly of low power for use as a local oscillator in a U.H.F. receiver.

The other type is the cavity magnetron developed during the war and supreme as a U.H.F. pulse generator of high peak power.

The application of these two electronic and thermionic devices to measurement is seen in the practice of radar, or radio-location, whereby measurement of distance or range is made. This is a direct form of measurement, while that of bearing and elevation may be considered an indirect measurement by null methods, such as the adjustment of the aerials to the position of equal signals.

Following the thermionic vacuum valve is the thermionic gas-filled valve, the main difference in effect being that the gas-filled valve has a grid control for starting or increasing anode current, but once started or triggered the grid is unable to control the current; it may therefore be considered a non-reversible action, an anode voltage change being necessary to change anode current again.

In general, greater currents can be handled by these valves and the device is often termed a gas-filled relay as it may operate direct in a control circuit instead of via an electro-magnetic relay as is usually necessary for a single stage of vacuum-valve amplification. But the scope is wider than just that of extra current rating and is chiefly concerned with the grid-start, anode-stop characteristic. Applications are to counters, etc., with a fairly wide scope of measurements generally, in conjunction with other devices.

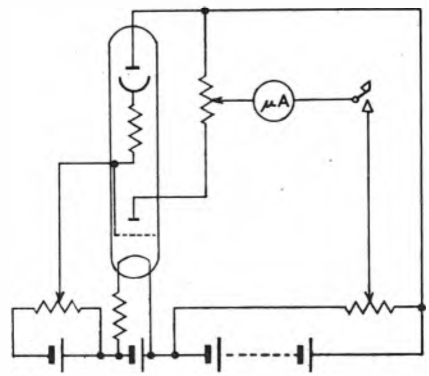
A further measuring device in this class is the X-ray thickness gauge, where in a given material absorption is proportional to thickness. Such measurements may also be made with γ rays produced by radium and its compounds, and by artificially radio-activated substances. While the applications are similar, the two sources do not fit into the table in this place.

The photo-electric effect has long been known, but only in recent years has it been so widely adopted in commercial measurements apart from laboratory use. Vacuum and gas-filled photo-emissive cells have characteristics rendering one type better for any particular purpose; generally it may be stated that vacuum cells are more accurate quantitatively, but gas-filled cells have a larger output.

Spectral sensitivity may be mainly in the ultra-violet, visible light or infra-red radiation, depending on the metal used in the cell and the material of the envelope.

Before dealing in more detail with these cells the other types should also be considered, as their uses overlap. These include the metal rectifier cell, also known as the barrier-layer type, which exhibits the photo-voltaic effect, so-called because the output is self-generated and unlike that of the other two types which require a source of D.C. E.M.F. applied.

Considering photo-cells in more detail, the early work was mainly due to Elster and Geitel, who made vacuum photo-emissive cells, particularly with sodium and potassium cathodes, but the type includes cathodes of pure metals, alkalis and alkali-hydride, as well as combinations of these. One photometric unit comprises a photo-cell and an electrometer-triode in one envelope. An illustration of this tube appears at the heading of this article. (Photo. by courtesy of G.E.C. Ltd.). Thus a degree of amplification is obtained with a minimum of apparatus. Photo-voltaic cells were first used commercially with copper-oxide cells, shortly after the application of the copper-oxide rectifier to instruments.



Osram photo-cell unit, comprising P.E. cell, electrometer-triode, and grid resistor, in one envelope, shown in elementary circuit for battery operation

Similarly the selenium rectifier was followed by the selenium photo-cell and both types are in active use, each with its own advantages and disadvantages, including slightly different spectral response. The output is such that many pocket photometers are on the market consisting merely of a metal photo-cell and a microammeter in a small case.

All these instruments have application in photometric measurements, using the term in its widest sense, and including picture transmission and sound recording on film.

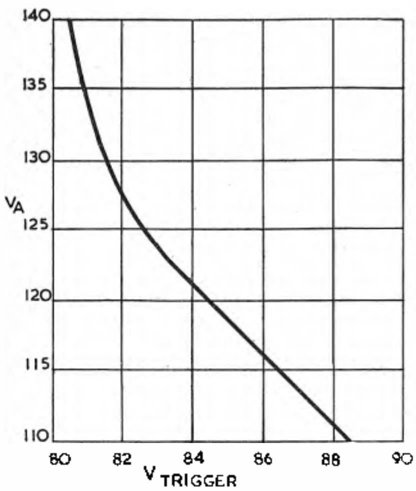
Finally, although not latest in time, is the photo-conductive type, in which a selenium cell acts as a resistance which is varied by the application of light, the greater the light incident on the cell the lower the resistance. This action is quite different from that of the photo-voltaic selenium cell.

The selenium photo-conductive cell requires a D.C. supply and its applications were originally to such photometric uses as picture facsimile and telegraphy and the recording of sound as light on film. It was in the early days used in television trials, but it is now completely ousted from that field.

In addition to the above devices using electronic emission for photometric purposes, the multiplier tube, under (2), should be considered here.

Following the thermionic valves, a new series of valves has appeared, mainly differing in the fact that a cold cathode instead of a hot cathode is used. Early valves of this class had solid cathodes, but a more recent development employs a liquid cathode. Where such a valve can replace a thermionic valve in the required characteristics it obviously has the great advantage of requiring *no* heating current and being instantly ready for use.

Electrodes vary from two upwards and the uses in measurement may be seen from the table. For many measurements a constant voltage is a necessity for some devices and the cold-cathode diode has a useful field here. In the Mullard 85A1 voltage reference tube the short-term stability is within 0.1 per cent, and double this over long periods. It may in some instances replace a standard cell as a source of constant voltage for measurement. The multi-electrode tube has a somewhat similar application as it may be used to provide stabilization of the voltage used in a measuring instrument against supply mains fluctuations. These tubes are largely neon-filled. Other fillings, such as mercury, are used for other measurement purposes, such as the liquid-cathode mercury tube used for speed measurement stroboscopically. Other applications to counters are obvious.

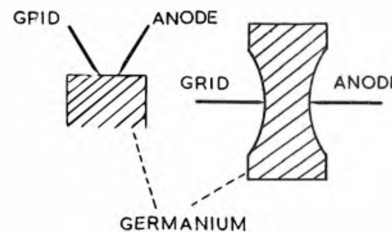


Typical cold-cathode triode characteristic

The phenomenon of secondary emission is associated with many electronic tubes, particularly in photometry, where it has already been mentioned.

The next group of electronic effects (3), electronic transfer, is perhaps not altogether distinguishable from vacuum and gaseous devices, where electronic transfer takes place also. It is here considered as transfer between solid surfaces, in the case of rectifiers. Copper oxide and selenium rectifiers have long been used for measurement; self-contained rectifier instruments were developed by the author in 1928. They have the advantage over other A.C. types of requiring less power from the circuit, but on the other hand the rectifier having a non-linear characteristic, may affect the circuit conditions if of low power, and as the instrument reads the mean rectified value, but is almost always calibrated in R.M.S. units, it necessarily has a waveform error. The crystal diode is used in some ultra-high frequency measurements as a separate adjunct to a moving-coil instrument and a very high frequency range made possible.

An electronic device of the greatest importance has been developed in more recent years. In the early days of radio the crystal rectifier was widely used. It was, of course, ousted by the more stable valve diode which, with the addition of a third electrode, the grid, produced the present multi-electrode, multi-purpose series of valves as amplifiers and oscillators. The new development is the addition of a third electrode to an improved type of crystal detector, using germanium as the crystal, which has also produced an amplifier having enormous possibilities, some similar to those for the cold-cathode valve. The "transistor" is necessarily very small, which is of great help in miniaturizing apparatus for modern requirements. This also leads to low capacitance and ultra-high frequency response.



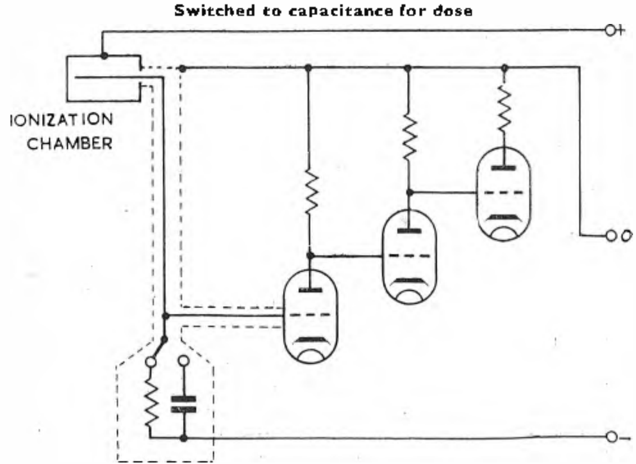
"Transistor" crystal triode

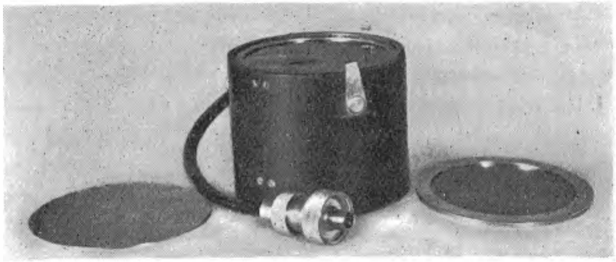
There is thus some replacing of thermionic devices both by cold-cathode tubes and by the "transistor," both of these having considerably longer life and absence of need for filament current.

Conduction by ionization, or ion pair production, is not a new phenomenon, and is now fairly widely used in the measurement of all ionizing radiations, including α, β, γ and X-ray measurements. Two general types of ionization chamber are common, one which is self-contained and the other which is continuously charged by connexion to the circuit. In each case the incidence of radiation increases the conductivity of the residual gas between the electrodes, this being measured by some suitable means such as an electrometer-triode and D.C. amplifier.

Two types of instrument are possible with the above basic foundation. In one a resistor is used in the grid circuit, and a dose-rate meter results, the pointer deflexion varying with intensity of radiation. In the other type a grid capacitor is used and the charge is thereby integrated and the instru-

D.C. amplifier with negative feedback, as used with ionization meter
Switched to resistance for dose-rate
Switched to capacitance for dose





Universal ionization chamber for α β, γ and X-rays, approx. 500 c.c.
(Courtesy Baldwin Instrument Co.)

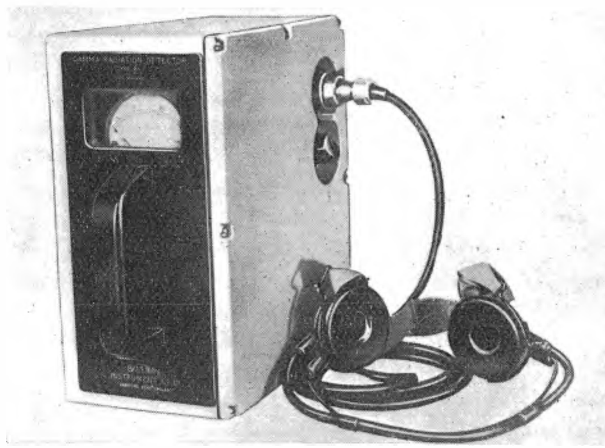
ment reading continuously increases and reads proportional to X-ray dose.

Ionization chambers have different characteristics, depending on the applied voltage. At low voltages, below about 200, no amplification takes place and the true ionization chamber results. External amplification is then necessary. At higher voltages, up to about 800, the curve of voltage and amplification increases, and proportional counters result. Over a much higher voltage range, about 1,100 to 1,300 very high amplification results and the Geiger counter, with amplification exceeding 10^8 and generally with a relay and a counter, provides audible and/or visual indication. Many of these instruments are being produced for prospecting for radium ores, and they are also of use for finding lost radium containers in hospitals, etc. A still later development is for civil defence purposes.

The phenomenon of electronic displacement, as exemplified in the "electret," is the least known of any, and although it is known that such units are electrically-strained dipoles showing a permanent polarity and a D.C. E.M.F., little practical use has yet been made, in the author's knowledge. It is possible that a most useful source of D.C. of no power output may result, with application to instruments of various sorts.

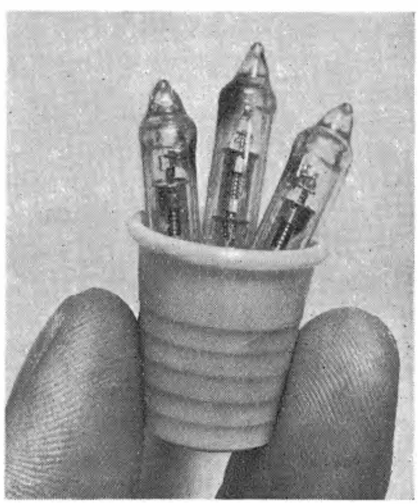
Acknowledgment is made to R. C. Walker, B.Sc., A.M.I.E.E., A.M.I.Mech.E. (G.E.C., Ltd.), L. Atkinson (Ferranti, Ltd.), and G. Syke, Dipl. Ing., A.M.I.E.E. (Baldwin Instrument Co., Ltd.), for advice on various points in their special fields.

Gamma radiation detector
(Courtesy Baldwin Instrument Co.)



Flat Sub-Miniature Valves

SINCE 1947, when Mullard Electronic Products, Ltd., received an order for 400,000 sub-miniature valves for the National Health Hearing Aid, Medresco, development work has been directed mainly towards reduction in size and power consumption. The accompanying photograph and figures show that the effort has been rewarded.



The new flat sub-miniature valves are the smallest of their class in the world, and it is expected that they will compete on very favourable terms with American types in the world market.

Having filament currents of only 15 milliamperes as against 25 milliamperes for the Mullard 10-mm. types, these new valves make possible the development of complete Monopack Hearing Aids weighing less than 5 oz.; providing a useful life of between 36 and 60 hours before replacement of the L.T. battery is necessary, depending on the type of cell used.

Despite the reduction in size and the saving of filament current, the performance of these new British sub-miniatures is actually better than that of the larger 10-mm. types. This is mainly due to improvements in the design of the filament and grid systems.

The two valves at present available are the voltage amplifier pentode DF66 and the output pentode DL66. Both are designed for use with a 22.5 volt H.T. battery, and are characterised by freedom from microphony. Using a 22.5 volt H.T. battery, the DF66 will give a voltage gain of about 30 db per stage. This represents an increase of one or two db on the equivalent 10-mm. valves. The DL66 will give an output of approximately 2.5 mW at no more than 10 per cent distortion. This is sufficient to meet the demands of 70 per cent of the hearing aids at present being manufactured.

The Determination of Gramophone Pick-up Tracking Weights

By E. S. MALLETT, B.Sc.(Hons).

THE heavy gramophone pick-ups which were almost universal some years ago are now fast disappearing. The use of massive armatures and needles, and the excessive stiffness of the armature movements of the older pick-ups, necessitated a high "tracking weight" to keep the needle in intimate contact with the record groove.

The new "lightweight" pick-ups, with reduced armatures and more compliant movements, require far less weight, but the determination of the tracking weight is still carried out by hit-and-miss methods. The usual method is to test the pick-up on a record cut with a large amplitude at a frequency of about 500 c/s., but this has the disadvantage that the measurements give no guide to the tracking of the pick-up when playing music.

In an effort to eliminate this disadvantage, various workers have employed tests based on the relative peak amplitudes of music over the audio-frequency range,[1] but this is unnecessary. The suitability of a given tracking weight is independent of the type of music or of the recording frequency response, and depends only on various mechanical constants of the pick-up and record.

Method of Recording

Modern commercial gramophone records are recorded by the lateral-cut process; but care has to be taken that over-modulation does not occur; that is, the groove must be cut so that the reproducing needle in the pick-up is able to follow continuously the original excursions of the tip of the cutter. There are two types of over-modulation: (a) amplitude over-modulation, which is caused by two adjacent grooves running into one another; and (b) radius over-modulation, which is caused by the cutting stylus (which is shaped like a triangular wedge—(a in Fig. 1), making a groove modulation of a smaller radius of curvature than the radius of the reproducing needle, which has a tip of approximately spherical shape (b in Fig. 1). The former defect is obvious even to the naked eye and is easily prevented. On the other hand, radius over-modulation is difficult to detect and appears to have been almost completely ignored in the recording industry.

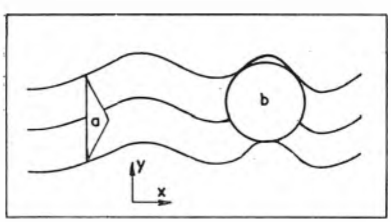


Fig. 1
A horizontal cross-section of a record groove showing (a) the shape of the cutting stylus, and (b) the inability of the reproducing needle to follow the excursion made by the cutting stylus if radius over-modulation is present

Tracking Weight and Mechanical Impedance

A diagram of a reproducing needle resting in a groove is shown in Fig. 2. The groove is assumed to have a 90° included angle, the bottom being rounded off with a radius smaller than that of the needle-tip. Owing to the mechanical impedance of the needle assembly of the pick-up, a horizontal force F acts on the tip of the needle as it follows a modulated groove. If the tip is to remain in the groove a vertical force W equal to or greater than F must be exerted; this force W is called the tracking weight.

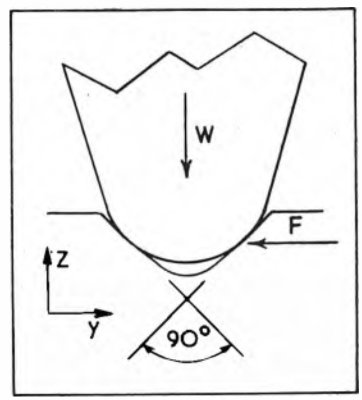


Fig. 2
A vertical cross-section of a reproducing needle resting in a record groove

In Fig. 3 is shown a cross-section of a typical moving-iron pick-up. The mechanical elements which affect the frequency response and impedance to lateral motion are as follows:

- C_o, the compliance of the needle and record material.
- C_a, the compliance of the armature movement formed in this case by the rubber bearing and rubber pad.
- M_a, the effective mass of the needle and armature assembly.
- M_p, the effective mass of the pick-up head and arm.

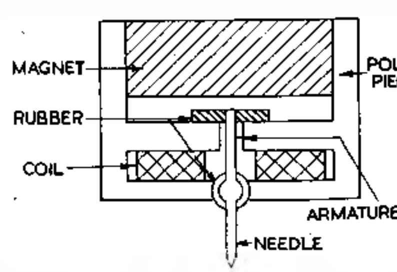


Fig. 3
A cross-section of a typical moving-iron pick-up

In order to simplify the calculations, it is preferable to refer all these constants to one point, usually the needle point. The compliances, measured in dyne-cm., are normally measured at the needle tip, but the masses must be corrected.

It can be shown that the effective mass at the needle tip is given by

$$M = I/l^2$$

where I is the moment of inertia (gm.-cm.^{2}) of the member about its axis of rotation, and l is the distance (cm.) between the axis of rotation and the needle tip.[2]

It is simpler to convert all mechanical elements, etc., to their electrical analogues, which are shown in Table 1.

Table 1

Mechanical Element	Symbol	Unit	Electrical Analogue	Electrical Symbol	Electrical Unit
Force	F	dyne	Electro-motive force	E	Volt
Displacement	y	cm.	Charge	Q	Coulomb
Velocity	$\dot{y}$	cm./sec.	Current	I	Amp.
Acceleration	$\ddot{y}$	cm./sec.^{2}	—	—	—
Mass	M	gm.	Inductance	L	Henry
Compliance	C	cm./dyne	Capacitance	C	Farad
Resistance	R	dyne/cm./sec.	Resistance	R	Ohm
Impedance	Z	dyne/cm./sec.	Impedance	Z	Ohm

The equivalent electrical circuit of the pick-up of

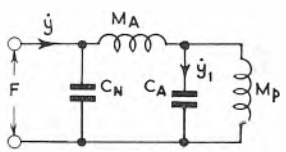


Fig. 4 The equivalent electrical circuit of the pick-up shown in Fig. 3

Fig. 3 is shown in Fig. 4. From Ohm's Law, the mechanical impedance is given by

$$Z = F/\dot{y} \text{ dyne-cm./sec.}$$

The frequency response, which depends on the relative velocities of the end of the armature in the magnetic air gap and the tip of the needle, is given by $\dot{y}_1/\dot{y}$.

Three resonances occur in this circuit. Two resonances present a high impedance to the record groove and also cause a peak in the frequency response, namely:

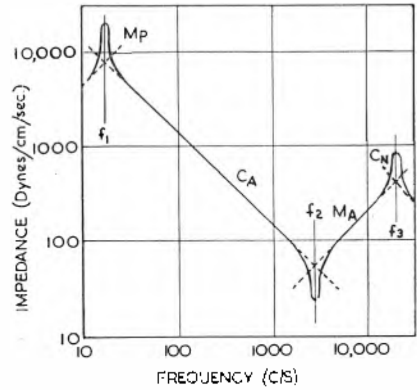
$$f_1 = 1/2\pi\sqrt{M_P C_A} \text{ and } f_3 = 1/2\pi\sqrt{M_N C_N}$$

and one resonance which presents a low impedance to the record and does not affect the frequency response,

$$f_2 = 1/2\pi\sqrt{M_A C_A}$$

Fig. 5 shows a graph of impedance against frequency for a pick-up to be discussed later. In this figure the diagonal straight lines represent the mechanical impedance of the separate elements, and where two lines cross a resonance occurs. The impedance would become infinite or zero at these frequencies were it not for the resistive damping which is always present, usually by intention. Resonances f_1 and f_3 should be adjusted so that they are outside the recorded range.

Fig. 5 A graph of impedance against frequency for the pick-up taken as an illustrative example



Forces Dependent on Amplitude and Radius of Modulation

Between frequencies f_1 and f_2 it will be seen from Fig. 5 that the impedance presented to the record groove by the needle is due to C_A; that is, the movement of the armature and needle assembly is "compliance-controlled," or, as it is usually called, "stiffness-controlled" (stiffness being the reciprocal of compliance). Therefore between f_1 and f_2 the maximum force required to move the needle tip is given by

$$F_{max} = y_{max}/C_A \qquad (1)$$

The maximum amplitude which may be cut on a record is fixed by the "land" between adjacent grooves. This land is .010 cm. on present commercial records, and assuming that the adjacent groove has a very small modulation, it is possible to record an amplitude of this value, as is indeed done in practice.

It should be noted that the expression for F is independent of frequency, so that the maximum force presented to the groove by the needle between f_1 and f_2 is independent of the recording frequency characteristic, being decided only by the mechanical constants of the pick-up and record.

Between the frequencies f_2 and f_3 the movement is "mass-controlled," and

$$F = M_A(d^2y/dt^2) = M_A\ddot{y} \qquad (2)$$

$$\text{but } d^2y/dt^2 = V^2(d^2y/dx^2) \qquad (3)$$

where V is the circumferential velocity of the record past the needle-point. Substituting (3) in (2), we have:

$$F_{max} = M_A V^2 (d^2y/dx^2)_{max} \qquad (4)$$

Now the radius of curvature of a function $y=f(x)$ is given by

$$\rho = \frac{[1 + (dy/dx)^2]^{3/2}}{d^2y/dx^2}$$

and the minimum radius of curvature by

$$\rho_{min} = 1/(d^2y/dx^2)_{max} \qquad (5)$$

Let us assume that $\rho'_{min} = 2r$, where ρ' is the radius of curvature perpendicular to either groove wall, and r is the radius of the needle tip, then the radius of curvature of the locus of the centre of the spherical needle tip will be $3r$ for one wall and r for the other wall. Then from (5), $(d^2y/dx^2)_{max}$ perpendicular to the groove walls will be $1/3r$ and $1/r$. Resolving horizontally,

$$(d^2z/dx^2)_{max} = (1/r + 1/3r)/\sqrt{2}$$
$$= 4/3\sqrt{2}r \qquad (6)$$

From (6) and (4),

$$F_{max} = \frac{4M_sV^2}{3\sqrt{2}r} \quad \text{......} \quad (7)$$

The circumferential velocity is given by $V = R\Omega$, where R is the radius of the record groove (i.e., the distance in cm. between the centre of the record and the needle point), and Ω is the angular velocity of the record in radians per second. Therefore

$$F_{max} = \frac{4M_sR^2\Omega^2}{3\sqrt{2}r} \quad \text{......} \quad (8)$$

gives the force between needle and record when the system is mass-controlled.

It might be thought that because F_{max} is proportional to R, the maximum tracking weight would be obtained when R is a maximum. This deduction assumes that the mean level of recording is reduced as the pick-up travels from the outside to the inside of the record, but as the mean level must be constant the maximum tracking weight is given by Equation (8) when R is a minimum.

Further interesting equations can be obtained from Equation (7).

If $y = y_{max} \cos \omega t$, then

$$|\dot{y}_{max}| = \omega y_{max} \quad \text{......} \quad (9)$$

$$\text{and } |\ddot{y}_{max}| = \omega^2 y_{max} \quad \text{......} \quad (10)$$

Substituting for $\ddot{y}_{max} = F_{max}/M_s$ from (7), we have

$$\omega_0^2 = \frac{4V^2}{3\sqrt{2}\,r\,y_{max}} \quad \text{......} \quad (11)$$

and substituting in (9):

$$\dot{y}_{max}^2 = \frac{4V^2y_{max}}{3\sqrt{2}\,r} \quad \text{......} \quad (12)$$

These equations give the maximum velocity of cut which can be obtained with the mechanical constants given, and the frequency at which it occurs.

Pinch Effect

Owing to the fact that the cutter is triangular-shaped whereas the reproducing needle is spherical, a vertical component of force is produced which is known as the "pinch effect." This force raises the needle twice for each horizontal wavelength so that the vertical frequency is twice that of the horizontal.

The equivalent electrical circuit of the pick-up for vertical motion is the same, although the circuit constants are different.

The vertical amplitude is given by[1]

$$z = \frac{r\dot{y}^2}{4\sqrt{2}\,V^2} \quad \text{......} \quad (13)$$

Substituting Equation (12) in Equation (13):

$$z_{max} = y_{max}/6 \quad \text{......} \quad (14)$$

The vertical acceleration may be obtained in a similar manner to Equation (6) by resolving vertically,

$$(d^2z/dx^2)_{max} = 2/3\sqrt{2}r$$

Therefore

$$\ddot{z}_{max} = \frac{2V^2}{3\sqrt{2}r} = 1/2\ \ddot{y}_{max} \quad \text{......} \quad (15)$$

Below 600 c/s. (the horizontal "turn-over" frequency being 300 c/s.) the vertical amplitude is inversely proportional to the square of the frequency, so that the pinch effect quickly becomes negligible as the frequency is decreased. The maximum vertical frequency is twice that of the maximum horizontal frequency. As with the horizontal case, f_1 and f_3 should be adjusted so as to be outside the recorded range.

Illustrative Example

Let us assume the following constants for a commercial record and needle:

y_{max} = 0.010 cm.
r = 0.0075 cm. (0.003 in.)
$\Omega = 2\pi \times 78/60$ rad./sec. (78 r.p.m.)

This gives

$V_{min} = R\Omega$ = 40 cm./sec.

at the inside of a record, R being 5 cm.

Then Equation (1) becomes:

$(F_{max})_1 = 0.010/C_s$ dynes,

and Equation (7) becomes:

$(F_{max})_2 = 0.20 \times 10^6\ M_s$ dynes.

From (10) and (11) f_0 = 714 c/s.

and $\dot{y}_{max}$ = 44.8 cm./sec.

For the pick-up, assume the following constants:

For Horizontal Motion	*For Vertical Motion*
f_1 = 15 c/s.	f_1' = 40 c/s.
f_2 = 2,500 c/s.	f_2' = 9,000 c/s.
f_3 = 20,000 c/s.	f_3' = 40,000 c/s.
$C_s = 1.2 \times 10^{-6}$ cm./dyne	$C'_s = 0.17 \times 10^{-6}$ cm./dyne
$M_s = 3.0 \times 10^{-3}$ gm.	$M'_s = 2.0 \times 10^{-3}$ gm.

The working range of this pick-up is taken as 30 to 10,000 c/s., i.e., tracking weight calculations will apply only on records *cut* within this frequency range.

From the formulae already given, the tracking weights are found to be:

Below f_2, F_1 = 8.5 gm.
Above f_2, F_2 = 0.6 gm.
Below f_2', F_3 = 10.0 gm.
Above f_2', F_4 = 0.2 gm.

The total minimum tracking weight is the sum of these forces, i.e., 19.3 gm. The actual working tracking weight would be adjusted to be between 20 and 25 gm.

Conclusions

The previous analysis has shown that, given certain assumptions, the tracking weight required for a given pick-up and the type of recording is determined by six mechanical constants. Unfortunately, the vast majority of the pick-ups at present available to the public fail to comply with these assumptions, namely, that none of the resonances come within the recorded range. The resonances which are most frequently at fault are f_3 and f_3'.

Moreover, even should the pick-up be free from fault in these respects, there is the other side to the problem, namely, that most commercial records are radius over-modulated to a considerable extent. This over-modulation accelerates wear of needle and record, and causes the "needle buzz" which is so distressing a feature of many modern records.

[1] A. L. Williams, "Further Improvements in Lightweight Record Reproducers, and Theoretical Considerations entering into their Design," *Jour. S.M.P.E.*, 33, August, 1939, p. 203.

[2] L. Fleming, "Notes on Phonograph Pick-ups for Lateral-cut Records," *Jour. A.S.A.*, 12, January, 1941, p. 366.

Transmission Monitoring

By H. B. RANTZEN, B.Sc., M.I.E.E. and A. R. RENDALL, Ph.D., M.I.E.E.

(Engineering Designs Department, B.B.C.)

THEORETICALLY, it should be possible to measure the distortion or disturbances that occur in a programme transmission chain by opposing equal samples of the input and output signals and observing any resultant out-of-balance component. One of the major obstacles in such an arrangement is, of course, the difficulty of anti-phasing the two signals with sufficient accuracy over the required frequency range. In the B.B.C's transmission chains, which are often of a complex nature involving many transmission units, the phasing difficulty arises in an acute form, and consequently the more recent B.B.C. development work in this field has been directed towards systems that oppose specialised D.C. signals derived from the programme signals. Since the apparatus for this system is suitable for simple transmission chains as well as for more complex circuits, it is probable that it will be adopted for universal B.B.C. use and that little or no further attention will be given to systems which oppose the A.C. signals directly.

Nevertheless, some of the ideas for a monitoring system using direct anti-phasing which have been examined during the course of this development work may still be of value and interest, especially where phasing problems do not arise with great force. These ideas are best explained by the specific examples which follow.

Suppose there are a number of outputs of a common programme which have to be monitored by either human or automatic means. It would, of course, be possible to monitor the outputs sequentially, but the period over which each one is observed would then be discontinuous. Fig. 1 shows an arrangement for monitoring an odd number of outputs simultaneously. Each signal is taken to a winding of a transformer: windings 1, 2, 3 and 4 are paired in opposition, and the 5th remains unopposed. If the signals are adjusted so that they are equal in magnitude, the only output which will normally be effective is the 5th one. If, however, any disturbance occurs in any of the others, such as noise, overload or frequency distortion, it will appear in the common output as strongly as if only one output existed. If all the outputs had been in parallel, then it is quite clear that a disturbance in any one of them would have shown a proportionately smaller effect in the common output.

If the disturbance occurs in a part of the chain common to two opposed outputs, then of course the disturbances also will cancel. However, this disadvantage can be obviated by choosing the input of such a common chain as one of the outputs to be monitored. Fig. 2 shows this arrangement applied to a common programme input equipment and two transmitters, T_1 and T_2. If a defect occurs in the programme input equipment, or in T_1 or T_2, it is shown up in the common output. In this particular example, outputs 1 and 2 are opposed and output 3 is unopposed. If the number of outputs is even, then one suitable extra output can be added in order to make the total number of outputs odd.

In some particular radio-frequency applications it may be desirable to phase the outputs. For example, Fig. 3 shows three outputs spaced at 90° in phase. It is clear that the resultant of the three outputs will be equal to one of them, and that any disturbance in any one of them will appear in the output at full strength relative to the signal output. For a greater number of sources it might be desirable to phase the

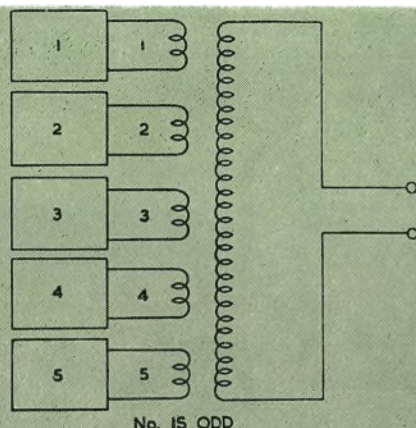


Fig. 1.
Monitoring an odd number of channels simultaneously

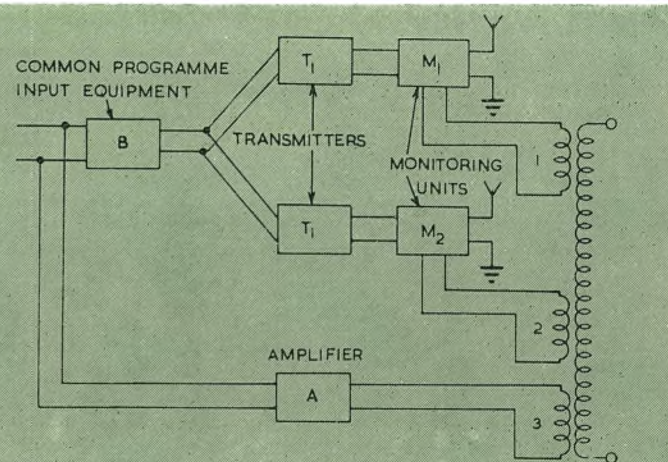


Fig. 2.
A practical application of the scheme shown in Fig. 1

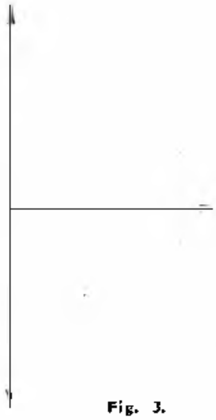


Fig. 3.
Three output signals with a phase spacing of 90°

outputs at different angles, and this can often be done where the signal is borne on a carrier. But this method is not really practicable for audio-frequency signals because of the difficulties in designing networks that will introduce any desired phase over several octaves.

The opposition principle can be utilised where the performance of a piece of appartus is to be checked automatically. Fig. 4 illustrates an arrangement for doing this. Signals proportional to the input and output are opposed in a transformer, the output of which is fed though an amplifier, B, whose gain is controlled by the magnitude of one of the source signals. Suppose that over a limited range of volume the gain of this amplifier B is equal to G divided by V, where G is some constant associated with the amplifier and V is the signal volume; then the output of the amplifier over that particular volume range will be independent of the input volume Suppose now that the source output 2 contains some spurious voltage ΔV: this will appear as ΔV at the output of the transformer 3 and as $\Delta V \times G/V$ at output 4. Thus the spurious output at 4 is independent of the actual volume of the programme and could, of course, be used to perform an automatic monitoring function.

Where a particular distortion characteristic is to be measured, the amplifier supplying windings 1 and 2 in Fig. 4 may be designed so as to increase the intensity of the spurious signal relative to that of the normal programme. Thus, where noise is to be monitored, for example, the amplifier may be arranged to have high gain for signals of low volume and decreasing gain for signals of higher volume. Any noise in one of the sources feeding windings 1 and 2 will then cause a disproportionately large output at 4, and the sensitivity of the monitoring equipment is thereby increased.

The application of these methods of monitoring is limited in practice by the precision with which the magnitude and phase of the signals to be compared can be adjusted to the desired degree of equality over the required frequency range. The problem can often be eased by reducing the sensitivity of the apparatus at the extreme ends of the frequency range, where phase and amplitude difficulties are likely to be encountered. There are some applications, however, where the propagation characteristics of the chains to be compared are very similar, and in these applications the realisation of the principles may be fairly simple.

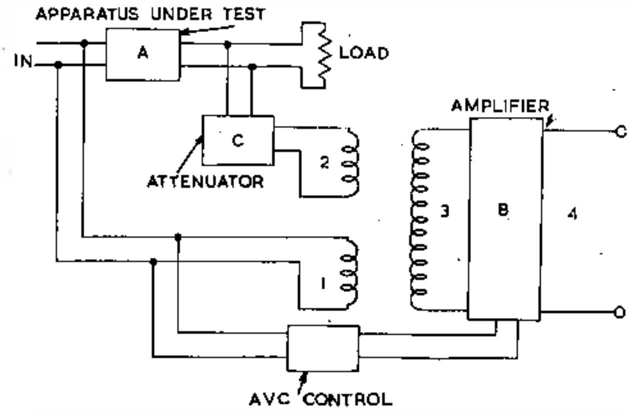


Fig. 4.
Illustrating the opposition principle for automatically checking the performance of a piece of apparatus

The Omegatron

The omegatron is the most recent development at the American National Bureau of Standards in the realm of atomic instrumentation. Basically a miniature cyclotron, the omegatron was developed by J. A. Hipple, H. Sommer and H. A. Thomas, and has already made significant contributions in two fields: (1) It makes possible measurement of the numerical value of the faraday with exceedingly high precision. For the first time the faraday is being evalued directly by physical methods—all previous faraday measurements have been electrochemical. (2) The value of the nuclear magneton may now be determined very precisely, so that the ratio of the mass of the electron to the mass of the proton will be known with greater precision than ever before.

Since the faraday was defined as a unit of quantity of electricity, many attempts have been made over a period of 100 years to determine its precise value, but only now with the development of the omegatron has an independent physical determination been possible. There is a discrepancy between the two best previous determinations—with the iodine voltameter and with the silver voltameter. This inconsistency has been distressing to scientists engaged in revising the tables of atomic constants, since the faraday is a key component of these tables.

The functioning of the omegatron can be explained in terms of a single physical law. If a charged particle is moving in a uniform magnetic field it will trace out a circular path. The angular velocity, ω_c, of the particle about the centre of the circular path is given by the so-called cyclotron equation $\omega_c = eB/M$, where e/M is the charge-to-mass ratio of the particle, and B is the magnetic flux density. In the cyclotron this property makes it possible to accelerate charged particles to extremely high velocities. In the omegatron, however, it is used to discriminate between particles of different masses: heavier particles will have a lower angular velocity. Measurement of the angular velocity, ω_c, with the aid of accurate frequency standards and measurement of B by means of nuclear resonance methods provide an absolute determination of e/M in terms of the magnetic field strength and the cyclotron frequency alone.

—*National Bureau of Standards*, March, 1950.

THE PHYSICAL SOCIETY'S EXHIBITION

A selection of some of the more interesting exhibits of new research items and electronic equipment at the Physical Society's 34th Exhibition held at Imperial College, South Kensington, London, from the 31st March to the 5th April.

Audio Generator

(Illustrated below)

THE type H.1 Audio Frequency Generator covers the audio-frequency range between the limits of 15 c/s. and 50,000 c/s., with low distortion (less than 1 per cent at 1,000 c/s.) and constant level over the full range. This coverage is achieved by using a bridge-type resistance-capacitance oscillator with three switched ranges. It incorporates a stabilizing circuit and is followed by two stages of amplification with heavy negative feedback.

The continuous and step potentiometers give a variation from 200mV to 20V on sine wave, or 400mV to 40V on square wave at an accuracy of plus or minus 1db.

Advance Components, Ltd.,
Back Road, Shernhall Street,
London, E.17.

Universal Bridge

(Illustrated right)

THE Universal Bridge is a self-contained 50 c/s. bridge having eight directly calibrated resistance ranges covering 0.5 ohms to 50 megohms, eight directly calibrated capacitance ranges covering from 5pF to 50μF, and four inductance ranges from 50 mH to 500 H.

Other features are phase balance control and a flashing neon for capacitor leakage testing. The valve voltmeter feeding the panel movement is provided with a variable sensitivity control so that balance sensitivity can be varied to suit the measurement under consideration.

Two other new exhibits were the Testmeter, Type "W," having in all some 80 ranges of measurement, and the Precision Valve Voltmeter with a 5 in. mirror scale in which special precautions have been taken to maintain a high degree of accuracy and stability.

The Automatic Coil Winder
and Electrical Equipment Co., Ltd.,
Winder House, Douglas Street,
London, S.W.1.

Avimo 35 mm. 16 in. Electronically Controlled Self-loading Drum Camera

THE camera unit consists of a 16 in. diameter drum mounted in a suitably designed main casting with the film wound round the periphery of the drum. When one strip is exposed, the drum is automatically reloaded, and with the film capacity of 100 ft. plus an 8 ft. leader and trailer, approximately 24 exposures of 50 in. length are possible.

A 4.5 in. f/1.9 lens is fitted, which is adjustable to suit different applications, and a reflex focusing system ensures correct positioning of the lens. A commutator system is incorporated to ensure the correct relationship between the camera drum and cathode-ray tube trace. There are no controls on the camera, as these are centralized on the electronic control unit.

The main features are: a form of electronic speed control to vary the speed of the drum giving a maximum speed of 3,000 in./sec. approximately; operation of the rewind mechanism after exposure and the electronic control of the beam of the cathode-ray tube, the trace of which is being recorded.

Avimo, Ltd.,
Taunton, Somerset.

Magnetic Field Strength Meter

THIS Magnetic Field Strength Meter employs the "Hall" effect in germanium.

A small flake of germanium $\frac{1}{4}$ in. by $\frac{1}{16}$ in. by 0.015 in. thick was shown mounted in a probe, thus being capable of exploring and measuring field strengths in very small gaps.

The range of the instrument is between 0 and 25,000 gauss, in three ranges, obtained from direct readings on a micro-ammeter.

The British Thomson-Houston Co., Ltd.,
Rugby.

Wide Range Capacitance Bridge

THIS Bridge has been designed as an accurate instrument capable of low capacitance measurement. The capacitance range is from 0.1 pF to 100μF, the first reading being 0.005 pF, whilst the resistance range is calibrated from 1 ohm to 30,000 megohms. This wide range is covered in 18 overlapping stages, each having an accuracy of $\pm$ 1 per cent of the full scale. Both the resistance and capacitance ranges are calibrated on slow-motion dials having 50:1 step-down ratio, thus enabling a very fine balance to be obtained. Balance is indicated by a dual electron ray tube. The operating frequency of the bridge is 1,592 c/s. (giving $\omega = 10,000$).

Square Wave and Pulse Generator

THIS instrument's main application is in the checking the frequency response of amplifiers of all types. The generator will provide a square wave 1:1 mark-space ratio, top and bottom flat $\pm$1 per cent over the frequency range 5 c/s. to 250 kc/s. Coarse and fine frequency controls are provided. The output voltage is also variable from 5mV to 5V in six stages. An output control calibrated to within $\pm$3 per cent covers each step of the range.

The Pulse Unit consists of four delay lines of different lengths, which may be selected by a switch. When the generator is used in conjunction with this unit, a pulse output waveform is obtained, the pulses being 0.05, 0.1, 0.2 or 0.3 microseconds at amplitudes up to 5V.

Cinema Television, Ltd.,
Worsley Bridge Road,
Lower Sydenham,
London, S.E.26.

Vibrating Reed Electrometer

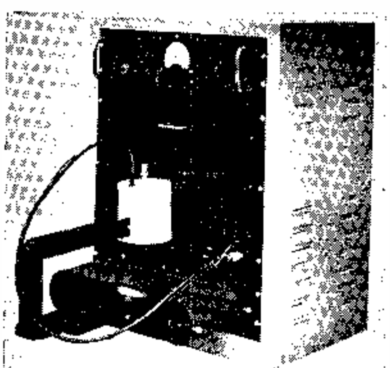
THIS instrument is a replacement for most forms of valve electrometer, as it has a greatly improved zero stability as compared with other types. It consists of two units—the head amplifier

and the main amplifier. These are connected by cables which may be up to 125 feet in length. The applied D.C. is converted to A.C. by means of a vibrating capacitor, and the A.C. is amplified and then rectified. Stability is maintained by the application of negative feedback.

Direct indication of the voltage or current being measured is given on a 3½ in. meter and simultaneously a recorded and/or a process controller may be operated. The instrument has been designed expressly for ionization current measurements.

Of particular interest at the Ekco stand was the radio-active thickness gauge (*illustrated below*), which utilizes the effect of absorption of radio-active particles and rays in materials. It is particularly suitable for gauging the thickness of materials where physical contact is undesirable.

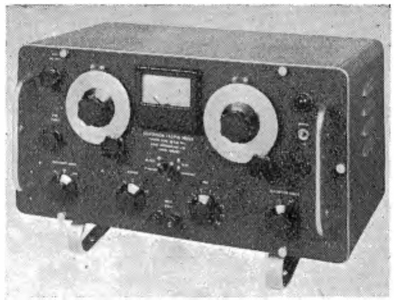
E. K. Cole, Ltd.,
Electronics Division,
Malmesbury, Wilts.



Distortion Factor Meter, Type 700C

(Illustrated top centre)

SUPERSEDING Type 700B, this instrument has a much wider frequency range, and the operation has been considerably simplified. Total harmonic distortion of 0.1 per cent to 50 per cent can be directly measured in an A.F. signal in the frequency range 20 c/s. to 20 kc/s. Measurement is of the ratio of the square root of the sum of the squares of all harmonics to the amplitude of the input tone. A tuned R.C. rejector circuit calibrated directly in frequency separates the fundamental from the harmonics, the harmonic voltage being compared with a fraction of the input voltage by means of a resistive potentiometer calibrated in percentage distortion. The indicator is a high gain amplifier and rectifier voltmeter. The harmonic percentage is read directly from the calibrated dial and multiplier. The amplifier and voltmeter have a response extending beyond 100 kc/s., enabling the fifth harmonic of 20 kc/s. to be included in the measurement. An input attenuator enables the meter to accommodate signals ranging in power level from 1 milliwatt to 2 watts.



Two other new developments produced by this firm were the Sound Level Meter, Type 1400C, and the Strobotuner, which is an electronic apparatus for accurate tuning of musical instruments.

Dawe Instruments, Ltd.,
130, Uxbridge Road,
Hanwell, London, W.7.

Laboratory Valve Voltmeter

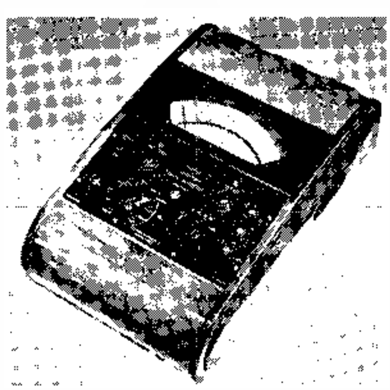
(Illustrated below)

THE new Model 26 Laboratory Valve Voltmeter has a high standard of accuracy with ranges of from 0.2V to 250V on both A.C. and D.C., with an upper frequency of 200 megacycles. It measures resistance from 500 ohms up to 500 megohms in four overlapping ranges: 0 to 500,000 ohms, 0 to 5 megohms, 0 to 50 megohms, and 0 to 500 megohms. It also measures variation in power level over a range of from —30 to 2 db., the reference level being 100 milliwatts in 600 ohms.

A feature of the instrument is its B.S.S. Grade I accuracy. Stability on A.C. is within 0.8 per cent in 24 hours after warming up, and on D.C. within 0.7 per cent.

Other new exhibits by the same firm were the Dynatherm Surface Temperature Meter, the Self-Monitoring Electrometer and the "Chronotron" Model 25C Millisecond Meter.

Electronic Instruments, Ltd.,
17, Paradise Road,
Richmond, Surrey.



Aerial Recording Magnetometer

THE instrument is a total force variometer which records, on a continuous writing record, variations in the earth's total magnetic force. Developed for geophysical surveying by air, it is designed with a view to easy installation in an aircraft, and comprises the following components: detector head, graphic recorder, metering unit, orientor unit, battery box, and power unit.

The mechanical arrangement of the orienting gimbals of the detector head has been designed to avoid gimbal lock at low magnetic latitudes.

Elliott Brothers (London) Ltd.,
Century Works, Lewisham,
London, S.E.13.

High-Speed Recording Cathode-Ray Tube

THIS tube has been developed for the photographic recording of high-speed transients when surge testing transformers, and is the result of an endeavour to overcome the problems which have arisen in using a continuously evacuated surge oscilloscope. The 6-in. diameter tube has electrostatic deflexion and magnetic focusing. With the final anode voltage at 15kV the writing speed is of the order of 3,000km. per second, without reduction in image.

This firm also showed new precision potentiometers which are toroidally wound, and have an accuracy of 15 minutes.

Ferranti, Ltd.,
Hollinwood, Lancs.

A Precision Radio Control System

THIS system was developed on behalf of the Royal Aircraft Establishment and is designed to control high-speed aircraft under test. Another application is the transmission of accurate data by radio or two-wire lines.

Seven remote servo-units may be independently controlled and one of these may be replaced by a multi-position switch.

The transmitter shaft positions are conveyed as phases relative to a reference phase of a low-frequency tone. These phase-shifted outputs are used to phase-modulate eight sub-carriers which may be conveyed by a two-wire line, or used to modulate a radio transmitter.

The servo system may be classified as Continuously Rotatable Position Control, with a 3-stage torque regulation.

The overall accuracy for radio transmission is better than $\pm 1\frac{1}{2}°$ in 360°.

The measurement of magnetic field by Hall effect in Germanium was another exhibit on this stand, and is a simple, self-contained apparatus.

The Research Laboratories,
The General Electric Co., Ltd.,
Wembley, Middx.

F.M./A.M. Signal Generator, Type TP948

THIS is an instrument suitable for tropical use and designed to provide R.F. signals over the range 20-80 Mc/s. in two bands. The output may be unmodulated, sinewave frequency modulated, or sinewave or squarewave

amplitude modulated either internally or externally. The effective scale length is over 14 feet and a dual-crystal frequency checking circuit is incorporated which includes a built-in amplifier complete with miniature loudspeaker as audio beat detector.

The basic R.F. level is monitored by one of two panel meters; two calibrated attenuators in cascade are used to set up the output voltage, which may be varied from 1μV to 0.1V at an output impedance of 75Ω. Also available are a high output of 1V R.M.S. and low outputs down to 0.1μV at 7.5Ω.

The internal modulation oscillator provides four fixed frequencies of 300 c/s., 1 kc/s., 1.6 kc/s. and 3 kc/s. When externally modulated, an internal limiting device provides, if required, squarewave modulation from a sinewave input voltage. The F.M. deviation (up to 300 kc/s. on the lower carrier band and up to 600 kc/s. on the higher band) or the A.M. depth (0-80 per cent) are read from the second panel meter.

Marconi Instruments Ltd.,
St. Albans, Herts.

Muirhead-Pametrada Wave Analyser D-894-A

THIS Analyser is of the degenerative feedback type, with resistance capacitance tuning, and one of its features is that a constant selectivity is obtained at all tune frequencies. Tuning is from 19-21,000 c/s. in three decade bands (with overlap), each band being subdivided into three. The main tuning control is a 72-stud rotary switch covering the range 19-88 c/s. in steps of 1 c/s. to which may be added 60 or 120 c/s., the correct frequency being indicated by a shutter mechanism. In addition, a fine control gives 0.2 c/s. to obtain intermediate readings.

To facilitate tuning to a signal of slightly variable frequency a band-pass control is available, giving 3 per cent or 10 per cent "flat tops" at all frequencies.

An input attenuator enables a maximum input of 10V to be used. The meter normally reads average values, but can be switched to read peak values below or above average if required. For oscilloscope work the output is brought out to terminals, and phone jacks are provided. The output voltage is the same frequency as the input, and not the intermediate frequency, as with heterodyne analysers.

At maximum selectivity setting the total effective Q is 80. The accuracy of the frequency setting is ½ per cent, and the frequency response is constant within $\pm$2 db over the whole range.

Muirhead & Co., Ltd.,
Elmers End,
Beckenham, Kent.

Valve Impedance Test Gear

THE Valve Impedance Test Gear is a new instrument for the accurate measurement of the input and output capacitance and damping resistance of thermionic valves under given operating conditions. The gear operates on a similar principle to the conventional Q meter; it consists of an oscillator feeding a tuned circuit, which includes the valve under test, across which is connected a bridge-type, high-frequency valve voltmeter. It is different from the Q meter in that the power developed in the tuned circuit is varied by means of a piston attenuator so that the voltage is adjusted to a pre-determined value. The frequency range is 10-150 Mc/s., and the voltage applied to the valve under test is 50mV R.M.S.

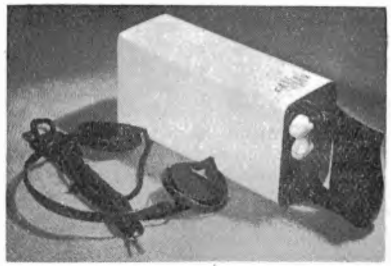
The system employed has two main advantages in that the accuracy of measurement is mainly determined by the piston attenuator which may be made to a high degree of precision.

Another new piece of equipment exhibited by this firm was the F.M. Signal Generator—Type E7572—which is for servicing F.M. receivers operating in the 90 Mc/s. region.

Mullard Electronic Products, Ltd.,
Century House,
Shaftesbury Avenue,
London, W.C.2.

National Physical Laboratory

IN the Electronics Section of the N.P.L.'s exhibit was shown the Automatic Computing Engine. This very large machine is intended to have a storage of about 200,000 binary digits. ("*Electronic Engineering*," **18**, 372, 1946.)



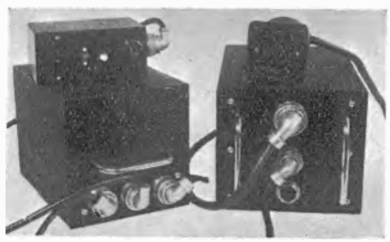
Model 33 Geiger-Muller Radiation Monitor

THE Model 33 (*shown above*) is a robust, battery operated instrument for the detection and location of radioactive sources. Indication of activity is given by light-weight headphones. All voltage supplies for the amplifier and Geiger-Muller tube are derived from a single dry battery of the portable radio type, with combined H.T. and L.T. voltages of 67½ and 1½. A voltage control enables the voltage for the Geiger-Muller tube to be adjusted, and compensation can be made for ageing batteries.

The standard instrument is fitted with a GM2 tube with an end window of duralumin which is just transparent to beta rays of 0.2 M.E.V. approx. If the instrument is required for monitoring medium-speed beta particles a GM4 tube can be supplied or an EHM2 mica-window tube for slow-beta work. The latter is especially recommended for carbon (C14) and sulphur (S35). All tubes are sensitive to gamma radiation.

The instrument is held by means of a pistol-grip handle and is brought into action by a single press-switch.

Panax Equipment, Ltd.,
347, London Road,
Mitcham, Surrey.



Precision Engine Speed Indicator—Airborne Type

(*Illustrated above*)

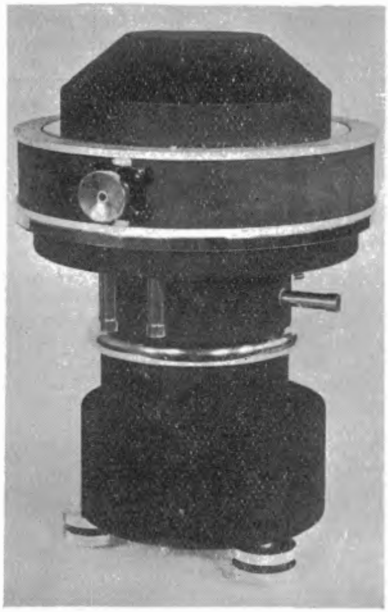
THIS is a compact, portable equipment capable of measuring shaft speeds up to 20,000 to the nearest 10 r.p.m. A standard time interval of one second is used, obtained from a low frequency N.T. cut crystal working at a frequency of 4,096 kc/s., allowing the complete division to 1 c/s. to be obtained by scale-of-two stages—i.e., 2^{12}.

The gating circuit is arranged for manual or automatic control. When using the latter, controlled switching permits an external camera to be synchronized with it to provide a continuous recording.

The pick-up from the engine shaft is by means of a slotted disk and photocell. The counter are units of four scale-of-two with feedback to obtain a scale-of-ten, the indicator unit being remote from the main equipment and using miniature neons.

Another exhibit was the 19 cm. diameter high temperature X-ray camera (*shown below*), with a tungsten wire furnace suitable for operation in a reducing atmosphere to a temperature in excess of 1,800 c degrees.

The Plessey Co., Ltd.,
Ilford, Essex.



Radar Research and Development Establishment

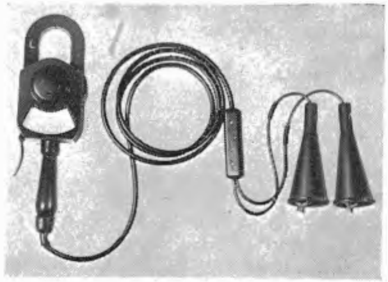
AN interesting new development was the automatic phase recorder demonstrating the properties of a centrimetric radar lens, which is designed to record radio-frequency phase variation along any desired paths as determined by the traversing mechanism. The results are produced as pen recordings of phase versus displacement.

Royal Aircraft Establishment

AN interesting exhibit on this stand was the Electronic Curve Follower, which will translate into voltage form recorded information to be fed to a differential analyser or an analogue computer.

Layer Thickness Meter

THE electrical instruments on the stand of Salford Electrical Instruments, Ltd. included a new Layer Thickness Meter (*illustrated right*), which measures the thickness of a layer of any protective coating directly, without damaging or marking the coating.



The layer thickness is read directly from a meter scale calibrated from 0 to 30 thousandths of an inch (0 to 0.75 mm.) and the measurement is accurate to within ± 10 per cent.

Apart from the pilot lamp, which is well under-rated, the instrument contains no components which need periodical replacement, and its reliability is therefore assured.

Link Testing Wattmeter
(*Illustrated above*)

Another exhibit on this stand was the Link Testing Wattmeter, which is suitable for measuring the power flowing in A.C. and D.C. circuits without interrupting the circuit.

The wattmeter functions as a normal dynamometer instrument with a wound voltage coil connected via the test leads, and a conductor passing through the pole-pieces which acts as the current coil. Four interchangeable movements will be available—0-12, 0-50, 0-100 and 0-200 kilowatts—and horse-power scales can be fitted if desired.

The voltage circuit is wound for a maximum of 250 volts. For the protection of the user, high-rupturing-capacity fuses are fitted in the equipment and the test leads are shrouded.

Salford Electrical Instruments, Ltd.,
Peel Works,
Silk Street,
Salford, Lancs.

Signals Research and Development Establishment

AT this stand was exhibited the frequency modulation deviation meter No. 3, which is an instrument for measuring deviations up to 500 kc/s. with modulation frequencies up to 120 kc/s. at an R.F. carrier frequency between 20 and 100 Mc/s.

D.C. Amplifier

THE D.C. Amplifier exhibited by Sunvic Controls, Ltd., is a new piece of equipment, which operates as follows: the D.C. input is connected to a vibrator which changes the D.C. voltage into a square wave. After suitable A.C. amplification, the amplified signal is rectified and connected to either a D.C. milliameter indicator or to a recorder. A high degree of negative feedback is applied, giving high stability and linearity. The degree of feedback is such that the overall gain is determined mainly by the feedback resistance. The resistance can therefore be used as a reliable gain adjustment.

There are four input voltage ranges from 0. to 0.1 millivolts to 0 to 100 millivolts. The accuracy of the instrument is one per cent of 0.1 millivolt range and 0.1 per cent of 1 millivolt range. The maximum speed is 1/10 second full scale, with a maximum output of $\pm$ 5mA into a maximum load of 4,000 ohms.

Other new equipment at this stand included a electronic relay type EA3, bimetal thermostat, a cold-junction thermostat and a fatigue machine control unit.

Sunvic Controls, Ltd.,
10, Essex Street,
Strand, W.C.2.

Telecommunications Research Establishment

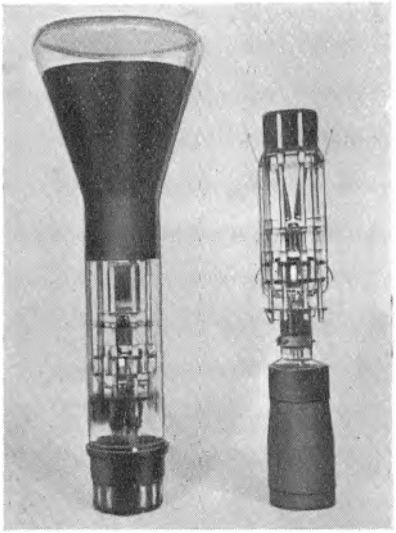
ONE demonstration was of locked oscillators for frequency multiplication, which were parts of a system for obtaining power at 3,000 Mc/s. from a crystal-controlled source at less than 10 Mc/s.

Another demonstration was of the two co-ordinate recorder which plotted the curve of current against voltage of a resistor or other impedance. It was shown that the curve could be traced by a recording meter on squared paper approximately as fast as manual adjustment of the current was possible.

Cathode-Ray Tubes

THE cathode-ray tubes exhibited by 20th Century Electronics included single beam types SB6 and SB4, the diameter of their flat faces being 6 and 4 inches respectively. These cathode-ray tubes have been designed to fulfil the need for precision tubes, and are not a replacement for the simple variety.

The operating voltage of the tubes is 4 kV maximum for the third anode and 2 kV maximum for the first. The focus voltage is proportional to the 3rd anode



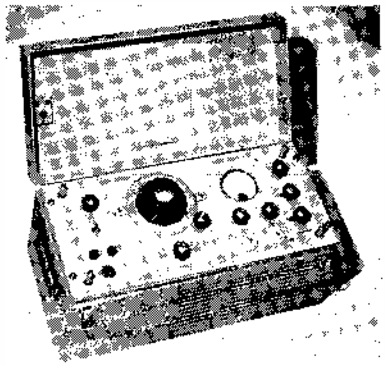
voltage, and is between 280 and 300 volts with the 3rd anode at 2 kV. Negative grid voltage for cut-off is 100V. 20V variation from voltage cut-off is sufficient to give 20mA of beam current. The heater voltage is 6.3 volts and the current is 0.8 to 1.0 amps.

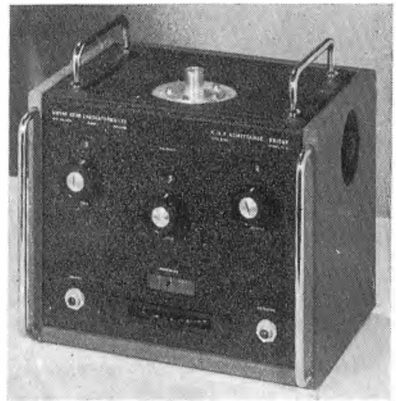
With the 3rd anode voltage 2 kV, plate sensitivity for SB6 on X plates is 0.4 mm. per volt approximately, and on Y plates is 0.6 mm.: for SB4 the plate sensitivity on X plates is 0.2 mm. and Y plates 0.4 mm.

20th Century Electronics,
Dunbar Works, Dunbar Street,
West Norwood, S.E.27.

Video Frequency Oscillator

THIS portable instrument is a variable frequency oscillator covering the frequency range 7 kc/s. to 8 Mc/s. in six ranges. The amplitude variation at any frequency setting does not exceed 0.1 db and the total harmonic distortion is less





than 0.2 per cent. The oscillator will deliver a maximum output of 1 volt r.m.s. into 75 ohms, and an attenuation of up to —65 db. below this level can be obtained in steps of 0.5 db. It has an output range of 10 db to —55 db on 1 volt push-pull.

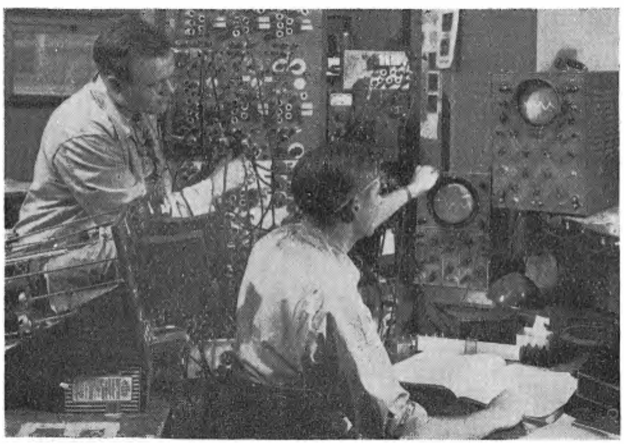
A V.H.F. Admittance Bridge Type B.901 (*illustrated above*) and an Audio Frequency Waveform Analyser Type A201, were two other new developments shown.

Wayne Kerr Laboratories, Ltd.,
Sycamore Grove,
New Malden, Surrey.

A New American Analyser

DEVELOPMENT of a bantam-size electronic differential analyser, a midget beside M.I.T.'s 100-ton computing machine, was recently announced at the Massachusetts Institute of Technology by Professor Albert G. Hill, director of the Research Laboratory of Electronics.

The new machine, its builders explain, uses radio circuits exclusively. It can solve at high speeds and with moderate accuracy the same problems undertaken by its larger counterparts. The new analyser has already been used successfully by many departments at the Institute to help solve such varied problems as chemical reaction rates, communication theory, and heat distribution. It presents the answers to its problems in terms of graphs on a C.R.T. To keep the picture continuously bright and clear, the machine repeats its solution to every problem 60 times per second. Each solution is completed in 1/100 second. When new instructions are given, it switches over to solving the new problem, and continues to present that new solution 60 times per second until still other information is provided.



The analyser is accurate to about 5 per cent; its repeated solutions to the same problem will always be within .002 to .1 per cent of the first one. Unlike conventional calculating machines which deal with numbers, it is used to solve problems involving rates of change of variable quantities. The solutions of such problems are not given as tables of numbers but as continuous pictures of the values of two or more constantly changing quantities. They are answers that tell where a moving body *is*, not where it *was* when the last measurements were made.

A typical complicated problem is the design of a hydrofoil boat, on which the electronic analyser has been used for the past several months. A hydrofoil boat—one which has wings extending into the water to support it in motion so that the hull is out of the water—has speed and stability advantages which may be important in military as well as civilian uses.

Since midsummer the electronic differential analyser has been used to study the action of an entirely hypothetical hydrofoil boat in waves of many different heights, with various different types and arrangements of "wings," and at various speeds. Given certain characteristics of the non-existent craft, the machine can show how the boat would behave: its up-and-down movement, its pitches, its change in speed and how rough a sea it could take without capsizing.

LETTERS TO THE EDITOR

(We do not hold ourselves responsible for the opinions of our correspondents)

Photocells

DEAR SIR,—Readers who attempt to make their own barrier-layer photocells according to the article reprinted in your March issue are likely to be disappointed with the results. Selenium rectifier disks available in this country show about one-fiftieth of the stated light sensitivity, unless most of the opaque conducting layer is removed from the selenium surface, leaving a semi-transparent but still conducting layer.

Fortunately the process is a simple one. The conducting coating melts at a lower temperature than selenium, and it is only necessary to heat the rectifier disk gradually on a metal plate until the coating begins to show signs of melting, and then gently wipe it off. It is advisable to leave untouched a small section of the centre, to which contact may be made with a flat-headed screw bolted through the disk. An insulating bush and washer (both obtained from the original rectifier assembly), one large and one small solder tag on opposite sides of the washer, and finally a nut completes the assembly. A dip in clear lacquer is advisable to keep out damp.

If painted disks are used, the paint should be rubbed or dissolved off before heating—one cannot rely on wiping off paint and conducting layer together. Care must be taken to avoid overheating, which would melt the selenium and convert it to the insensitive black form, besides removing the last of the "ghost" coating.

Cells prepared in this way show a sensitivity ranging from 25 per cent to 50 per cent of that of conventional barrier layer cells of the same area. They are more robust, however, and will better withstand exposure to direct sunlight. A 45 mm. disk facing the North sky gave 300 mA into a meter of 100 ohms resistance, on a bright day in February. Larger disks were not proportionately more sensitive, however.

Four 45 mm. disks in parallel have been used to control the parking lights of an unattended car. The cells, mounted underneath the windscreen, operate a moving-coil relay made from one half of a blind-landing indicator meter, price 7s. 6d. from the surplus stores. The pointer was replaced by a silver-plated wire (gold plating would be better still) with silver foil as the fixed contact. The new pointer is deliberately over-weighted to avoid contact sticking, since the original movement was unnecessarily sensitive. This relay operates a type 3000 relay (2000 ohms, damped by a 10,000 ohm resistance) which when energised, via the six volt car battery, switches off the lights.

This type of cell is not really suitable for photographic use, being unduly red-sensitive. A blue-green filter could be incorporated, however, and using one of the above mentioned meter movements (100 mA F.S.D.) a moderately sensitive exposure meter may be made for a few shillings.

Yours faithfully,
L. P. LEARNEY,
Fulham, London, S.W.6.

Interference from Incandescent Lamps

DEAR SIR,—The article quoted from *Electronics* entitled "Interference from Incandescent Lamps" does not give a satisfactory explanation of the phenomenon. The resonant filament of the hypothesis given would have to have a Q value of the order of 100,000 to explain the very long period during which the interference persists. This is an impossible figure, of course.

I have observed this type of interference from two of four "candle lamps" (40 watt) in two twin wall sockets. The interference is certainly *not* a damped wave train but is exactly as described otherwise. The level is fairly constant during most of the "pulse."

The effect is not always present in the same degree (the duration of the pulse varying from day to day) and it is often completely absent. Possibly the atmospheric humidity has something to do with it.

It has been observed that placing one's hand over the bulb usually increases the width of the band on the television screen. On removing the hand the interference ceases completely for about half a second and then returns at its original width. This suggests that the effect is influenced by electric charges on the glass. The potential on the glass was observed by means of a C.R. oscilloscope and a small pick-up electrode. This voltage consisted of a mains frequency sine wave with a superimposed pulse (shaped like a clipped sine wave) which behaved in exactly the same way as the interference pulse. The pulse repetition frequency was 50 a second. Of several different types of bulb tried, all showed voltage pulses of a similar type, about half of them having a 100 c/s repetition frequency. These other bulbs had not caused interference.

One can only conclude from these results that the oscillations are of the "plasma" type, produced in the gas filling of the bulbs by the potential between the two ends of the filament. The reason for asymmetry may be differences in the surface purity of the two ends of the wire, affecting its emissivity.

My receiver is a "straight" type, so the oscillation *must* be at or near the carrier frequency (45 Mc/s).

Yours faithfully,
W. S. MORTLEY,
Chelmsford, Essex.

A D.C. Amplifier using an Electro-Meter Valve

DEAR SIR,—We have observed in an article, page 49, February issue, reference to a valve styled Osram VX3088. We should like to make it clear to the author that this is purely a Services reference and does not apply to a commercial type of valve.

We raise this because we have received one or two inquiries for this valve from commercial

sources and we must make it clear that we have no production or supply of the type for other than Government demand.—

Yours faithfully,

F. E. Henderson,

The General Electric Co., London, W.C.2.

The Noise in Fixed Resistors

Dear Sir,—This company, as specialist manufacturers of resistors, is naturally very interested in Mr. Oakes' article upon "The Noise in Fixed Resistors." Our interest arises from the fact that this phenomenon has been actively investigated by us during the past two years and we feel that with regard to the noise generated by the so-called carbon black resistors we have, possibly, more practical experience.

At the outset it is necessary to emphasise that the name "carbon track" is not a really satisfactory description for the so-called high stability resistors, since a carbon track resistor can be made from a composition of insulating varnish and carbon powder, and such material has been used for many years. If the high stability resistor is to be described without ambiguity it would be preferable to refer to it as a cracked carbon resistor, from which all readers would understand that the material was the pure crystalline carbon obtained by decomposition of organic compounds at high temperature. With regard to the noise generated we must say that after measuring many thousands of cracked carbon resistors we have never yet encountered one having a noise voltage of the order of 20 microvolts per volt, and the only explanation we can give for the samples so found by Mr. Oakes is that the tracks have been damaged in some way and a discharge was taking place in the component.

This raises a further point that, according to our measurements—which confirm work in North America by Chipman, and by Christianssen and Pearson—the noise generated by a carbon resistor of any type is not strictly proportional to the voltage applied thereto, so that the expression of noise voltage in terms of microvolts per volt is not a really satisfactory one. In many cases the departure from a linear relationship is quite small but if the noise level of the resistor is large, a much more complex expression is necessary to describe properly the nature of the noise produced.

A further factor, which may have escaped Mr. Oakes' attention, is that the noise generated by resistors of identical values will depend very largely upon the method of construction, so that a cracked carbon resistor's noise level can be controlled to some extent, particularly by the use of films having the lowest possible resistivity.

A further factor which is of interest is that it is regarded as the best practice for manufacturers of this type of component to subject all products to a noise level test to eliminate those with the highest noise level, as this would indicate faulty construction which might give rise to failure in service for other reasons.

It is a matter of interest that with cracked carbon resistors noise level, temperature coefficient and voltage coefficient are intimately related and one of these factors might be predicted from the others.

It is emphasised that the purpose of this letter is to make it clear that there is a great deal of information upon the noise level of cracked carbon resistors to which reference has not been made in the very interesting contribution by Mr. Oakes. It is not to belittle the information he has given or to criticise the accuracy but to draw the attention of your readers to the fact that, because of the intensive effort being made by both this company and others, a very much clearer picture of the nature and causes of noise in this type of resistor can be expected in the near future.

Yours faithfully,

R. H. W. Burkett,

Welwyn Electrical Laboratories, Ltd., Northumberland.

The author replies: "Mr. Burkett mentions in his letter that the name "carbon track" is not really a satisfactory description for the so-called high stability resistor. We are quite aware of this, and in fact, the high stability resistor is only one particular type of the many various designs which would come under the collective term "carbon track" resistor; this term, of course, includes cracked carbon resistors as well as other types of carbon deposit upon insulating bases. It is quite obvious that from a high stabliity resistor a noise voltage of the order of 20 microvolts per volt could not be expected unless with a faulty sample. A voltage of that order, however, can be found occasionally with bad specimens of other designs and of course more easily so, if it is one of the older and less efficient types of design.

"It was never inferred in the original article that the noise generated by a carbon resistor is strictly proportional to the voltage across its termination, and while the expression of noise voltage in terms of microvolts per volt is not really a satisfactory one from the theoretical point of view, it is quite widely used, and as a rule quite an adequate measure of the noise produced by a particular resistor. It is quite obvious that for an accurate description not only the voltage applied but also the ambient temperature and other factors would have to be stated.

"Mr. Burkett mentions that we might not be aware of the fact that the noise generated by resistors of identical values will depend very largely upon the method of construction; this fact is actually mentioned on page 58, column 1.

"In an article of a general kind covering not only cracked carbon resistors but also other carbon track resistors and solid composition resistors it is not possible to go into great details concerning individual designs; it would, of course be interesting for specialist manufacturers to cover their own particular subject and go into more technical details.

"It is interesting to hear that intensive efforts are being made to get a much clearer picture of the nature and causes of noise in different types of resistors because many sides of this subject still need clarification."

BOOK

Photoelectricity and its Application

By V. K. Zworykin and E. G. Ramberg, 478 pp. Chapman & Hall, 1949. Price 45s.

A LARGE proportion of the text books on photoelectricity originates in the United States. The present book by acknowledged experts in the field must be included among them, not as a newcomer, but as a new and enlarged presentation of a previous, well known volume "Photocells and their Application" by Zworykin and Wilson. Since the last edition of that book appeared in 1934 considerable advances have been made both in the development of new photosurfaces and of associated devices. In these we would include the recent "alloy" surfaces, photomultipliers and television cameras of both low and high velocity scanning types. As a result there has been a need for many years for a revision of the original book.

The first two chapters of the present book, which deal with historical and fundamental aspects of the subject, are followed by several chapters which describe the preparation of photocells and associated techniques such as the production of high vacua and the making of metal to glass seals. The term photocell includes the three main types, photoemissive, photovoltaic and photoconductive respectively. One of the important developments described in this part of the text is that of the "alloy" surfaces, in particular the antimony-caesium surface, having a high efficiency for blue light. In the description of its preparation no mention is made of the final stages of processing which involve oxidation of the surface under critical control conditions. This process of oxidation can increase the sensitivity by a factor of ten when carried out by those "skilled in the art."

In another chapter in this first part of the text some description is given of lead sulphide photoconductive cells. However, only passing reference is made to lead selenide cells and no mention is made of lead telluride cells which extend the response of this class of cells to longer wavelengths in the infra red region. This omission can hardly be attributed to lack of literature since a British text book of electronics published in 1947 gave considerable space to a description of the characteristics of such cells, and short communications have since appeared in scientific journals indicating developments of significance in this field.

As stated by the authors in their preface, the stress is on practical applications of photoelectricity, and the latter half of the book is concerned with these. Among the various practical devices described are included the more significant applications in facsimile picture transmission, television cameras, photometry, colorimetry, spectrochemical analysis and sound reproduction. One chapter is devoted to television cameras of various types including the recently developed low velocity beam cameras of the orthicon type. This chapter might have been made more complete by some reference to British practice as distinguished from American by the use of the C.P.S. Emitron rather than the image orthicon. In another chapter the use of photoconductive cells in infra red detectors is described. This chapter lacks reference to the application of these cells in infra red spectroscopy which has increased the ease and rapidity of determining molecular structures by a large factor.

The book concludes with chapters on miscellaneous applications of photoelectricity in industry, in meteorological work, such as cloud height determinations, in the sighting and guiding of telescopes in astronomical systems, and on the future possibilities of improvement in photoelectric surfaces. Two possibilities are considered, the increase in cell sensitivity and the extension of the response to longer wavelengths. While the authors indicate the effects of thermal disturbances in long wavelength regions they do not point out that in present practice these are minimized by refrigeration and that this procedure will be effective for regions not yet reached by present photocells. Advances in cell sensitivity are at present reaching quantum efficiencies of 20 per cent for surfaces and so no spectacular developments are likely. However, as pointed out by the authors, the conductive type of cell offers the possibility of combining high sensitivity with compactness, both of the cell and of its associated equipment. This is of importance to the practical user of these devices.

The general treatment of the subject is non-mathematical although footnotes provide some mathematical approach. There is an appendix containing a list of elements, the periodic table, systems of units and useful conversion factors, the authors showing a preference for the M.K.S.

REVIEWS

system of units. The book can be thoroughly recommended, particularly to readers concerned with industrial and commercial uses of photocells who require an adequate and up to date view of the subject.

G. F. J. GARLICK.

Radio, Television and Electrical Repairs

Edited by Roy C. Norris. 448 pp., 429 illustrations. Odhams Press, 1949. Price 10s. 6d.

THIS book devotes most of its attention to radio and electrical repairs, two short chapters in the middle being included on television, while part of a third on aerials deals with television types. The book is well illustrated throughout by means of carefully made sketches, so that it makes good appeal for its visual presentation.

Two chapters introducing principles of electricity in simple terms are followed by an introduction to basic radio receiving circuits, methods of testing and types of equipment required, which are progressively arranged to cover the whole practical range of radio servicing quite well. The ensuing brief chapters on components, loudspeakers, pick-ups and gramophone motors are not quite so up to date as some of the rest of the book; while earlier types of pick-up and gramophone motor are described in detail, the modern light weight pick-up is just mentioned, and the rim-drive motor is omitted.

The chapters on television give a brief outline of the principles of television and the waveforms of transmitted signals. Although the receiver is treated sectionally, the information on each section is scant, the only types of E.H.T. and time base described employing a mains operated half wave rectifier and a blocking oscillator respectively. The chapter on faults, symptoms and cures, treats matters only in a very general way. The chapter on aerials contains more information of a practical nature, although there is very little on the connexion of extension speakers, the subject coupled in by the title.

The remainder of the book can be placed under the general heading of electrical repairs: a comprehensive chapter on house wiring is followed by one on small appliances, including electric indicators, bells and door chimes. Leclanché cells, blankets, hair driers, toasters, clocks, fans, kettles and household irons, and shavers; the following chapters deal with various types of electric fire and space heater, and vacuum cleaners and polishers; much practical information on fault location and repair is given on all this electrical equipment. The next chapter treats the rewinding of small motors, giving useful information on fault location, but not quite such complete information on actual rewinding from the practical point of view. There follow two short but informative chapters on cookers and washing machines, a comprehensive one on refrigerators, and a longer chapter on A.C. motors that gives more information on rewinding. The last two chapters deal quite well with electric water heating and battery charging respectively.

The book forms a very helpful and convenient source of reference in the fields covered, and it would appear to be almost inevitable that a book attempting to cover so large a field in one volume of reasonable size should be somewhat less explicit in some portions of the field.

N. H. CROWHURST.

Scientific Foundations of Vacuum Technique

By Saul Dushman. 882 pp. John Wiley & Sons, Inc., New York. Chapman & Hall, Ltd., London, 1949. Price 90s.

WHEN in 1922 Dushman's "Production and Measurement of High Vacua" appeared as the first monograph of its kind it was greeted as the "Bible of the vacuum technician." Meanwhile quite a few books have appeared about the same subject (see ELECTRONIC ENGINEERING *20*, 8, 1948; *20*, 372, 1948; *21*, 32, 1949). The present book differs from the previous publications in that it confines itself to the scientific foundations only. Of course in a book of this description one must not expect to find anything of the more practical aspects of vacuum technique like the vacuum plumbing, the joints, valves, glass-to-metal seals or the special seals for the transmission of motion, the cleaning of the vessels and of the pumping fluids. Also on the various applications of high vacuum technique in electronic, chemical, metallurgical and optical engineering not very much will be found, an exception being some general remarks on vacuum distillation of metals and deposition of films in section 3 of the eleventh chapter. Nevertheless the practical electronic and chemical engineer will find a vast amount of useful information, e.g., in the chapters on the clean-up of gases at low pressures (chapter 10) and on degassing of metals and on dis

BOOK REVIEWS (Continued)

sociation pressures and rates of oxidation (chapters 9 and 12).

The initial chapter gives the principles of the kinetic theory of gases, including the theory of diffusion. Then follows a brief chapter on the flow of gases through tubes and orifices. The next three chapters deal with high vacuum pumps, followed by a chapter on the different kinds of high vacuum gauges. This chapter includes a section on leak detection. Here the most recent development, the application of the mass spectrometer, is also discussed. Chapters 7 and 8 deal with absorption phenomena, gettering and similar processes.

The experience of a lifetime of research, in which the author of the book himself did so much original work, is contained in this monumental volume, not the least advantage of which is the detailed documentation. It is a rich mine of information for all those concerned with high vacua, and it will for a large number of years be considered as a standard work.

R. Neumann.

Elementary Plastics

By J. Maitland-Edwards, B.Sc., A.R.C.S., A.R.I.C. 192 pp. 71 figs. Chas. Griffin & Co. Price 12s. 6d.

SINCE the early twenties plastics have found their way into every branch of engineering, as indeed they have into almost every part of our lives. Their varied uses in the form of sheets, mouldings, surface coatings, adhesives, etc., are of no less interest to the electrical than to other industries, and a book such as "Elementary Plastics" will be very useful. Although Mr. Maitland-Edwards particularly had in mind a book suitable for students, it will be of interest to all those in industry who wish to obtain a general knowledge of plastics, and will form an introduction for those who wish to go on to more specialized study. It is a book in which it is easy to refer to any particular branch of the subject because there are a number of chapters concerned with each of the main groups of plastics. For example, there is a chapter on the raw materials and methods of manufacture of the phenolic resins, then another dealing with methods of fabrication from them, and finally one giving their properties. It covers the wide field from the well known urea formaldehyde, phenol formaldehyde, cellulose nitrate, etc., to the more recently developed materials such as polyvinyl chloride and polyethylene. It includes a useful description of materials such as shellac and bitumen which are sometimes omitted from books on plastics, but which are widely used in electrical engineering. A small criticism of the book is, however, that some rather obscure materials are mentioned which might better have been left to a more advanced work.

This is not the sort of book which sets out to prove that plastics are a panacea for all our technical troubles. The author is clearly conscious that they have limitations as well as advantages and will be judged strictly on their merits in competition with other materials.

C. J. Moss.

Radio Engineer's Pocket Book

By F. J. Camm. Ninth (Revised) Edition. 175 pp. George Newnes, Ltd., 1949. Price 5s.

THIS small book is a useful compendium of radio facts, figures and formulæ which are needed by those engaged in many branches of the radio industry.

The most important trigonometrical, logarithmic and arithmetical tables and algebraic formulae have been included.

Electric Cables

By Francis W. Main, M.I.E.E. Third Edition. 142 pp. 52 figures. Sir Isaac Pitman & Sons, Ltd. 1949. Price 12s. 6d.

THE third edition of "Electric Cables" has been rewritten and brought up to date, and includes many new illustrations. It deals with the properties, construction, installation and maintenance of electric cables. Its scope includes those cables used for lighting, power, telephony and telegraphy, their technical characteristics and methods of manufacture.

Written by the former technical director of Enfield Cables, Ltd., this book is primarily for students, although it would also appeal to all who require a concise description of the developments in this branch of electrical engineering.

It has been well produced with clear type and diagrams, and contains a short bibliography and index.

NOTES FROM THE INDUSTRY

New President of the Organization for Standardization

M. Caquot (France) has been elected President of the Organization for Standardization (ISO) in succession to Mr. Howard Coonley (U.S.A.).

For his services to the allied cause during the 1914-18 war the British awarded M. Caquot the D.S.O. and C.M.G.

Membership of the I.S.O. is confined to representatives of the national standards bodies throughout the world. The British Standards Institution represents the United Kingdom, and implements international recommendations by reference to them in the appropriate British Standards.

In order to secure effective co-ordination of standards within the international field, the B.S.I. would be grateful if all those associated with international movements concerned with standardization would get in touch with the B.S.I. at 28 Victoria Street, London, S.W.1.

Hunts Trimmers

From 1 April, 1950 the production of trimmer capacitors by A. H. Hunt, Ltd., was discontinued.

In order to ensure continuity of supplies of the special types manufactured by Hunts, the tools and equipment have been acquired by Sydney S. Bird & Sons, Ltd., Cambridge Arterial Road, Enfield, Middlesex.

Arrangements have been made for supplies of trimmers to be available from A. H. Hunt, Ltd., to the wholesale and service trades as hitherto.

Pre-amplifiers for the Televisor

Apologies are offered for the appearance of an error in the article by W. I. Flack in the April issue. In both Figures 3 and 4 "*L3*" should be read where "*L2*" appears, and *vice versa*.

The Miller Circuit as a Low Speed Precision Integrator

By I. A. D. Lewis (February 1950 Issue, page 66).

It has been brought to the author's attention that the subject matter of the above article has several features in common with certain work done by Messrs. Standard Telephones & Cables, Ltd., Aldwych, London, W.C.2. Readers may wish to refer to British Patent No. 629,244 for a description of similar types of electronic integrating circuits.

British Plastics Exhibition and Convention

A British Plastics Exhibition and Convention are to be held at Olympia, London, early in June, 1951, the year of the Festival of Britain. Exact dates are to be announced later.

The exhibition, which will be the first trade exhibition representing the whole industry, will be open to all British firms who produce, mould and fabricate plastics materials or supply raw material or equipment to the plastics industry. While primarily for the trade, it will be open also to the public. At the convention lectures, discussions and films will cover all aspects of materials, production and applications.

The exhibition and convention are being organised, with the full approval and co-operation of the British Plastics Federation, by *British Plastics*, one of the journals published by Associated Iliffe Press.

The Television Society's Meetings

The growing popularity of the Society's lectures is reflected in the fact that many members are now unable to obtain admission to meetings owing to the large number of visitors present.

The Council have decided therefore that admission of visitors to the Society's meetings will in future be by means of ticket only. Tickets can be obtained from the Lecture Secretary, 180 Bromley Road, Beckenham, Kent.

Mond Nickel Fellowships, 1950

The Mond Nickel Fellowships Committee now invites applications for five Fellowships of average value of £750 each for 1950. Fellowships will be awarded to selected candidates of British nationality with degree or equivalent qualifications to enable them to obtain wider experience and additional training in industrial establishments, at home or abroad, to make them more suitable for future employment in senior technical and administrative positions in British metallurgical industries. Each Fellowship will cover one full working year. Applicants will be required to state details of the programme they wish to carry out.

Particulars and application forms are available from: The Secretary, Mond Nickel Fellowships Committee, 4 Grosvenor Gardens, London, S.W.1.

Completed application forms are required by June 1, 1950.

Holme Moss Television Station: Building Contract

The B.B.C. announces that the contract for the building work for the new television station at Holme Moss, near Huddersfield, has been awarded to John Laing and Son, Ltd., of Mill Hill, London.

The 35-kilowatt vision transmitter, the 12-kilowatt sound transmitter, the aerial and the aerial feeder system are being manufactured by Marconi's Wireless Telegraph Company, Ltd. A 750-foot mast similar to that at Sutton Coldfield will be supplied and erected by British Insulated Callender's Construction Company, Ltd.

As recently announced by the Postmaster-General in Parliament it is hoped that this station will be completed by the middle of 1951.

Appointment of Engineer-in-Charge, Alexandra Palace

Mr. H. Walker, O.B.E., A.M.I.E.E., has been appointed Engineer-in-Charge of the London Television Station at Alexandra Palace in succession to Mr. H. W. Baker, who was recently appointed Assistant Superintendent Engineer, Television.

Mr. Walker has been with the B.B.C. since 1931. During the war years he served in the R.A.F. He joined the staff of the London Television Station just before it opened in 1936, and returned as Assistant Engineer-in-Charge when the service was restarted in 1946.

Tender for Laboratory Equipment in Southern Rhodesia

The United Kingdom Trade Commissioner at Salisbury, Southern Rhodesia, has reported that the Southern Rhodesian Government is calling for tenders for laboratory equipment.

The closing date for the receipt of tenders, which should be addressed to the Secretary, Tender Board, The Treasury, Vincent Buildings, P.O. Box 123, Causeway, Salisbury, is 28 April, 1950.

Three copies of the specification are available in the Department. One will be retained for inspection by representatives of London firms at the Commercial Relations and Exports Department (Industries Branch), Room 1084, Thames House North, Millbank, London, S.W.1. The remaining two copies of the specification will be loaned to provincial firms in order of application.

MEETINGS THIS MONTH

INSTITUTION OF ELECTRICAL ENGINEERS

Unless otherwise stated, all meetings are held at 5.30 p.m. at the Institution of Electrical Engineers, Savoy Place, London, W.C.2.

Ordinary Meetings

Date : May 18. Time : 3 p.m.
Lecture : Commemoration of the Centenary of the Birth of Oliver Heaviside : "Heaviside The Man."
By : Sir George Lee, O.B.E., M.C.

Date : May 18. Time : 5.30 p.m.
Lecture : Commemoration of the Centenary of the Birth of Oliver Heaviside : "An Appreciation of Heaviside's Contribution to Electromagnetic Theory."
By : Professor Willis Jackson, D.Sc., D.Phil
Lecture : Heaviside's Operational Calculus.
By : Professor B. Van Der Pol, D.Sc.

Extra Meetings

Date : May 11. Time : 5.30 p.m.
Lecture : The Analysis of Action Potentials in Electromyography."
By : P. Bauwens, M.C.R.S., L.R.C.P.

Radio Section

Date : May 10. Time : 5.30 p.m.
Lecture : A Million-Volt Resonant-Cavity X-ray Tube."
By : B. Y. Mills, B.Sc., B.E.
(Joint Meeting with the Utilisation Section.)

Utilisation Section

Date : May 4. Time : 5.30 p.m.
Lecture : "Evolution of the Lighting Art."
By : J. W. T. Walsh, D.Sc., M.A.

North Western Centre

Date : May 2. Time : 6.15 p.m.
Lecture : The Continental Development of Single-Anode Mercury-Arc-Rectifier Valves for High Power.
By : H. Von Bertele.
Held at : The Engineers' Club, Albert Square, Manchester.

Northern Ireland Centre

Date : May 2. Time : 7.30 p.m.
Held at : The Wellington Hall, Belfast.
Lecture : Faraday Lecture on Radar.
By : R. A. Smith, M.A., Ph.D.

South Midland Radio Group

Date : May 1. Time : 6 p.m.
Held at : The James Watt Memorial Institute, Great Charles Street, Birmingham.
Lecture : Some Electromagnetic Problems.
By : Professor G. W. O. Howe, D.Sc., LL.D.

Southern Centre

Date : May 3. Time : 6.30 p.m.
Held at : University College, Southampton.
Lecture : Electrical Weighing.
By : H. L. Andrews, Ph.D.

THE ROYAL SOCIETY

Date : May 4.
Held at : The Royal Society, Burlington House, W.1.
Lecture : The Bakerian Lecture.
By : Professor P. W. Bridgman, Foreign Member R.S. (Harvard Univ.).

THE INSTITUTE OF NAVIGATION

Date : May 19. Time : 4 p.m.
Held at : The Royal Geographical Society, 1, Kensington Gore, S.W.7.
Lecture : Marine Radio Position Fixing Systems.
A Symposium of Papers

SECRETARIES OF ASSOCIATIONS

INSTITUTION OF ELECTRICAL ENGINEERS

The Secretary, Institution of Electrical Engineers, Savoy Place, W.C.2.

Cambridge Radio Group

G. E. Middleton, M.A., University Engineering Laboratory, Cambridge.

North-Eastern Radio and Measurements Group

G. A. Kysh (Asst. Sec.), Carliol House, Newcastle-on-Tyne, 1.

North-Western Radio Group

A. L. Green (Asst. Sec.), 244, Brantingham Road, Chorlton-cum-Hardy, Manchester, 21.

South Midland Radio Group

W. H. Brent, B.Sc., Regional Director's Office, Midlands Region (G.P.O.), Civic House, Great Charles Street, Birmingham, 3.

BRITISH INSTITUTION OF RADIO ENGINEERS

The General Secretary, 9, Bedford Square, London, W.C.1.

Merseyside Section

J. Gledhill, 123, Portelet Road, Liverpool, 13

North Eastern Section

Secretary, c/o 26, Denewell Avenue, High Heaton, Newcastle-on-Tyne.

INC. RADIO SOCIETY OF GT. BRITAIN

General Secretary, New Ruskin House, Little Russel Street, W.C.1.

BRITISH SOUND RECORDING ASSOCIATION

Richard W. Lowden, "Wayford," Napoleon Avenue, Farnborough, Hants.

TELEVISION SOCIETY

Constructors Group

G. T. Clack, 10, Tantallon Road, Balham, London, S.W.12.

Midland Centre

W. Summer, 31, Beech Road, Bournville, Birmingham, 30.

Main Society

T. M. Lance, 180, Bromley Road, Beckenham, Kent.

RADAR ASSOCIATION

Technical Committee : J. C. Warren, 57, Gallows Hill, Kings Langley, Herts.

INSTITUTION OF POST OFFICE ELECTRICAL ENGINEERS

W. H. Fox, A.M.I.E.E., Engineer-in-Chief's Office (T. P. Branch), Alder House, E.C.1.

INSTITUTION OF ELECTRONICS

Lecture Sec. : W. Summer, 31, Beech Road, Bournville, Birmingham, 30.

North West Branch

L. F. Berry, 105, Birch Avenue, Chadderton, Lancs.

INSTITUTION OF POST OFFICE ELECTRICAL ENGINEERS

Date : May 5. Time : 5 p.m.
Held at : Institution of Electrical Engineers, Savoy Place, W.C.2.
Lecture : Cinematography in Engineering.
By : W. A. J. Paul, F.R.P.S., and C. A. Steed, A.R.P.S.

BRITISH SOUND RECORDING ASSOCIATION

Date : May 20 and 21.
Time : 20th, 2.30 p.m. to 6 p.m.
21st, 10.30 a.m. to 6 p.m.
Held at : Waldorf Hotel, Aldwych, London, W.C.2.
Exhibition of Sound Recording, Reproducing and Audio Equipment.

TELEVISION SOCIETY

Date : May 2. Time : 7.15 p.m.
Held at : The Royal Society of Arts, John Adam Street, W.C.2.
Lecture : Motion Picture Film for Television. (Captain A. G. D. West Memorial Lecture).
By : I. D. Wratten, Hon. F.B.K.S., F.R.P.S.
(Joint meeting with the British Kinematograph Society and the Royal Photographic Society).

Programme Group

Date : May 4. Time : 7 p.m.
Held at : The C.E.A., 164 Shaftesbury Avenue, W.C.2.
Lecture : Television Auditions.
By : Miss Mary Cook (B.B.C.).

Constructors' Group

Date : May 12. Time : 7 p.m.
Held at : The C.E.A., 164 Shaftesbury Avenue, W.C.2.
Lecture : The Design and Operation of Television C.R. Tubes.
By : L. S. Allard, B.Sc., A.Inst.P.

Main Society

Date : May 26. Time : 7 p.m.
Held at : The C.E.A., 164, Shatesbury Avenue, W.C.2.
Lecture : Modern Development in Phosphors in Television.
By : Dr. L. Levey, M.A. (Cantab.), D.Sc. (London), F.R.I.C., F.C.S.

Midlands Centre

Date : May 1. Time : 7 p.m.
Held at : The Stafford Room, Imperial Hotel, Birmingham.
Lecture : V. H. F. Link.
By : Mr. Mumford, M.I.E.E.

BRITISH INSTITUTION OF RADIO ENGINEERS

Date : May 25. Time : 6.30 p.m.
Held at : London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.
Lecture : Multi-Station V.H.F. Communication Systems Using Frequency Modulation.
By : E. G. Hamer and W. P. Cole, B.Sc.

Merseyside Section

Date : May 3. Time : 7 p.m.
Held at : Accountants' Hall, Derby Square, Liverpool.
Lecture : History and Development of Rediffusion Systems.
By : M. Exwood.

North-Eastern Section

Date : May 17. Time : 6 p.m.
Held at : Neville Hall, Newcastle-upon-Tyne.
Technical Film.