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Wireless World

Writing it Down

THE stimulating and exemplary article on the use of words by P. P. Eckersley in our November 1959 issue and the corollary advanced by R. A. Waldron on page 22 of this issue must serve as pretexts for referring on this occasion to ourselves and to our chosen medium—the written and printed word.

To us it is axiomatic that printing is the best medium for the communication of technical knowledge. It is cheap and it is permanent. No time factor is involved. The reader can skim or study at leisure. There is no obligation to keep up with the pace of the thought processes of an author, as there may be with the spoken thoughts of a lecturer or broadcaster.

The benefits of good writing to the reader are obvious. What may not be quite so apparent, except to those who have tried it, is the value of writing for its own sake, as an exercise, as a discipline and as means of finding out how much (more often how little) one knows about a subject. The act of writing is a clarifying and very often a scarifying experience. Many people fight shy of writing because they think that a special gift or specific training is necessary, that writing is an esoteric craft to be learned by hard and long apprenticeship, for which they cannot spare the time. It may be true that special training is necessary for the writing-up of technical specifications and instructional manuals (as distinct from the writing *down* of levitating facts and ideas) and we would not deny that there are general precepts of which a conscious knowledge is sometimes advantageous. Certainly the techniques of preparation for press and of printing production are the province of specialists. Many excellent textbooks* and training courses exist for the guidance of those who wish to take up technical writing as a profession, but for the beginner essaying his first article for submission to a journal the less he knows about these things the better. The recipe for good writing is quite simple and involves only two processes; first, making up one's mind what to say, and then saying it. As in painting and decorating it is the preparation that takes the time. Putting on the paint is the easy part, but it will soon have to be done all over again if the preparation has been less than thorough.

In a technical journal like ours the content of an article is of greater importance than the style in which it is written; matter is more important than manner. But that is not to say that style is unimportant. It may help or hinder the reader in getting to grips with the subject. It is even more significant in revealing the writer's mental make-up and capacity. As Buffon has put it (rather more succinctly), "*Le style est l'homme même.*" And if a turgid and obscure first draft, full of irrelevant digressions is turned by the author into a simple and direct exposition of a single central theme, the struggle will not have been made without leaving its mark on the man.

In writing there is no substitute for practice, but one should not despair if there seems to be too slow a gain in facility; remember the dictum that "easy writing makes hard reading."

If the matter seems worthy of a wider readership and it is decided to send the article to a journal, it should be typed or legibly written on one side of the paper with space between the lines for printers' instructions (and, who knows, spelling corrections). Time spent by the author on beautifully inked-in diagrams, and lettering on photographs is usually wasted, as most journals like to prepare illustrations themselves. There are many technical reasons why this should be so, and in this journal all we ask is legibility, and, if there is any doubt about size or quality of photographs, the loan of the negatives to make our own enlargements. It is not safe to assume that there will always be time to send proofs to authors for reading. Do not count, therefore, on having an opportunity for second thoughts, but make sure that the manuscript is in a finished state *before* it is submitted. We will then see that the printer has properly interpreted the author's intentions, and it goes without saying that no major alterations will be made without consultation (*pace* Mr. Waldron).

There can be no doubt that a well-written article gains wide recognition for its author, not only from his compeers but also from his employers. The Radio Industry Council and the Electronic Engineering Association have acknowledged this by making a number of premium awards annually for technical writing, and on the occasion of the last prize distribution L. T. Hinton, Chairman of the E.E.A., had this to say:

> "I can tell you that we look upon [these awards] as of the utmost importance in so far as they encourage technical authors to give of their best.
>
> "These articles are not only helpful to British industry, but the prestige and standing of British research and engineering in the countries of the world can be greatly enhanced by the standard of technical writing. The product we sell is highly technical. we sell it to technical customers and good, authoritative, well presented and well distributed technical writing does more to help our vital exports than all the glossy brochures put together."

* For example "The Technical Writer" by J. W. Godfrey and G. Parr (Chapman & Hall).

THE SMITH CHART

Survey of Transmission Line Phenomena : Derivation and Uses of the Chart

*By R. A. HICKSON**

THE Smith chart[1] is a transmission-line chart which facilitates the solution of almost all problems arising in the use of coaxial or balanced transmission lines, and some related problems, such as the design of lumped-element matching networks. However, its forbidding appearance, and the severely mathematical tone of most references to it in the literature[2, 3, 4] have given it a reputation for difficulty which is not merited. The Smith chart is no more difficult than the slide rule and saves a comparable amount of time and effort in its own field. In addition, its use is of great assistance in understanding transmission-line behaviour at very high frequencies.

Transmission-line Phenomena.—If a radio-frequency generator is connected to one end of an infinitely long transmission line the power supplied to the line will travel along it towards the remote end and will gradually be dissipated in the line. There will be no power travelling in the opposite direction. If now the line is cut, a certain load can be connected to the cut end which will simulate the missing portion of the line by absorbing all the power reaching it; the impedance of this load is the same as the characteristic impedance of the line (Z_0). This is for practical purposes equal to a pure resistance of value $\sqrt{L/C}$ where L is the inductance and C the capacitance of equal lengths of line. This formula is an approximation which assumes that the loop resistance is negligible in comparison with the inductive loop reactance and that the conductance between the two conductors is negligible in comparison with the capacitive susceptance between them. In other words it assumes good conductors and a good dielectric, and operation at a reasonably high frequency.

Any load other than the characteristic impedance will not absorb all the power travelling from the generator. (The power may be dissipated directly as heat at radio frequency, or rectified and used to operate, e.g., a meter, or radiated, as in the case of an aerial). The power which is not absorbed by the load is reflected by it and travels back along the line towards the generator. It will be assumed for the moment that the generator has the same impedance as the line and so absorbs all the reflected power. A load or generator having the same impedance as the line is said to be matched to the line.

The extent to which a load is matched to a line can be expressed by stating the voltage reflection coefficient or the return loss of the load. The value of the concept of return loss has been discussed recently[5] and we will mention only the definition at this point. Return loss is the attenuation between the incident power and the reflected power. A related concept is reflection loss, which is the attenuation between the incident power and the power absorbed by the load. Formulae for both these losses, which are customarily expressed in decibels, will be derived later.

The voltage reflection coefficient K is the ratio of the reflected wave voltage E_r to the incident wave voltage E_i. The best possible match, given by a load of impedance equal to Z_0 will produce a voltage reflection coefficient of zero. The worst possible match, given by a loss-free load, i.e. an ideal open circuit, an ideal short-circuit, an ideal capacitor or an ideal inductor, will produce a voltage reflection coefficient of unity. The phase of the reflected wave with respect to the incident wave will depend on the nature of the load, and may have any value from 0° (in-phase) to ± 180° (exactly out-of-phase). As the incident and reflected waves are being propagated along the line in opposite directions the phase angle will vary with the distance from the load. In a distance in which each wave alters in phase by 180°, that is, in a half wavelength, the total change in phase between the two waves will be 360°.

The phase angle of the voltage reflection coefficient will therefore have the same value at half-wavelength intervals along the line. For a frequency of F Mc/s, one wavelength in air is approximately equal to 300/F metres. For other dielectrics the wavelength in air is divided by the square root of the effective permittivity of the dielectric, or multiplied by the velocity factor of the line.

The reflection coefficient may be plotted on a polar chart showing the phase angle as the angle from an arbitrary direction and the magnitude E_r/E_i as distance from the centre. Movement along a transmission line will then correspond to movement round a circle of constant radius on the chart, assuming that line losses are negligible. In cases where the line losses are not negligible the magnitude of the reflection coefficient will decrease as distance from the load increases. If the attenuation between two points is N dB each voltage will change by antilog N/20, so that their ratio E_r/E_i will change by antilog N/10.

Movement along a line having attenuation will therefore be represented by movement along a spiral on the chart, the radius of the spiral decreasing as distance from the load increases. Fig. 1 shows the change in reflection coefficient entailed in moving along loss-free and lossy lines through a distance of one half-wavelength from a load giving a voltage reflection coefficient of 0.8 (180°). The loss of 2.5dB per wavelength is greater than will normally be encountered. For example, a typical cellular polythene feeder in Band III would have a loss of only about 0.25dB per wavelength. The choice

* Belling and Lee Ltd.

of the clockwise direction to represent movement away from the load is the accepted convention.

Effect of Type of Load on Reflection Coefficient.—The nature of the voltage reflection coefficient produced by various types of load will now be considered. Considering the current and voltage relationships in the incident wave, the reflected wave and the load, we may write:—

$$E_i = Z_o I_i$$
$$E_r = -Z_o I_r$$
$$E_l = Z_l I_l$$

The minus sign in the second equation expresses the fact that the reflected power is propagated in the reverse direction.

Applying Kirchoff's laws to the junction of line and load:—

$$E_i + E_r = E_l$$
$$I_i + I_r = I_l$$

Simultaneous solution of these five equations gives:—

$$\frac{E_r}{E_i} = \frac{Z_l - Z_o}{Z_l + Z_o}$$

As stated above, Z_o may be considered as a pure resistance, which we may call R_o, so that:—

$$\frac{E_r}{E_i} = \frac{Z_l - R_o}{Z_l + R_o}$$

Writing K for E_r/E_i

$$K = \frac{Z_l - R_o}{Z_l + R_o}$$

(*a*) *Characteristic impedance R_o.*—By definition, see above, this will produce a voltage reflection coefficient of 0 (0°).

(*b*) *Short circuit.*—As this cannot absorb any power, $E_r = E_i$ and, as no voltage can exist across a short circuit, E_r and E_i must be exactly out of phase. The voltage reflection coefficient is 1 (180°). Mathematically

$$K = (0 - R_o)/(0 + R_o) = -1.$$

This is equivalent to + 1 (180°) as can be seen by considering that the positive direction along the 0° line is from the centre of the chart towards the edge,

(*c*) *Open circuit.*—As with the short circuit no power is absorbed and $E_r = E_i$. Since no current can flow across an open circuit the current due to E_i must be exactly out of phase with that due to E_r, that is, $I_i = -I_r$.
As $(E_i/I_i) = Z_o = -(E_r/I_r)$, $E_i = E_r$, that is, they are in phase and the voltage reflection coefficient is 1 (0°).

$$K = (\infty + R_o)/(\infty - R_o) = 1$$

(*d*) *Capacitor.*—A loss-free capacitor whose reactance at the operating frequency is numerically equal to the line impedance will be considered:-

$$Z_l = 0 - jR_o$$

$$K = \frac{0 - jR_o - R_o}{0 - jR_o + R_o} = \frac{-j1 - 1}{-j1 + 1}$$
$$= \frac{(-j1 - 1)(+j1 + 1)}{(-j1 + 1)(+j1 + 1)}$$
$$= \frac{-j^2 - j2 - 1}{-j^2 + 1} = -j1$$

In polar notation, K = 1 (− 90°).

(*e*) *Inductor.*—For a loss-free inductor whose reactance at the operating frequency is numerically equal to the line impedance, $Z_l = 0 + jR_o$. A calculation on the same lines as that for the capacitor, above, shows that K = 1 (90°).

We are now ready to derive the Smith chart.

Derivation of the Smith Chart.—The five points corresponding to loads of R_o, 0, ∞, $0 + jR_o$ and $0 - jR_o$, as determined previously, are indicated in Fig. 2, which shows the voltage reflection coefficient produced at the load itself; as discussed in connection with Fig. 1, the reflection coefficient will change as we move along the line away from the load. Further calculations on the same basis will show that the reflection coefficients produced by the five possible types of load are as shown in Fig. 3. It will be appreciated that infinite reactance is, like infinite resistance, an open circuit; similarly

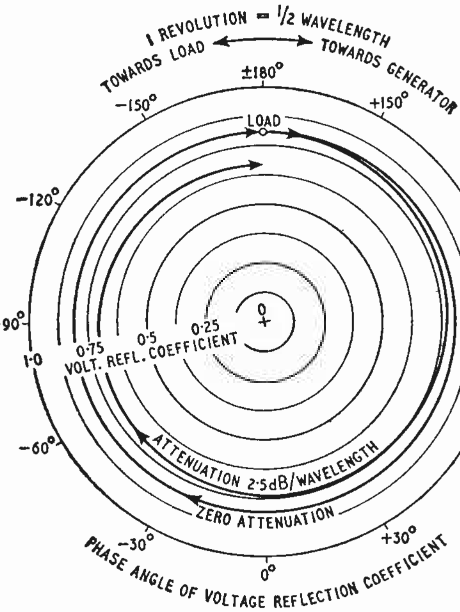
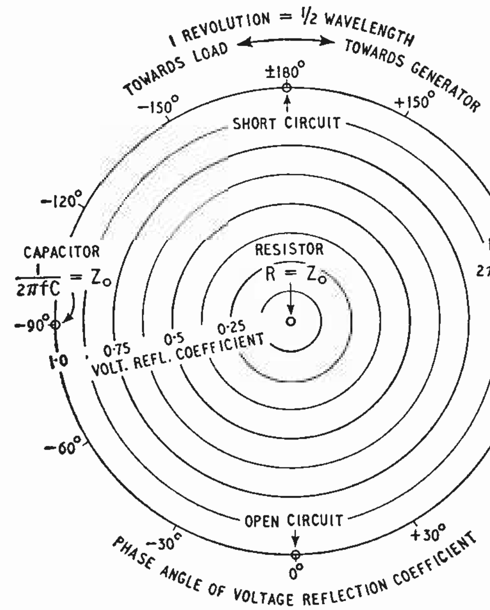


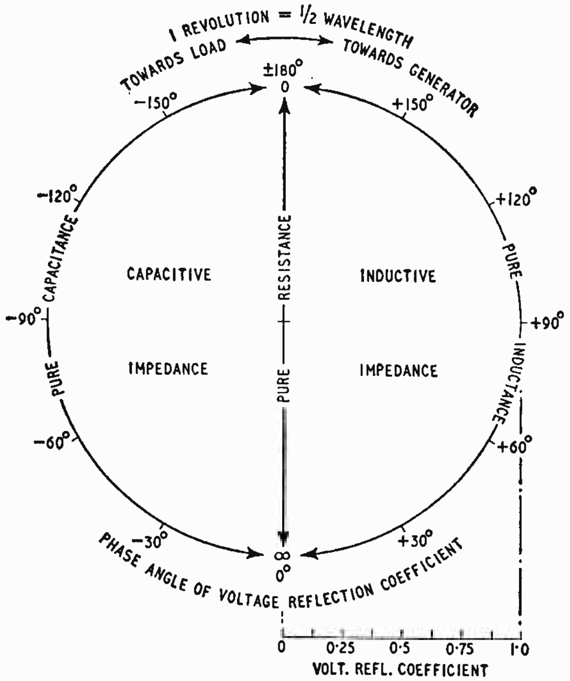
Fig. 1. Polar diagram of voltage reflection coefficient. Effect of movement along loss-free and lossy lines.

Fig. 2. Voltage reflection coefficients produced at the load by five specific loads.



zero reactance is, like zero resistance, a short circuit, so that the points ∞ and 0 are common to the resistance and reactance axes.

Since in any particular problem the characteristic impedance of the transmission line is a constant, it is customary to normalize the load impedance by expressing it as a multiple of the line impedance. Fig. 4 shows the same loads as Fig. 2, now normalized, together with certain intermediate points obtainable by means of similar calculations.



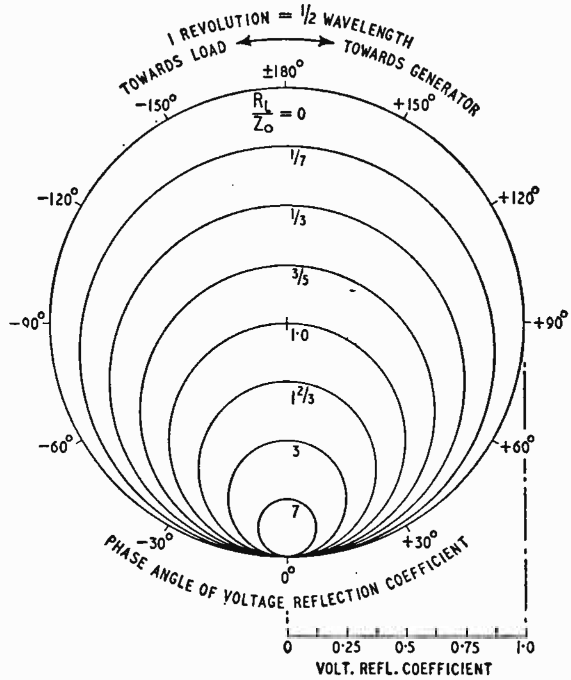
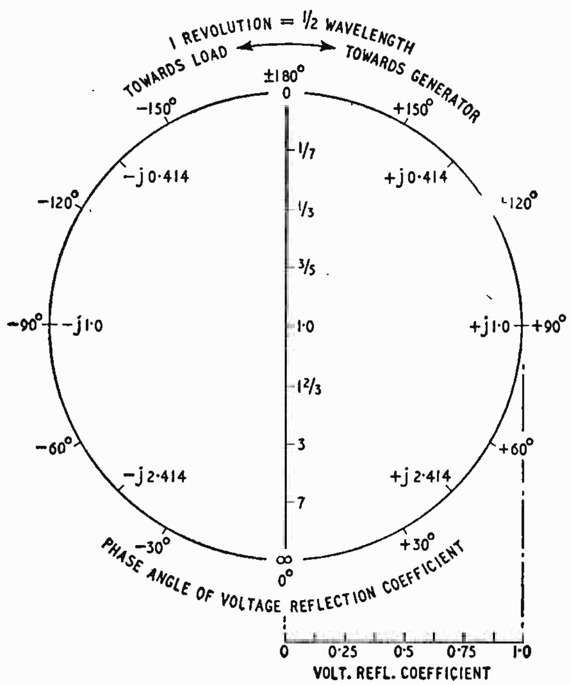


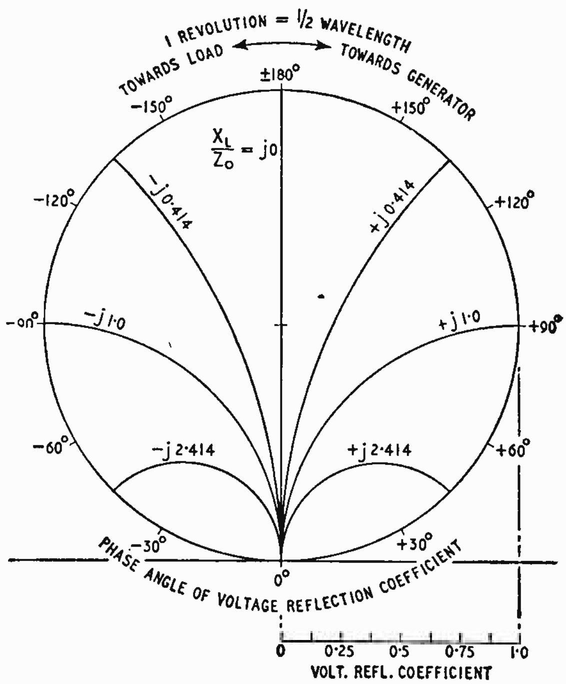
Fig. 3. Voltage reflection coefficients produced at the load by the five possible types of load. Magnitude of the reflection coefficient is shown on an auxiliary scale.

Fig. 4. Voltage reflection coefficients produced at the load by various normalized loads.

Fig. 5. Voltage reflection coefficients produced by loads having the same normalized resistive component of load impedance lie on a circle.

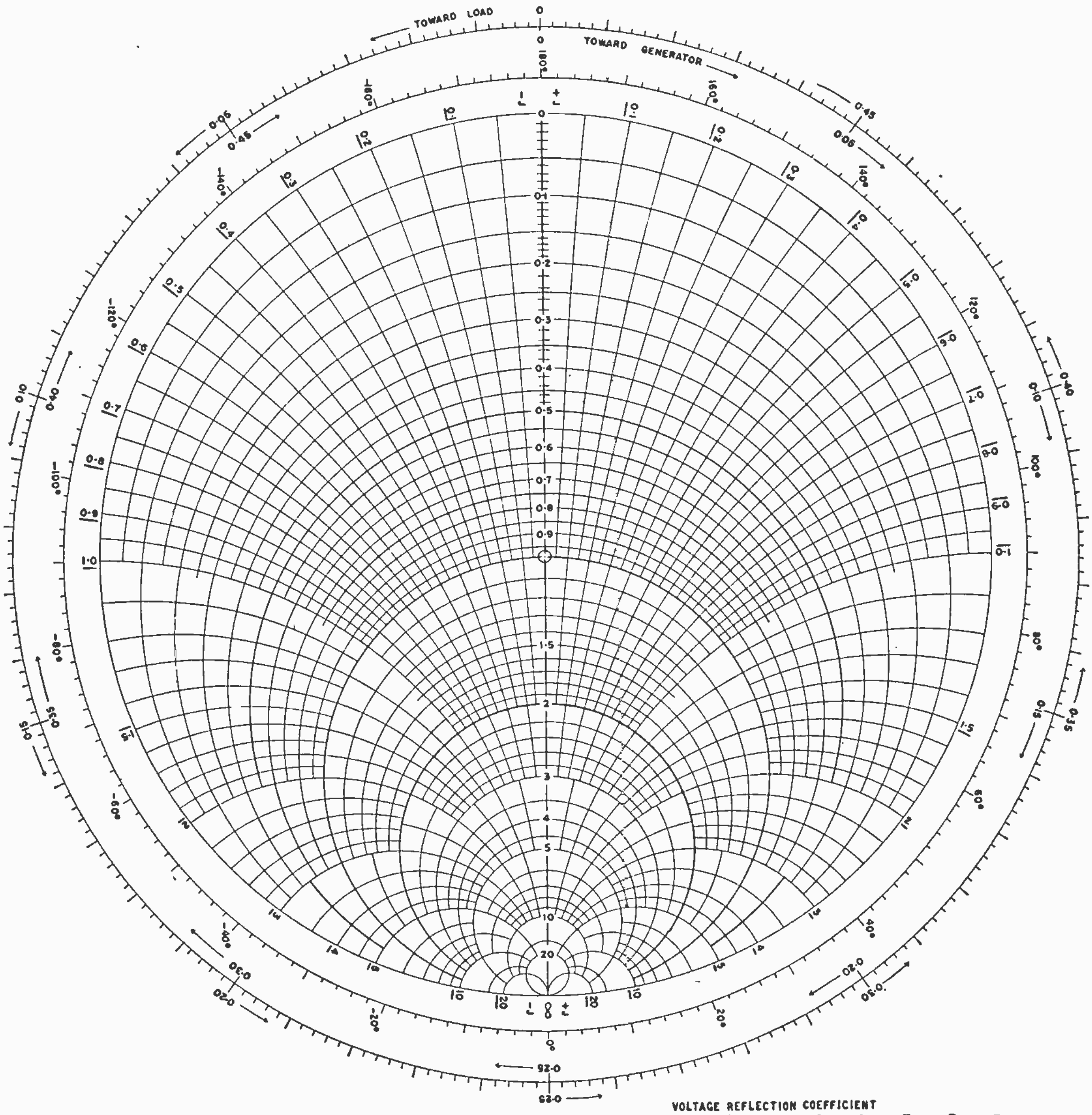
Fig. 6. Voltage reflection coefficients produced by loads having the same normalized reactive component of load impedance lie on an arc of a circle.





It is found that all loads having the same normalized resistive component of load impedance R_l/R_o produce reflection coefficients which lie on a circle. A mathematical demonstration of this is given in Appendix I. The centre of the circle lies on the resistance axis and the circle passes through the point of reflection coefficient 1 (0°). Some of these circles of constant ratio R_l/R_o are shown in Fig. 5.

Similarly it is found that all loads having the same normalized reactive component of load impedance $\pm jX_l/R_o$ produce reflection coefficients which lie on an arc of a circle. Each circle again passes through the point of reflection coefficient 1 (°) and the centre of each circle lies on the line through this point at right angles to the resistance axis. Some of these arcs of circles of constant ratio



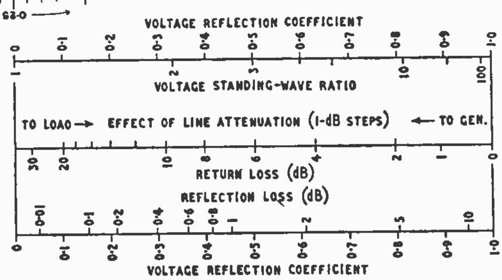


Fig 7. The Smith chart is composed of the circles of constant normalized load resistance and reactance.

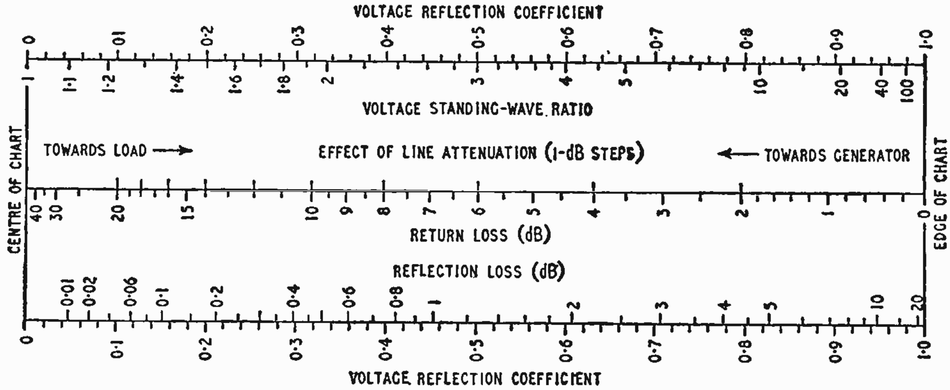


Fig. 8. Auxiliary scales are provided for radially-scaled parameters to avoid additional circles on the chart.

$\pm jX_l/R_o$ are shown in Fig. 6. The portions lying outside the circle defined by a reflection coefficient of unity have no physical significance here, as we are considering only passive loads, which cannot reflect a voltage greater than the incident voltage.

The Smith chart, Fig. 7, is a reflection coefficient chart drawn in terms of these circles of constant normalized load resistance and reactance.

The underlying circles of constant magnitude of voltage reflection coefficient and the radial lines of constant phase angle of voltage reflection coefficient are not shown on the chart, to avoid confusion. Instead, a separate auxiliary scale is provided for the magnitude, and a scale of phase angles is provided round the perimeter of the chart.

In addition to the phase-angle scale, scales for "Wavelengths towards Generator" and "Wavelengths towards Load" are normally provided round the outside of the chart. As shown earlier, a complete circle round the centre of the chart represents a distance of one half-wavelength: movement clockwise represents movement towards the generator and vice versa. These scales are customarily shown with their zeros at the point of minimum impedance (phase angle 180°). This is, of course, an arbitrary choice, and in practical problems one may wish to start at any phase angle. In one commercially available Smith chart calculator the wavelength scales are movable and the zeros can be set to any phase angle.

Returning now to radially scaled parameters, Fig. 8, these may include, in addition to voltage reflection coefficient:—

(*a*) Voltage standing-wave ratio.
(*b*) Return loss.
(*c*) Reflection loss.
(*d*) Effect of line attenuation.

(*a*) *Voltage standing-wave ratio.*—The v.s.w.r. scale is the same as the resistive component scale along the pure resistance axis. This is demonstrated in the later section "Voltage Variations along a Mismatched Line," where it is also shown that, writing S for v.s.w.r., $S = (1 + K)/(1 - K)$.

(*b*) *Return loss.*—This is the attenuation between the incident wave and the reflected wave, so that it is equal to the square of the reciprocal of the voltage reflection coefficient. It is usually expressed in decibels so that:—

Return loss = 20 log 1/K .. dB.

(*c*) *Reflection loss.*—This is the attenuation between the incident wave and the power absorbed by the load. As the power absorbed P_a is that which is not reflected P_r, the reflection loss is complementary to the return loss:—

$$P_a = P_i - P_r$$

$$\frac{P_a}{P_i} = 1 - \frac{P_r}{P_i} = 1 - \left(\frac{E_r}{E_i}\right)^2 = 1 - K^2$$

$$\frac{P_i}{P_a} = \frac{1}{1 - K^2}$$

$$\text{Reflection loss} = 10 \log \left(\frac{1}{1 - K^2}\right) \ldots \text{dB}$$

(*d*) *Effect of Line Attenuation.*—This effect on the voltage reflection coefficient was discussed in the first section, where it was shown that if there is an attenuation of N dB between two points the ratio of the voltage reflection coefficients at the two points is antilog N/10. The effect of line attenuation on the v.s.w.r., return loss and reflection loss can be arrived at by use of the radial scales. As with the wavelength scales round the perimeter of the chart, the line attenuation scale may be entered at any point and the graduations, shown here as 1-dB steps, are not normally numbered. This makes interpolation rather difficult at the open end of the scale. However, the difficulty may be eased by use of the "Return Loss" scale. Steps of 2dB on this scale are mathematically equivalent to steps of 1dB on the "Effect of Line Attenuation" scale. The two scales are placed side by side to facilitate this use. It should be pointed out that the equivalence is purely mathematical and it is meaningless to say that, for example, a return loss of 4dB corresponds to a line attenuation of 2dB. The "Return Loss" scale is an absolute one, in the sense that any point on the scale has a definite significance. The "Effect of Line Attenuation" scale is a relative one, and a point on this scale has no significance in itself; only distances along this scale are of interest.

Impedance Variations Along a Mismatched Line.—Comparing Fig. 1 with Fig. 7 it will be seen that the impedance looking towards the load will vary at different points along a mismatched transmission line. The Smith chart shows directly the effect of the length of line on its input impedance.

Taking the example of Fig. 1, in which the load is resistive and less than the characteristic line impedance, the input impedance, moving away from the load, is inductive for the first quarter-wavelength, then, at $\lambda/4$ from the load, a resistance greater than the characteristic line impedance, then capacitive for a quarter-wavelength, then, at $\lambda/2$ from the load, again becomes resistive and less than the line impedance. If it is permissible to neglect line losses, then the line input impedance is the same at half-wavelength intervals. Thus a half-wavelength section of line may be said to repeat the load: the impedance of the line itself does not enter into this result. This is not the case for any shorter length. At quarter-wavelength intervals, for example, the impedances are such that, when multiplied together, the result is equal to the square of the characteristic impedance.

This result is easily verified in the case of resistive impedances; for example, the point $2 + j0$ is on the same voltage reflection coefficient circle as the point $\frac{1}{2} + j0$. Similarly, an open-circuit at the end of a line will appear as a short circuit a quarter-wavelength away from the end, and vice versa. A quarter-wavelength section of line is said to invert the load. In the case of loads which are not purely resistive, the impedance is inverted and the phase angle is changed by 180°, so that a capacitive load is transformed into an inductive load, and vice versa, by a quarter-wavelength section of line. For example a load of impedance $3 + j4$, i.e., $Z_l = 5$, is transformed into $(0.12 - j0.16)$, i.e., $Z_l = 0.2$. This can be seen by starting from the point $3 + j4$ and moving through 180° round a circle centred on the centre of the chart; as stated in connection with Fig. 1, this angle corresponds to a movement along the line of one quarter wavelength. The apparent impedance is $0.12 - j0.16$ after this movement, and the phase angle of the reflection coefficient has changed from $+18°$ to $-162°$, i.e., from inductive to capacitive.

Voltage Variations Along a Mismatched Line.—The instantaneous voltage along the line is varying sinusoidally at the operating frequency, and it is not this voltage, but the peak value which it attains, that is referred to here. Neglecting line losses, the power flowing along a line under steady conditions does not change. As $P = E^2/R$, the maximum total voltage $E_i + E_r$ will occur at points of high impedance. As E_i and E_r are vector quantities, this implies that they are in phase at these points. Fig. 7 indicates that the phase angle of the reflection coefficient (i.e., the vector difference between E_i and E_r) is zero for a load of infinite impedance. Similarly, at points of low impedance the resultant voltage will have a minimum value, and E_i will be exactly out of phase with E_r. This is again in agreement with Fig. 7, which indicates a phase angle of ±180° for a load of zero impedance. The maximum and minimum points do not move along the line with time, and the resultant pattern of peak voltage distribution is referred to as a quasi-stationary or standing-wave pattern. The ratio between the maximum and minimum peak voltages is called the voltage standing-wave ratio, S.

$$S = \frac{E_{max}}{E_{min}} = \frac{E_i + E_r}{E_i - E_r}$$
$$= \frac{1 + (E_r/E_i)}{1 - (E_r/E_i)} = \frac{1 + K}{1 - K}$$

A number of British workers define v.s.w.r. as (E_{min}/E_{max}) but the American practice, followed here, is becoming more common. As the v.s.w.r. is never greater than unity in the one system, and never less than unity in the other, there is no possibility of confusion.

For loads other than resistive, the v.s.w.r. will bear the same relation to K. The only difference in the v.s.w.r. pattern produced by resistive and reactive loads of the same voltage reflection coefficient will be in the positions of the maxima and minima with respect to the load. The whole standing-wave pattern will be displaced along the line according to the phase angle of the reflection coefficient at the load.

It is interesting to note that the v.s.w.r. is simply related to the load impedance.

$$S = \frac{1 + K}{1 - K} \text{ and } K = \frac{Z_l - R_o}{Z_l + R_o}$$

Writing z for $\frac{Z_l}{R_o}$, $K = \frac{z - 1}{z + 1}$

$$S = \frac{1 - \left(\frac{z-1}{z+1}\right)}{1 + \left(\frac{z-1}{z+1}\right)} = \frac{z + 1 + z - 1}{z + 1 - z + 1} = z$$

In words, the v.s.w.r. is equal to the normalized load impedance, or to its reciprocal if this is greater than unity.

The importance of the v.s.w.r. is that it can be measured with comparatively simple equipment, and from the result useful deductions can be made. It is clear that movement along a line having attenuation will result in a change in v.s.w.r., as it does in voltage reflection coefficient. The change can be evaluated with the aid of the auxiliary line attenuation scale of the Smith chart.

A quantity sometimes encountered in the literature is the so-called power standing-wave ratio. In fact, of course, there are no standing waves of power. The power flowing along a transmission line can only vary gradually, by attenuation, or once-for-all, by reflection, not in the cyclic manner in which the voltage varies when reflection occurs. The term arises when a square-law indicator is used in the measurement of v.s.w.r. The readings obtained are proportional to the square of the voltage and so their ratio represents the power ratio which would correspond to the voltage ratio if both voltages were developed across the same impedance. As they are not, the term is meaningless. Some workers, to avoid the possibility of confusion, convert their standing-wave ratios to decibels. This cure is worse then the disease, as the decibel is a power ratio, and may only be used for voltages when the voltages are developed across identical impedances.

Representation of Admittance of the Smith Chart.—In certain applications, such as the addition of a matching stub in parallel with a load impedance, the use of normalized admittance is convenient. This is because admittances add when placed in parallel. The normalized admittance y is the reciprocal of the normalized impedance z.

$$y = \frac{1}{z}$$
$$z = \frac{1 - k}{1 + k}$$
$$y = \frac{1 + k}{1 - k}$$
$$= \frac{1 - (-k)}{1 + (-k)}$$

Thus the relation of y to $-k$ is the same as that of z to k. The Smith chart may therefore be used for admittance calculations with the scale for reflection coefficient angle rotated through 180°.

When it is necessary to change from an admittance to an impedance basis during the course of a calculation, all that is necessary is to rotate the point representing the value through 180° round a circle of constant K. This operation amounts to finding the reciprocal of a complex number.

Some Smith charts are provided with a circle of unity conductance to facilitate operations. This is the circle of unity resistance rotated bodily through 180° about the point $(1 + j0)$.

Loads expressed as admittances, conductances or susceptances are normalized by dividing the values by the characteristic admittance of the line, that is, by multiplying the values by the characteristic impedance. For example, a load of $0.02 - j0.01$ mhos on a 75-ohm line would have a normalized value of $1.5 - j0.75$.

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APPENDIX I.

Construction of the Smith Chart.—The voltage reflection coefficient is shown in Fig. 1 in polar co-ordinates. However, it may also be expressed in rectangular co-ordinates, and this will be done here, as it leads to easier mathematics.

The use of $u + jv$ does not imply that the reflection coefficient has resistive and reactive components. It is merely a mathematical device for describing the location

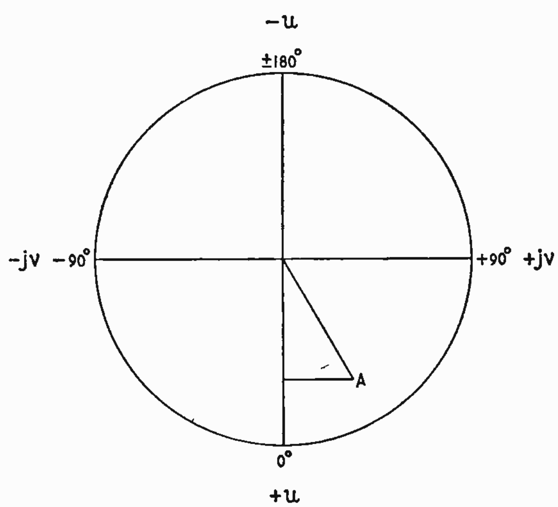


Fig. 9. Use of rectangular co-ordinates for voltage reflection coefficient.

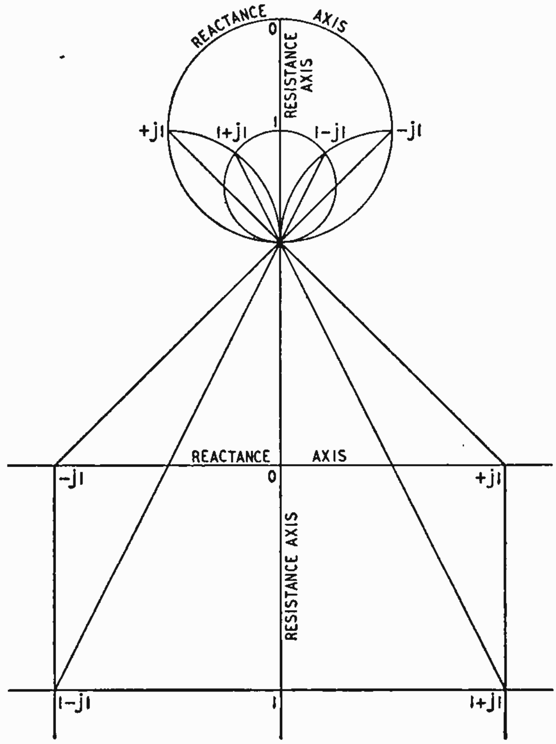


Fig. 10. The Smith chart is geometrically related to the Cartesian impedance diagram.

on the chart of the point representing the reflection coefficient. For example, point A in Fig. 9 represents a reflection coefficient of 0.75(30°): using the $u+jv$ notation it would become $0.65+j0.375$.

Let $K = u+jv$

$$\frac{R_l}{Z_o} = r$$

$$\frac{X_l}{Z_o} = x$$

Then $\dfrac{Z_l}{Z_o} = r + jx = \dfrac{1+K}{1-K}$

$$r + jx = \frac{1 + u + jv}{1 - u - jv}$$

Rationalizing

$$r + jx = \frac{1 - u^2 - v^2 + j2v}{(1-u)^2 + v^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Equating the real parts of (1)

$$r = \frac{1 - u^2 - v^2}{(1-u)^2 + v^2}$$

$$r(1-u)^2 - rv^2 = 1 - u^2 - v^2$$

$$r + ru^2 - 2ru + u^2 = 1 - v^2 - rv^2$$

$$u^2(1+r) - 2ru + r = 1 - v^2(1+r)$$

$$u^2 - \frac{2ru}{1+r} - \frac{r}{1+r} = \frac{1}{1+r} - v^2$$

Subtracting $\dfrac{r}{(1+r)^2}$ from both sides

$$u^2 - \frac{2ru}{1+r} - \frac{r^2}{(1+r)^2} = \frac{1}{(1+r)^2} - v^2$$

$$\left(u - \frac{r}{1+r}\right)^2 + v^2 = \frac{1}{(1+r)^2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

This is the equation of a circle in the u, v plane with centre at the point $\frac{r}{1+r} + j0$ and with radius $\frac{1}{1+r}$.

Substitution of the value of r in these formulae will give the circle of constant normalized resistance equal to r.

Similarly, equating the imaginary parts of (1)

$$jx = j\frac{2v}{(1-u)^2 + v^2}$$

$$x - 2ux + xu^2 + xv^2 = 2v$$

$$u^2 - 2u + 1 + v^2 - \frac{2v}{x} = 0$$

Adding $\frac{1}{x^2}$ to both sides

$$u^2 - 2u + 1 + v^2 - \frac{2v}{x} + \frac{1}{x^2} = \frac{1}{x^2}$$

$$(u-1)^2 + \left(v - \frac{1}{x}\right)^2 = \frac{1}{x^2} \quad \ldots\ldots\ldots \quad (3)$$

This is the equation of a circle in the u, v plane with centre at the point $(1 \pm j\frac{1}{x})$ and with radius $\frac{1}{x}$. Substitution of the value of x in these formulae will give circles of constant normalized reactance equal to x. For a given arithmetical value of x, jx may be positive or negative.

Equations (2) and (3) give the basis for the construction of the chart itself. The auxiliary radial scales are constructed on the basis of the equations given earlier.

APPENDIX II.

Original Derivation of the Smith Chart.—The Smith chart can be obtained from the Cartesian impedance diagram by means of a conformal transformation. This is the method originally used by Smith (1) and is referred to in the standard texts [2, 3, 4]. However, it is less satisfying from the physical standpoint than the approach presented above. The Cartesian diagram is the normalized form of the Argand diagram of impedance; the negative resistance axis is omitted, as only passive loads are considered. To accommodate an open circuit this diagram would require extension to infinity, and so it is not in common use. Another, related, defect of this diagram is that the voltage reflection coefficient cannot be represented on it in the skeleton form used in the Smith chart, but must be shown in full.

A suitable conformal transformation distorts the straight constant-resistance and constant-reactance axes into circles, but preserves the orthogonality of their intersections. Details are given in references 1, 2 and 3. The geometrical equivalent of the transformation is shown in Fig. 10.

The Cartesian chart is inverted about the point $(-1 + j0)$, which becomes the infinity point on the Smith chart. Corresponding points in the two charts lie on the same straight line and the distances of the points from $(-1 + j0)$ are reciprocally related. Derivation for the Argand diagram is the reason why the Smith chart is often shown with the resistance axis horizontal, although the chart itself is more readily handled with the resistance axis vertical.

Radio Hobbies Exhibition

SINGLE-SIDEBAND EQUIPMENT ON SHOW

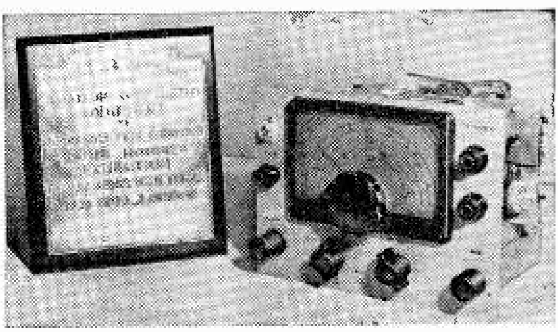
THIS year, two awards for outstanding design and construction were made. Both took the form of silver plaques; one, as in previous years, being awarded for the most outstanding home-constructed piece of equipment and, an innovation, one for the piece of commercial equipment of the greatest value to the amateur.

W. J. Colclough, G3XC, gained the amateur award with his transistor communications receiver, which uses 14 transistors, covers 1.9 to 29.5Mc/s in six bands and operates from an internal 6-V dry battery. The receiver is a double superhet with an r.f. amplifier using OC170 transistors for this stage, the first mixer and the oscillator: the first i.f. is 1Mc/s and the second, is 500kc/s. A "Q-multiplier" operates on the 500kc/s i.f. stage and a.g.c. is derived from a two-stage amplifier.

The Minimitter Company won the commercial award with their MR44 communications receiver. This is an 11-valve set—again a double superhet—covering six amateur bands between 1.8 and 30Mc/s, each band being represented by 8-in of tuning scale. The MR44 is designed for reception of a.m. R/T, s.s.b. and c.w. signals; for s.s.b. it uses a half-lattice crystal filter and a product detector. This, though, was not the only commercial equipment offering single-sideband facilities but all the apparatus seen used the filter system for generation or demodulation of s.s.b. signals.

The recent relaxation of dollar-import regulations resulted in the appearance of two well-known American names at the show—Collins and Hallicrafters—both with equipment which, in appearance and performance specification, is of the highest quality. James H. Scott, representing Hallicrafters, were showing an extensive range of receivers and transmitters, notable among which was the SX-101A—a 15-valve double superhet giving a.m., c.w. or s.s.b. reception on the amateur bands between 160m and 10m: it has a sensitivity of better than $1\mu V$ for a signal-to-noise ratio of 10dB. On show was the Collins KWM-2 which, in a cabinet $8 \times 15 \times 13$in, combines a five-band s.s.b./c.w. transmitter of 100W p.e.p. output and a receiver of sensitivity $0.5\mu V$ (for 10dB s.n. ratio). The power supply is separate and two versions are available; one is a straight-forward a.c.-mains unit and the other is a low-voltage transistor convertor so that the KWM-2 may be used as a mobile station. Two interesting features of Collins equipment are their s.s.b. filters, and a noise suppression circuit which, in contrast to more common arrangements, uses the slow response of the narrow-band main receiver as an advantage. The noise-blanking unit receives electrical interference on a separate wide-band receiver

W. J. Colclough's amateur-award-winning receiver.

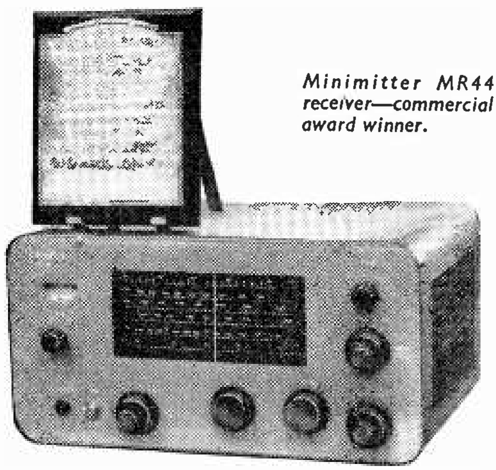


(±0.5Mc/s) operating at about 40Mc/s and produces from the noise a pulse which is used to cut off the main receiver. Due to the difference in speed of travel of the noise through the two receivers (slow in the main set, fast in the wide-band receiver) this blanking action can occur before the noise has completed its transit through the main receiver. For s.s.b. generation and detection Collins use a "mechanical filter" which consists of a set of resonant discs coupled together mechanically and excited by a magnetostrictive transducer.

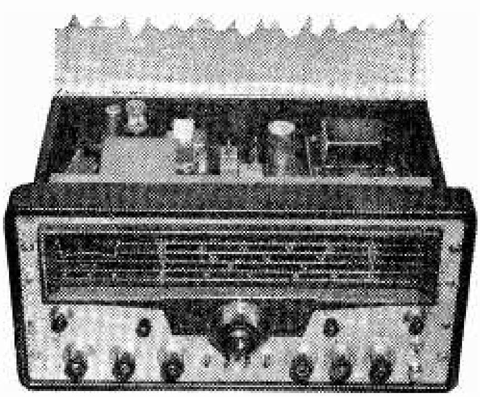
Another s.s.b. transmitter, using an exciter unit based on a design by G2NH, comes from K. W. Electronics. The basic output of the exciter is in the 80-m band and for operation on other bands crystal beat oscillators are switched in by the band switch. Provision is made for normal a.m. and c.w. transmission and the s.s.b. output is 180W p.e.p. from the class-AB1 push-pull stage.

Printed-circuit panels are used for the exciter and modulator of the Labgear LG50 50-W and "Topbander" 160-m, 10-W transmitters. These employ screen-grid modulation and they have a "power control" which varies the power-amplifier screen-grid potentials, allowing the maximum power to be reduced to 7W and 3W respectively, whilst preserving a reasonably linear modulation characteristic.

Often the problem of coupling 300-Ω or 80-Ω twin feeder to a coaxial 80-Ω transmitter output, or *vice versa* is encountered. Whilst it is relatively easy to make up a balance-to-unbalance transformer—with, if necessary an impedance adjustment—for one band, a wide-band device is rather more of a problem. Heathkit, however, now offer a "balun" unit consisting of two bifilar transformers in a screening box. These have one pair of windings connected in parallel to a coaxial socket, and the other windings may be joined in series or parallel to give either a 300-Ω or 80-Ω balanced feeder connection. Minimitter were showing an aerial rotator with a beam-direction indicator consisting of a sector of light of included angle equivalent to the beam width shining through a great-circle map centred on London. This is rotated in synchronism with the aerial (not the drive motor) by a selsyn system. Labgear have produced a three-band "quad" design (14, 21 and 28Mc/s) consisting of three separate "quad" aerials, which are supported concentrically on eight bamboo poles radiating from castings at the ends of the boom. These poles are angled so that correct parasitic-element spacing from the driven elements avoids the need for tuning stubs.



Minimitter MR44 receiver—commercial award winner.



Hallicrafters SX-101A receiver.

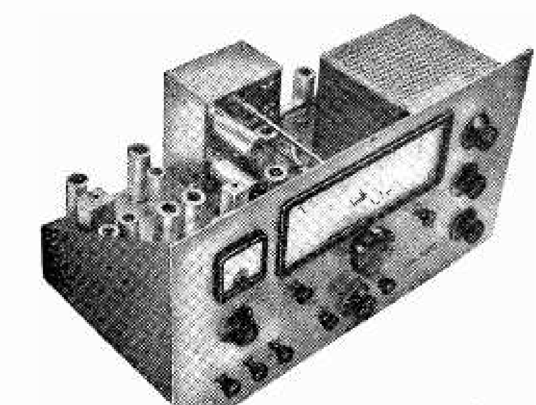
To the R.S.G.B. credit is due for another innovation—a most successful one, too. Entitled "Communications Receivers of the World," this exhibit comprised thirteen "famous name" receivers of British and foreign manufacture. In all except one case, the receivers were working and visitors to the exhibition were invited to put the sets through their paces. This they did, most enthusiastically!

The items in the display of R.S.G.B.-members' work again reached a very high standard, both in ingenuity of approach to electrical design and in the mechanical execution of the design idea. Here mention must be made of J. D. Heyes' (G3BDQ) mains-powered communications receiver, which has one of the most comprehensive specifications any "DX-hound" could want. Using 18 valves, this set provides for s.s.b., a.m. and c.w. reception on the 14, 21 and 28Mc/s bands in four ranges, the 28-Mc/s band being split into two parts. Using a grounded-grid buffer first stage followed by a tuned r.f. amplifier, the double-superhet design utilizes a wide-band first i.f. amplifier which is followed by a fixed-frequency second i.f. section at 460kc/s. The oscillator for the first frequency-changer is crystal controlled: the second is tunable to give band-spread.

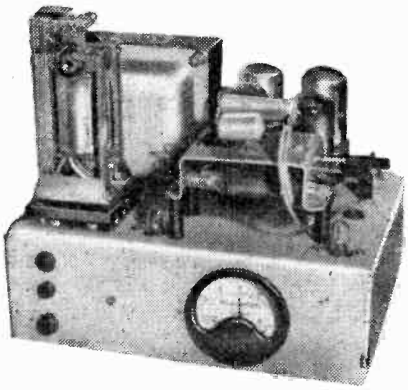
Mullard were demonstrating, for classroom use, a simple method of displaying the properties of magnetic materials using an oscilloscope.* Two coils with a large number of turns (about 3,000) are used and one coil is fed with 50c/s a.c. which provides the horizontal deflection for the c.r.o. The output from the second coil, when a magnetic core is used to couple the pair, represents the rate of change of flux density. Integration of this by an R-C combination provides the vertical-deflection voltage for the oscilloscope, which then displays the hysteresis loop.

A new item of test equipment from Jason is the W11 "wobbulator." This gives a frequency-modulated output from 0 to 85Mc/s on fundamentals, in three ranges (0-2, 0-40 and 35-85Mc/s), using only two double valves and a rectifier. The basic oscillator operates at 150Mc/s

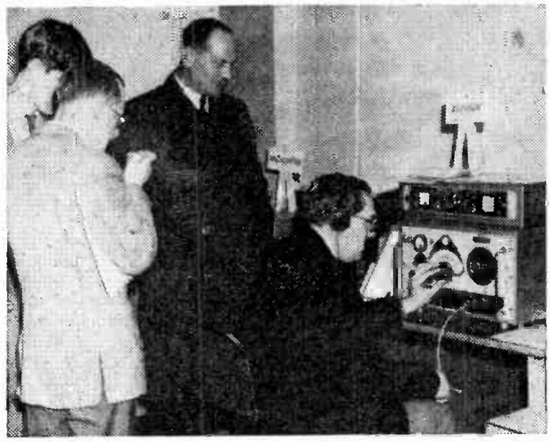
**Wireless World*, Vol. 64, p. 433 (September, 1958) (oscilloscope), and "Demonstrations and Experiments in Electronics No. 9." Mullard Educational Service (hysteresis demonstration).



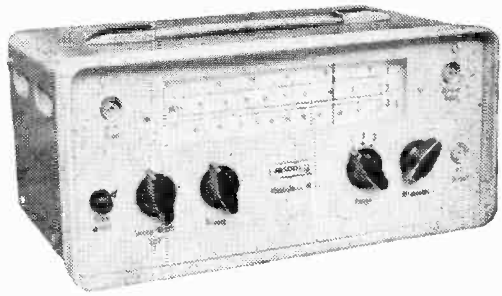
S.s.b. transmitter by K. W. Electronics.



G2UK's f.s.k. teleprinter terminal unit.



" Communications Receivers of the World ". Visitors put one of the working receivers through its paces.



Jason frequency-modulated test oscillator.

Untouched reproduction of 120-line picture from slow-scan television (British Amateur Television Club).

and is frequency modulated by a back-biased junction diode. The output from this oscillator beats with another oscillator whose frequency is varied by the manual controls, the beat being detected and amplified for use as the generator output. In this way a maximum sweep of about 8Mc/s is achieved, but the relation between frequency and back-bias voltage for a semi-conductor-diode-controlled oscillator is not linear. Thus, to provide a linear sweep, the 50c/s sweep voltage is fed through a non-linear amplifier, whose non-linearity is the inverse of the bias/frequency characteristic.

Amateur television activity was represented, as usual, by the British Amateur Television Club. Right up to the minute, one of the items on this stand was a working display of slow-scan television equipment, similar in principle to the method used recently by the B.B.C. over the transatlantic cable†. Chemical processing of quantities of film was regarded as ruling out this means of storing the pictures, so they were recorded on magnetic tape running at 7½in/sec. Two systems were represented; one, developed by WA2BCW of the U.S.A., uses an amplitude-modulated 2kc/s sub-carrier, whilst J. A. Plowman (G3AST) uses a composite a.m./f.m. system. A recording made by WA2BCW was played back at the exhibition on Plowman's equipment, which uses a VCR517 long-persistence c.r.t. to build up the picture: the line-scan frequency was 20c/s, resulting in a read-out time of 6 sec for the complete 120-line picture.

Mobile radio is another facet of the amateur's interests and a recently formed group—the Amateur Radio Mobile Society—caters for enthusiasts. The transistor has done much to ease both the physical and electrical loads on cars—some examples of both British and American transistor power convertors were shown on this stand. One, available as a kit of parts or "ready made" from Transipack, provides an output of 115W high-voltage d.c. at the seemingly incredible efficiency of 95%. This is achieved by the use of a toroidally-wound transformer, silicon-junction bridge rectification of the transformer output and a diode circuit which recovers the energy stored in the transformer core.

Teletype is not often thought of as a means of communication between radio amateurs; but it has for some years been gaining ground in the U.S.A. and it has now gained a foothold in the U.K., with the formation of the British Amateur Radio Teletype Group. Due to a purchase of some G.P.O.-surplus machines, several amateurs now have the basic facilities for generating and receiving teleprinter signals. These are used with frequency-shift keying (the normal form for teletype transmission) transmitter exciters in which the shift is usually achieved by "pulling" the v.f.o. by the required amount. Reception is effected by a unit which, fed from the receiver, converts the 860c/s frequency shift back into ±80V signals for the machine. These convertors are usually specialized discriminators, and A. C. Gee's (G2UK) unit, using modified TV width-control coils for the tuned circuits, was on show, together with some "copy" from several contacts with the U.S.A. and Australia, made over radio "circuits." The great advantage of f.s.k. is, of course, the small bandwith required; but a side issue of the work of this group is that the identity of commercial operators who infringe the amateur band allocations can now be established without the necessity for professional help.

† High-speed Facsimile, *Wireless World*, Vol. 65, pp. 314 and 362 (July/August, 1959).

WORLD OF WIRELESS

Sound Broadcasting

IN view of the recent discussion both in Parliament and the lay Press on the subject of commercial broadcasting and especially its potentialities as a local broadcasting service, the B.B.C. has stated that "Any major extension of the existing services, particularly for local broadcasting, depends in the first instance on the allocation of additional frequencies in the v.h.f. band."

The B.B.C. has already made known to the Post Office its desire to use further frequencies to fill gaps in its present v.h.f. coverage and for local broadcasting, and the statement adds "These frequencies, which are allocated internationally for broadcasting, are at present used in this country by other services, and their release for broadcasting is problematical. Until this question is resolved it is not possible to proceed with detailed plans."

The frequencies referred to are those between 95 and 100Mc/s. Although the 88-100Mc/s band is allocated throughout the world for broadcasting, the Atlantic City allocation table does include a provision that the top 5Mc/s may be used in the U.K. for fixed and land mobile services. There is also a provision that the meteorological aids service in the U.K., France and India may be operated between 94.5 and 95Mc/s.

It remains to be seen what changes in these allocations will be made at the Geneva Conference.

Government Radio Research

WITH the announcement of the appointment of J. A. Ratcliffe as successor to Dr. R. L. Smith-Rose (see "Personalities") as director of the D.S.I.R. Radio Research Station, the Council for Scientific and Industrial Research has also announced changes in the terms of reference of the Station.

The Radio Research Station at Slough, which has an international reputation for its detailed studies of ionospheric and tropospheric radio propagation, is to extend its programme to take advantage of the techniques provided by rockets and earth satellites.

Under its new terms of reference the Station, which has a staff of about 160 scientists and assistants, will undertake investigations of the upper atmosphere and outer space by both radio and non-radio methods. At the invitation of the present director, Mr. Ratcliffe will assist in planning the future research programme before taking up his appointment in October.

Broadcasting in Italy

ITALY'S network of v.h.f. transmitters is by far the largest in Europe and possibly in the world. At the beginning of December she had 235 stations and as each station radiates three programmes, the total number of f.m. transmitters in use was over 700.

Television stations in Italy now total some 340. They are all accommodated in eight 7-Mc/s channels in Bands I and III. Only about 10% of them have an e.r.p. of over 1kW and some are as low as 0.4W.

The majority of both the television and v.h.f. sound broadcasting stations are operated as satellites of main transmitters. Italy also operates 116 transmitters in the medium-wave band, more than half of which are low-power. A total of about 7.5M licences, including well over 1M for television, are now in force.

International Conferences.—In our comment on page 421 of the October, 1959, issue we suggested the desirability of a Conference on conferences to anticipate congestion. We now learn that the 1st Congress of International Congress Organizers and Technicians was, in fact, held in Düsseldorf in February, 1959, and that the 2nd Congress is already arranged for March 15th-18th, 1960, in Lausanne. It will be held under the auspices of the Union of International Associations whose U.K. representative is E. S. Tew, 91, Lyndhurst Gardens, London, N.3. Other participating bodies include the International Association of Congress Palaces and the International Association of Conference Interpreters.

Medical Electronics Conference.—The third international conference on medical electronics is to be held at Olympia, London, from July 21st to 27th, 1960. It is being organized by the Electronics and Communications Section of the I.E.E. in association with the International Federation for Medical Electronics, which was set up at the Paris conference a few months ago. Those requiring registration forms and further particulars or who are interested in submitting a paper should write to the secretary, I.E.E., for further information. The I.E.E. is also promoting an international scientific exhibition which will be run concurrently with the conference. The exhibition organizers are Industrial Exhibitions Ltd., 9 Argyll Street, London, W.1.

Vibration.—The Acoustics Group of the Physical Society will hold a symposium on the subject of "Vibration" in the Physics Department, Imperial College, Imperial Institute Road, London, S.W.7, at 2.30 on January 20th. Papers will be read on the analysis of noise-excited vibrations in aircraft, on vibration-isolation, on ground vibrations and on the influence of vibration, including that from small power tools, on the human body. Speakers will include Prof. E. J. Richards and Dr. B. L. Clarkson, of Southampton University, P. H. Allaway, of Absorbit, Dr. N. Ambraseys, of Imperial College, Dr. J. N. Agate, formerly of the London Hospital, and Flt. Lt. Guignard, of the R.A.F. Institute of Aviation Medicine.

The College of Technologists, established by the National Council for Technological Awards last May to administer "an award higher than the Diploma in Technology," to be known as M.C.T. (Membership of the College of Technologists), has issued a memorandum giving guidance to applicants for registration. It outlines the qualifications required, the procedure for the submission of an application and the fees payable. The eight-page leaflet is available from the National Council for Technological Awards, 9 Cavendish Square, London, W.1.

Correspondence Courses.—Approval has now been given by the Royal Navy, the Army and the Royal Air Force for the acceptance of the C.R.E.I. (Capitol Radio Engineering Institute) courses in electronic engineering as qualifying for part refund of fees for external correspondence courses used by members of the Armed Services. The value of the concession may amount to up to 50% of the cost of the course.

V.H.F. radio-telephone service to ships, which is already provided on the Clyde and from the North Foreland, Niton (Isle of Wight) and Humber coast radio stations, will soon be available from the Land's End station also. All these stations operate on frequencies around 160Mc/s. The charge for a three-minute call to a vessel within the 40 to 50 mile service area of a station is 6s 6d plus a land line charge of from 6d to 2s 6d, depending on the distance the inland telephone subscriber is from the coast station.

Orkney Television Station.—The permanent installation at the B.B.C.'s Orkney television station, replacing the temporary low-power equipment which has been in use for the past year, was brought into service on December 17th. The station radiates in channel 5 (vision 66.75Mc/s, sound 63.25Mc/s) and its directional aerial provides an e.r.p. of from 4 to 14kW, depending on direction. Transmissions are vertically polarized. The station serves the whole of the Orkney Islands and a large part of Caithness.

E.B.U. Station Lists.—Revised lists of television and v.h.f. sound broadcasting stations in Europe have been prepared by the European Broadcasting Union. These show the situation at July 1st last year. The next edition will give the position on January 1st, 1960, and in future only one edition will be published each year, but supplements will be issued every two months. The price for each of the lists plus the supplements is 50 Belgian francs. They are obtainable from the E.B.U. Technical Centre, 32 avenue Albert Lancaster, Brussels 18, Belgium.

Television Society.—In an endeavour to attract more student members into the Television Society, the Council has decided to waive the entrance fee, which is 30s. Student membership, for which the annual fee is £1, is open to those over 16 but under 21, but students over 21 who are taking a recognized college course in television are also eligible. Details of membership are obtainable from the secretary, Television Society, 166, Shaftesbury Avenue, London, W.C.2.

Provincial Centres.—Readers in South Wales may be interested to know that a Centre of the Television Society has been formed in the area. The secretary is D. M. Thomas, 39 Gron Ffordd, Wenallt Road, Rhiwbina, Cardiff. The Society also announces the re-formation of the Leicester Centre (secretary E. F. Dawson, 28 Clumber Street, Melton Mowbray) and plans to revive the Manchester and Birmingham centres.

"Engineering Education in the Region" is the title of a booklet produced by the London and Home Counties Regional Advisory Council for Technological Education to assist those who wish to follow a recognized course in some branch of engineering in the region. The courses, grouped under some 50 subjects, are also classified under "grades," ranging from degree and diploma courses to those for craftsmen. The 38-page booklet costs 3s 6d from the Council at Tavistock House South, Tavistock Square, London, W.C.1.

Control Engineering.—A course of ten evening lectures on the principles of control engineering, covering both linear and non-linear servo systems, will be given at the South East London Technical College, Lewisham Way, S.E.4, on Wednesdays, from January 20th. Fee £1.

The Technical Publications Association is donating two £10 awards annually to the City and Guilds of London Institute for the top students in the final grade in the two recently introduced training courses in technical authorship and technical illustration.

Norwood Technical College, London, S.E.27, celebrated its centenary by holding in December a two-day exhibition. It included demonstrations showing some aspects of the work of the various departments and also equipment lent by manufacturers.

Swedish Television.—In the three years since Sweden opened her television service, the number of stations has grown to 23 and half a million television receiving licences are now in force. Although the present stations cover only about 60% of the 7.4M population, the present number of licences represents a television density of 66 sets per 1,000 inhabitants. It is planned to open a further 19 stations before July 1st this year. Sweden employs the 625-line 7-Mc/s standard with f.m. sound and all the present transmitters operate in Bands I and III.

Receiving Licences.—October's total of 9,844,365 combined sound and television licences in the U.K. was 125,893 up on the previous month. Sound-only licences totalled 5,084,380 including 410,372 for car radio.

West German TV.—The number of television licences issued in the German Federal Republic and West Berlin increased by 102,000 in September, and the total is now well past the three million mark.

U.S.S.R.—Television sets in the U.S.S.R. are stated to be among the consumer goods in short supply. Steps are therefore being taken to increase the output from the 1958 total of 979,300 to 1,926,000 in 1961.

Soviet Radio Telescope.—The first Soviet steerable radio telescope was recently completed at the scientific station of the Lebedev Physics Institute near Moscow. It has a 22-metre (over 72-feet) paraboloid with a focal length of 9.5 metres. The parabolic mirror weighs 65 tons and the overall weight of the telescope is 380 tons. The paraboloid of the Jodrell Bank radio telescope has a diameter of 250 feet.

For Yachtsmen.—Details of radio beacons and coast radio stations, a map showing the weather forecasting areas and details of the B.B.C.'s transmissions of time signals are included in the 52-page reference section of the *Yachting World* Diary, 1960. It costs 6s 3d (with leather cloth cover) or 9s 9d (Morocco leather).

CLUB NEWS

A.R.M.S.—A meeting of the Amateur Radio Mobile Society will be held on January 30th at 3.0 in the Small Hall of the St. Bride Foundation Institute, Bride Lane, Fleet Street, London, E.C.4. The programme will include a lecture and films. Details are available from the secretary, G. E. Storey, 10 Avon Road, Sunbury-on-Thames, Middx, from whom information on the mobile rally planned for April or May is obtainable.

Birmingham.—The January programme of the Midland Amateur Radio Society includes a talk on the 7th by R. Rew on the construction of a 70-cm transmitter and on the 19th a talk by H. Buckley, of Bradmatic, on sound recording and reproduction. Meetings are held at 7.0 at the Birmingham Midland Institute, Paradise Street.

Calcot.—A lecture-demonstration will be given by a representative of Dynatron Radio to members of the Calcot Radio Society on January 21st at 7.45 in the St. Birinus Church Hall, Calcot, near Reading.

Cleckheaton.—A representative of Philips is giving a talk on tape recorders to members of the Spen Valley and Leeds Amateur Radio Societies at the George Hotel, Cleckheaton, at 7.30 on January 20th.

Halifax.—A talk on television interference is to be given by H. Swift (G3ADG) to the Halifax and District Amateur Radio Society on January 5th at the Sportsman Inn, Ogden.

Mitcham.—Meetings of the Mitcham and District Radio Society are held every Friday at 8.0 at "The Cannons," Madeira Road, Mitcham. Lecture meetings alternate with instruction classes. On January 8th a member of the G.P.O. engineering department will give a talk on cable link systems.

Wellingborough.—"Transistors" is the title of the talk to be given by F. Manning at the January 21st meeting of the Wellingborough and District Radio and Television Society. Meetings are held every Thursday at 7.30 at Silver Street Club Room.

Personalities

Brigadier Sir Lionel Harris, K.B.E., T.D., M.Sc., F.C.G.I., M.I.E.E., who is 62, is retiring at the end of January from the position of Engineer-in-Chief of the Post Office. He joined the Post Office research branch at Dollis Hill in 1922 having previously spent four years with signals in the Australian Imperial Forces. During the 1939-45 war he successively commanded G.H.Q. Signals; was Chief Signal Officer, Lines of Communication; and for two years chief of General Eisenhower's Telecommunications Section. From 1949 until his appointment in 1954 as engineer-in-chief he was controller of research.

Sir LIONEL HARRIS.

A. H. MUMFORD.

A. H. Mumford, O.B.E., B.Sc.(Eng.), M.I.E.E., deputy engineer-in-chief of the Post Office for the past six years, succeeds Sir Lionel Harris as Engineer-in-Chief. He joined the Post Office as a probationary assistant engineer in 1924 and after a short period at headquarters went to Dollis Hill laboratory. He was in charge of the Radio Branch during much of the war. Mr. Mumford was a member of the Post Office team which first recorded aircraft reflections of radio waves in June, 1932. He is 56.

The Postmaster-General has also appointed two deputy engineers-in-chief—**Capt. C. F. Booth,** O.B.E., M.I.E.E., and **D. A. Barron,** M.Sc., M.I.E.E. Both have been assistant e.-in-c. since 1954. Capt. Booth, who is 59, joined the Post Office in 1923 and was for twenty-five years at Dollis Hill. He led the U.K. delegation to the recent I.T.U. Conference at Geneva. Mr. Barron entered the Post Office engineering department as a probationary assistant engineer in 1927 at the age of 20. In 1947 he was placed in charge of a working party which examined problems of subscriber trunk dialling.

A. H. M. Arnold, Ph.D., D.Eng., has had the title of Professor of Electrical Engineering conferred upon him by the University of London in respect of his post at King's College, where he has been reader in electrical engineering since 1955. Professor Arnold, who is 59, graduated at Liverpool University in 1923. He spent a year with Metropolitan-Vickers before going to the National Physical Laboratory in 1926 where he was head of the electronics section of the Electricity Division when he left in 1955 to join the staff at King's College.

R. G. Kenwright has rejoined the Plessey Co. as chief engineer, Television Components Division, Ilford. He was a radio design engineer with the company prior to 1940 when he joined Pilot Radio of which he became chief engineer in 1946. For ten years Mr. Kenwright was a member of the B.R.E.M.A. technical committee.

R. Hanbury Brown, B.Sc.(Eng.), who has been I.C.I. Research Fellow at the Jodrell Bank Research Station, Manchester University, since 1949 has been granted the status of professor with the title of Professor of Radio Astronomy from January 1st. This chair is a personal appointment and is additional to that held by Professor A. C. B. Lovell, F.R.S. Professor Brown, who received a monetary award from the Royal Commission on Awards to Inventors for his contribution to the development of radar—especially metre-wave AI and ASV—joined the staff of the Bawdsey Research Station in 1936. He participated in the early experimental flying with night-fighter equipment (AI) and ship and submarine detection gear (ASV). With Dr. E. G. Bowen he detected the first submarine by radar in 1939. From 1942 to 1945 Professor Brown was in the Naval Research Laboratory, Washington, D.C., as assistant head of the combined research group working on the development of radar equipment. He is 43.

V. J. Cooper, B.Sc., A.C.G.I., M.I.E.E., M.Brit.I.R.E., since 1956 Marconi's chief television engineer (an office which, under a reorganization, no longer exists), has been appointed manager and chief engineer of the company's new Closed Circuit Television Division. He joined Marconi's in 1936 and was chief engineer, advance development, from 1954 to 1956. Mr. Cooper is a member of the technical sub-committee of the P.M.G.'s Television Advisory Committee.

J. E. H. Brace, B.Sc., who joined Marconi's Broadcasting Division in 1954 when a specialist industrial TV unit was established, has been appointed deputy manager and chief of sales and contracts of the Closed Circuit Television Division. Since 1956 he has been chief of the industrial television group with headquarters at the company's Basildon works.

N. N. Parker-Smith, B.Sc., A.M.I.E.E., is appointed chief development engineer of Marconi's Closed Circuit Television Division. He has been with the company since 1947 and for most of the time has been engaged in television development work. From 1953 to 1956 he headed the section of the advance development group handling colour television.

Consequent upon the formation of the new division by Marconi's, the following appointments have been made in the Broadcasting Division: **G. E. Partington,** B.Sc., A.M.I.E.E., becomes chief engineer and **J. F. James,** B.Sc., M.I.E.E., chief development engineer. Mr. Partington joined Marconi's in 1938 when he attended a course of advanced training for post-graduate engineers at the Marconi College. In 1949 he was appointed chief of the television studio development group and in 1956 became deputy chief television engineer. Mr. James went to Marconi's from the Ministry of Supply (where he was a senior scientific officer) in 1949. He became deputy to the chief of the radar development group in 1952 and for the past four years has been in charge of this group.

R. E. Burnett, M.A.(Oxon.), A.M.I.E.E., A.Inst.P., general manager of Marconi Instruments since 1956, has been elected to the board and appointed managing director of the company. Mr. Burnett, who is 44, joined the Marconi organization in 1950 when he was appointed principal of Marconi College and manager of the Technical Personnel and Education Department. In 1954 he became assistant to the general manager of Marconi's W/T Co., and a year later transferred to Marconi Instruments as deputy general manager.

A. J. Young, B.Sc.(Eng.), M.I.E.E., general manager of the English Electric Valve Co. since 1956, has been elected to the board and appointed managing director of the company. He joined Marconi's W/T Co., as a valve engineer in 1934 and in 1947 transferred to the English Electric Valve Co. as assistant general manager. He is 51. **F. N. Sutherland,** C.B.E., M.A., M.I.E.E., managing director of Marconi's W/T Co., has also been elected to the board of the English Electric Valve Co.

Dr. R. L. Smith-Rose, C.B.E., is to retire from the directorship of the Radio Research Station of the D.S.I.R. at the end of September and is to be succeeded by **J. A. Ratcliffe,** C.B.E., F.R.S., who is head of the radio section of the Cavendish Laboratory, Cambridge. Dr. Smith-Rose, who is 65, has been in the Scientific Civil Service since 1919 and was from 1939 until 1947 superintendent of the Radio Division of the National Physical Laboratory. In 1948 he was appointed as the first Director of Radio Research when the post was created by the D.S.I.R. Dr. Smith-Rose, who has served on many national and international scientific committees, is a member of the technical sub-committee of the Television Advisory Committee and also of the P.M.G.'s Frequency Advisory Committee. Mr. Ratcliffe joined the Cavendish Laboratory in 1924 and worked with E. V. Appleton (now Sir Edward) on his researches on the ionosphere. He founded the Army radar school at Petersham and he later built up the "Post-Design Service" for the R.A.F. which was concerned with the study of radar equipment under Service conditions. During the latter part of the war he was superintendent of T.R.E. He is 57.

J. A. RATCLIFFE.

Prof. E. B. MOULLIN.

Professor E. B. Moullin, M.A., Sc.D., M.I.E.E., is to retire next October from the chair of electrical engineering at Cambridge University, which he has occupied since it was established in 1945. He is 66. Dr. Moullin, who is a Fellow of both King's College, Cambridge, and Magdalen College, Oxford, was a lecturer at Cambridge from 1920 until 1929 when he was appointed Donald Pollock reader in engineering science at Oxford where he stayed until 1945. He is author of a number of books including "Principles of Electromagnetism" and "Radio Aerials", and his research studies have covered a very wide range of radio subjects. Professor Moullin is a member of the Editorial Advisory Board of our sister journal, *Electronic Technology* (previously *Electronic & Radio Engineer*).

C. Collaro, O.B.E., has resigned from the board and chairmanship of Hartley Baird, Ltd. **A. W. M. Hartley** has succeeded him as chairman and simultaneously has resigned as managing director. **H. J. D. L. Walmsley** and **J. Symonds** have been appointed joint managing directors. Mr. Collaro has also resigned from the board of Camp Bird, Ltd., and from Camp Bird Industries, of which he was managing director. He joined the Camp Bird Group in 1957 following his resignation from the chairmanship and managing directorship of Collaro, Ltd.

E. R. Lewis, chairman of the Decca Group of Companies, and **Group Captain E. Fennessy,** C.B.E., managing director of Decca Radar, Ltd., have joined the board of General Precision Systems, Ltd. (formerly Air Trainers Link, Ltd.), following the acquisition by Decca Radar of a 25% interest in that company. The two companies are to co-operate in the development of air traffic control systems.

OUR AUTHORS

Dr. Manfred von Ardenne, a pioneer in the development of the cathode-ray tube for television, writes in this issue on the evolution of the c.r.t. Dr. von Ardenne, who is now head of a research institute in Dresden, East Germany, first wrote for *Wireless World* over thirty years ago and has made many notable contributions to the development of television. Sydney Moseley and H. J. Barton Chapple in their book "Television Today and Tomorrow" wrote of von Ardenne "he commenced his researches on television in 1930 . . . within a year he earned the distinction of being the first to demonstrate publicly cathode ray reception comparable with that produced by mechanical means."

A. R. Bailey, M.Sc.(Eng.), author of the article on page 25, took his London B.Sc. degree in 1953 at Bradford Technical College (now Bradford Institute of Technology) where he stayed to undertake research into precision three-phase a.c. voltage stabilizers under a D.S.I.R. grant. He went into industry for a short while but returned to the college where he is now a lecturer.

A. E. Falkus, B.Sc.(Eng.), M.I.E.E., who writes in this issue on loudspeaker magnet design, was chief loudspeaker designer of the Plessey Company for eight years until 1958 when with D. A. Newbold he formed Fane Acoustics Ltd. He obtained his degree at London University in 1925 and was at one time chief engineer of Reproducers and Amplifiers Ltd.

Robert Hickson, whose article on the Smith Chart is on page 2, is technical librarian of Belling and Lee, Ltd. During his national service in the Royal Navy (1945-47) he was a radio mechanic and before joining Belling and Lee he had been a technical writer on the staffs of Marconi Instruments and S.T.C.

J. M. Waddell, M.A., A.M.I.E.E., who with D. R. Coleman discusses Zener diodes in an article on page 17, spent a little over two years in R.E.M.E., after leaving Cambridge where he read physics. From 1949 to 1958 he worked in the Rectifier Division of Standard Telephones and Cables and from 1956 was responsible for the development and applications of silicon rectifiers. For the past year he has been with Texas Instruments, Ltd., Bedford.

D. R. Coleman, B.Sc.(Eng.), A.M.I.E.E., co-author of the article on Zener diodes, joined S.T.C.'s rectifier division in 1956 and is now in charge of the group concerned with the evaluation and applications of semiconductor devices. After three years in the Royal Engineers he studied at the Regent Street Polytechnic and then spent five years (1951-56) on the development of aircraft electrical equipment.

OBITUARY

Hilary F. C. Williams, B.Sc., chief electronics engineer of Andec, Ltd., for the past 12 months, died suddenly on November 11th at the age of 45. After graduating at London University in 1935 he became a schoolmaster and during the war was at the Royal Aircraft Establishment where he held an honorary commission in the Royal Air Force. He was with Cossor's for nine years after the war as a development engineer and later assistant chief engineer of Racal Engineering.

Joseph Poliakoff, founder of the Multitone Electric Co. in 1931, died on November 24th at the age of 86. Mr. Poliakoff, who established the Telephone Construction Co. in Russia (it was nationalized in 1921), came to this country in 1924. He was managing director of Multitone until 1938 when owing to ill-health he resigned in favour of his son, but continued on the board and took an active part in the day-to-day affairs of the company. Although his life-work was devoted to the alleviation of deafness, he was an engineer of wide interests—he had a patent for recording sound on film in 1894.

News from the Industry

A.E.I. Reorganization.—On January 1st the British Thomson-Houston Co., Metropolitan-Vickers Electrical Co. and Siemens Edison Swan changed their names to Associated Electrical Industries (Rugby) Ltd., Associated Electrical Industries (Manchester) Ltd., and Associated Electrical Industries (Woolwich) Ltd., respectively. At the same time five new Product Divisions of A.E.I. (making 12 in all) come into operation. They are: Cable Division and Construction Division combining the interests of the S.E.S. Cables Division with those of W. T. Henley's Telegraph Works Co. and Liverpool Electric Cables; Telecommunications Division, hitherto a Product Division of Siemens Edison Swan; and a Radio and Electronic Components Division. These four Divisions will be managed by Associated Electrical Industries (Woolwich) Ltd. The fifth is the Instrumentation Division combining the interests of Sunvic Controls with the instrument and meter, X-ray, and scientific apparatus departments of Metropolitan-Vickers and will be managed by Associated Electrical Industries (Manchester).

G.E.C.-Plessey Co-operation.—An arrangement has been entered into by the Semiconductor Division of the G.E.C. and Semiconductors Ltd., of the Plessey Group, whereby each will handle information on the products of both organizations.

Plessey's trading profit for the year ended in June was £2.206M compared with £1.350M the previous year. The net profit after tax deduction was £1,194,499 as against £561,991 last year.

Gresham Automation Ltd. has been formed to handle the Gresham Unit Sequencing System. The directors are John P. Coleman (chairman of Gresham Transformers Ltd. and of the Gresham Lion Group) and R. M. Campbell, a director of Gresham Transformers. Dr. D. B. Foster is appointed as consultant to the board. The offices of the new company are at Gresham House, Twickenham Road, Hanworth, Middx. (Tel.: Feltham 2271.)

Marconi's W/T Co. have received a contract from the B.B.C. for the supply of a considerable quantity of equipment, valued at approximately £115,000, to extend the coverage of the television and v.h.f. sound broadcasting services to "difficult" areas. The order includes 10 television translators (for picking up sound and vision signals from one station, and re-transmitting them on other frequencies); 4 television transmitters and 30 f.m. translators—all of 10 watts output. The associated amplifiers for the equipments vary in power from 100 watts to 1kW.

Electronic Associates Ltd., with offices and works at Victoria Road, Burgess Hill, Sussex, have been formed by Electronic Associates Inc., of Long Branch, N.J., U.S.A., manufacturers of Precision Analog Computing Equipment (PACE). The Burgess Hill works will be managed by H. Turner, a director of the new company and a graduate of Manchester University, who has been with the parent company for several years. The managing director is Dr. B. Murphy, who is also general manager of the European branch of Electronic Associates Inc, set up in Brussels in 1957.

Pye Telecommunications Ltd., have moved their London sales and service headquarters to 1 Carrol Place, Highgate Road, N.W.5 (Tel.: Gulliver 8771), where Brigadier E. J. H. Moppett, the London-based director, has an office.

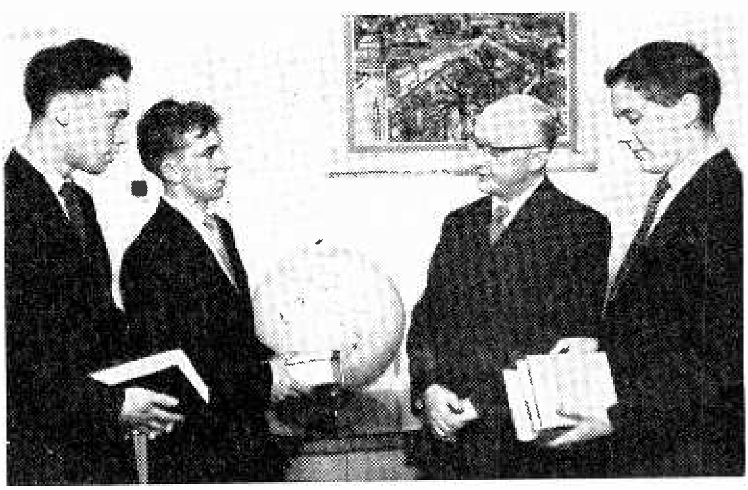
Datum Metal Products Ltd. (formerly Davis and Thompson), members of the J. Langham Thompson Group, have moved into a new factory on the Colne Way Trading Estate, Watford By-Pass, Herts (Tel.: Watford 22351). These new premises have trebled the production area of the company.

Aircraft-Marine Products (G.B.) Ltd., who market the range of A-MP solderless terminations, have moved from Regent Street to Amplo House, 87-89 Saffron Hill, London, E.C.1 (Tel.: Chancery 2902). The building houses the head office, the research laboratory (formerly at Bournemouth), the sales and engineering departments, and the international trade division (previously at Bedford Row).

Lasky's Radio have opened new premises at 207 Edgware Road, London, W.2 (Tel.: Paddington 3271), in addition to their branch at 42 Tottenham Court Road, London, W.1.

Pye have supplied the equipment for the inter-branch television network recently introduced by the Westminster Bank in Manchester. The cable system linking two branches with the central book-keeping department in the main city office, is provided by the G.P.O. The 625-line system is employed.

Smiths.—Examples of many of the products manufactured at the twenty factories in the Smiths Group, which includes Kelvin-Hughes and Radiomobile, are displayed at the Smiths Centre, Cricklewood, which was officially opened by H.R.H. the Duke of Edinburgh on November 19th.



E.M.I. apprentices with Clifford Metcalfe, C.B.E., managing director of E.M.I. Electronics, who presented them with prizes for obtaining their Higher National Diploma in electrical engineering with three or more distinctions. The recipients (from left to right) are David Jackson, George East and James Jordan, who were among thirteen E.M.I. apprentices who enrolled for the first four-year sandwich course at Southall Technical College in 1956. All thirteen have obtained their H.N.D. and are taking the fourth year of the course to qualify as Grad. I.E.E.

ZENER DIODES — THEIR PROPERTIES AND APPLICATIONS

By J. M. WADDELL,* M.A., A.M.I.E.E., AND D. R. COLEMAN,† B.Sc. (Eng.), A.M.I.E.E.

AMONG the many new components now appearing in electronic equipment as a result of the intensive work which has been done on semiconductors in the last few years is a useful group usually known as "Zener" diodes. What are these "Zener" diodes, and what do they do?

If we examine the reverse characteristic of a typical silicon junction rectifier, shown in Fig. 1, we can see that the reverse current remains extremely small at all voltages below a certain value, the "Zener voltage." Then, as the voltage is raised slightly above this value, the current increases very rapidly indeed into the so-called "breakdown" region. For power rectifiers, the manufacturer arranges that this breakdown region occurs well above the normal reverse operating voltage, in order to avoid excessive power dissipation in the reverse direction and consequent failure due to overheating.

It should be noted that this phenomenon is not a breakdown in the ordinary sense of the word (in the sense in which a dielectric breaks down), but is a completely reversible process which of itself causes no damage to the rectifier. However, if the rectifier were run continuously in this region it is probable that the maximum allowable dissipation of the device would be exceeded and the rectifier damaged; but if excessive dissipation is avoided the diode can be run in the "broken down" condition indefinitely. A diode used deliberately in this way for any purpose is called a "Zener diode."

The term "Zener diode" was coined when this breakdown was first observed[1] because it was thought that the mechanism responsible was that proposed by C. Zener in 1934 to account for the breakdown of solid dielectrics[2]. It turns out that this "Zener breakdown" is responsible where the breakdown occurs at low voltages (below 5 volts in silicon), but that at higher voltages breakdown is due to another mechanism, "avalanche multiplication," similar to the breakdown process in gaseous dielectrics described by Townsend.[3] Thus the higher voltage Zener diodes should really be called avalanche diodes. While one of the purposes of this article is to draw attention to the different behaviour of Zener and avalanche diodes—for example, the "knee" of the breakdown characteristic is more rounded in a Zener diode and so the slope resistance of such diodes is higher than that of the corresponding avalanche diodes—it is convenient to have a generic term to cover all such devices, and the term "Zener diode" has received widespread acceptance.

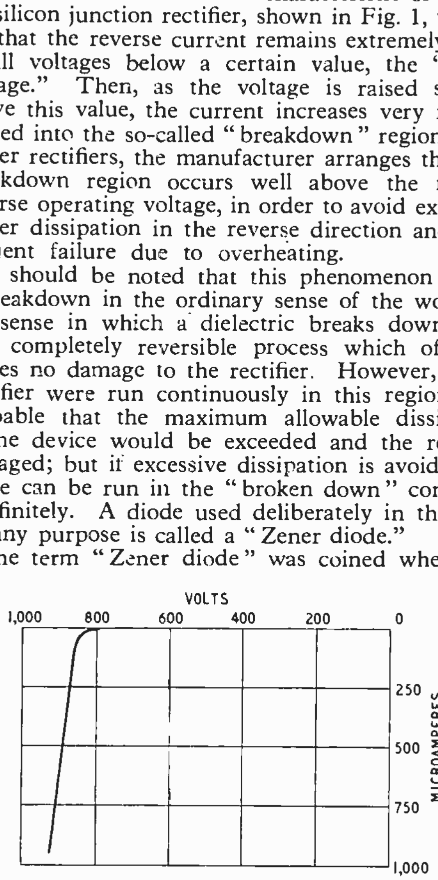
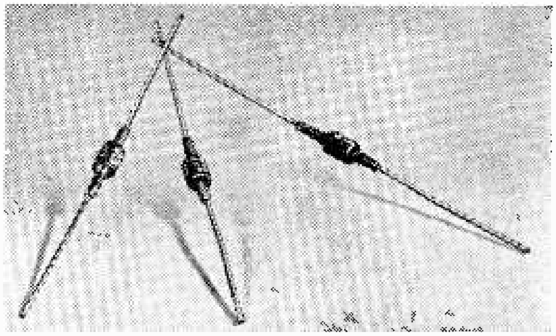


Fig. 1 Reverse characteristic of a typical silicon junction rectifier.



A group of typical Zener diodes.

It is possible to use a term denoting the application, e.g., "reference diode," "regulator diode," but the range of use of these devices is so vast that no one application can be singled out for such special mention. We recommend the continued use of "Zener diode" as the most useful general term.

One of the great advantages of these devices over previously available voltage stabilizing devices, such as gas discharge tubes, is that the breakdown voltage can be controlled during manufacture to any value from about two volts to several hundred volts. In addition the transition from "off" to "on" takes place smoothly, without the discontinuity associated with gas discharge tubes. No special arrangements are needed for starting, and the absence of negative resistance means that shunt capacitance can be added without causing oscillation. Under appropriate conditions, substantially zero temperature coefficients of voltage may be obtained. Furthermore, Zener diodes are smaller and more robust than gas tubes or batteries, and by comparison they have an almost indefinite life.

Fig. 2 shows typical characteristics of some diodes specially made for use in this way. It will be noted that here the breakdown voltages are quite low, from about 4 to 9 volts. From this graph the important parameters which define the properties

* Texas Instruments, Ltd., formerly with Standard Telephones & Cables, Ltd.
† Standard Telephones & Cables, Ltd.

[1] K. B. McAfee, E. J. Ryder, W. Shockley and M. Sparks, "Observations of Zener current in germanium p-n junctions," *Phys. Rev.*, **83**, p. 650, 1951.
[2] C. Zener. "Theory of the electrical breakdown of solid dielectrics," *Proc. Roy. Soc.*, **145**, p. 523, 1934.
[3] J. S. Townsend. "The passage of ions in gases," *Nature*, **62**, p. 340, 9th August, 1900.

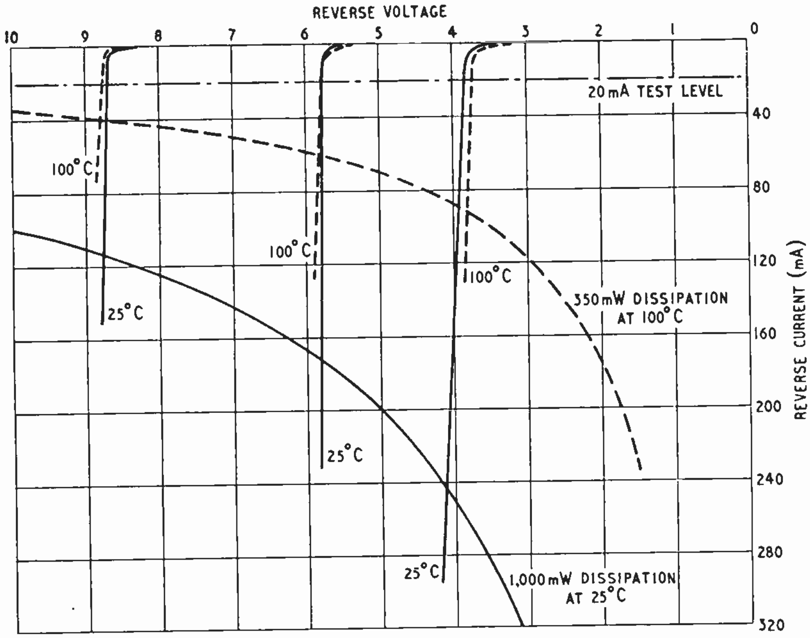


Fig. 2 Typical characteristics of diodes specially made for Zener operation.

current as that at which the nominal voltage is measured. The lower the slope resistance the more constant is the operating voltage with changes in current. As will be seen from the curves, the operating voltage at a given current changes with working temperature, and so for many applications the temperature coefficient of voltage is also important. Finally, since these devices, like most components, are given a maximum operating temperature, the maximum dissipation limits the maximum continuous working current.

of a particular Zener diode can be clearly seen. The first and most important is the voltage in the breakdown region. This is not a unique and fixed value, but increases with the operating current; thus the current at which the voltage is measured must be specified. Usually the manufacturer chooses a particular value of current and quotes the voltages of a complete range of diodes at this particular current.

The next most important parameter is the "slope resistance," or the dynamic resistance of the diode in the "breakdown" region. This again is measured at a particular current, usually the same

Operating Mechanism.—In order to understand the way in which these various parameters change for different values of working voltage, it is helpful to have some understanding of the alternative mechanisms involved in the breakdown region. In a silicon rectifier biased in the reverse direction almost all the applied voltage appears across the narrow depletion layer located immediately on either side of the junction, and the remaining volume of the silicon is essentially field free. For a given applied voltage the field in the depletion layer depends on the width of this layer, being a function of the centre region resistivity of the diode. This resistivity is controlled during manufacture so that the field in the finished diode can be made to have any desired value for a given voltage across the diode: the higher the resistivity, the wider the depletion layer and the smaller the field per unit of applied voltage. The depletion layer is normally quite narrow, so that fields of the order of several hundred thousand volts per cm. are readily reached.

With fields of this order in the depletion layer the current carriers which constitute the reverse current are accelerated to considerable energies between each collision with the stationary silicon atoms of the

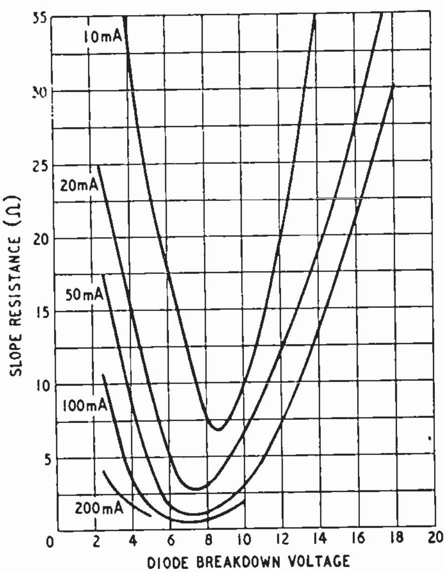


Fig. 3 Variation of slope resistance with reverse current for a typical range of Zener diodes.

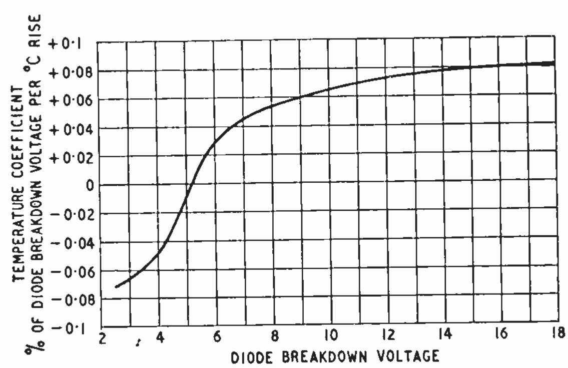


Fig. 4 Temperature coefficient of voltage for a typical range of Zener diodes.

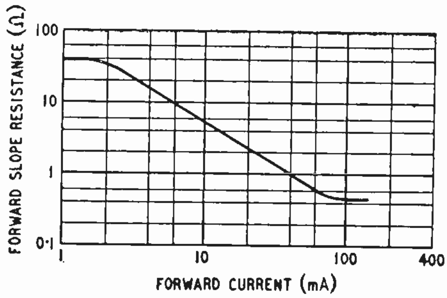


Fig. 5 Variation of forward slope resistance for a typical Zener diode.

lattice. As the voltage across the diode is raised, the field increases, and when it reaches a critical value the energy obtained by each electron or hole between collisions is sufficient to eject an additional electron from the atom with which it collides, thus creating a hole-electron pair. These additional free carriers are also accelerated in their turn, and produce yet more free carriers which all add to the total reverse current. Thus the reverse current, initially no larger than the saturation reverse current present at low voltages, is multiplied to a much larger value by this "avalanche" process, in a manner analogous to the Townsend mechanism in gas discharge tubes.

Zener Effect.—In order to produce low breakdown voltage diodes, the depletion layer must be made very narrow. Under these conditions the current carriers are accelerated through the barrier without ever striking an atom of the lattice, and so the avalanche effect does not occur. In these circumstances, as the voltage across the diode is increased the field can rise until it reaches a higher critical value at which true Zener effect occurs. This is a quantum mechanical effect in which hole-electron pairs are generated directly from the energy of the electrical field. The resultant current increases rapidly with voltage, but not quite as rapidly as with the avalanche effect, so that the "knee" of the curve is more rounded.

For silicon junction diodes the changeover occurs in the region of 5-8 volts, those diodes below 5 volts exhibiting Zener breakdown, while those above 8 volts exhibit avalanche breakdown. The breakdown of diodes between 5 and 8 volts is due to a combination of the two mechanisms. An important difference between these two mechanisms is that the temperature coefficient of voltage or the Zener process is negative, whereas that for the avalanche process is positive.

Characteristics.—As a result of the above, it is customary to present the characteristics of a particular series of Zener diodes (that is, a range manufactured to the same physical dimensions and differing only in breakdown voltage) in the form of curves showing the various parameters plotted against the breakdown voltage at which the diode under consideration actually operates. Since the characteristics of Zener diodes are related to their operating temperature, it is important to distinguish between a "convection-cooled" (such as a wire-ended) diode for which the immediate ambient temperature is considered, and a "conduction-cooled" (such as a stud-ended) diode for which the characteristics are

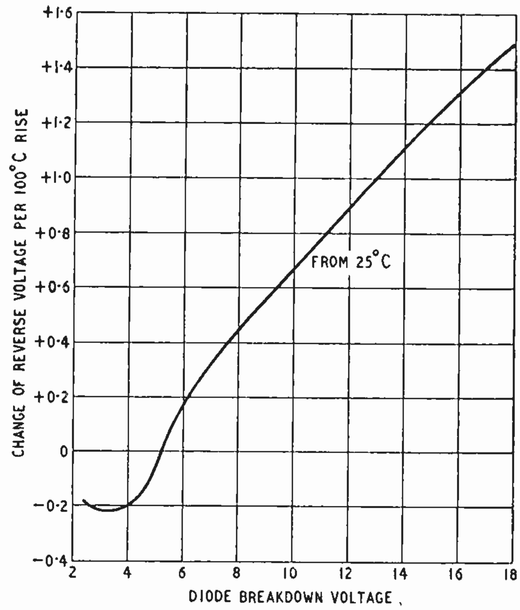


Fig. 6 Change of reverse voltage (at constant current) for a typical range of Zener diodes.

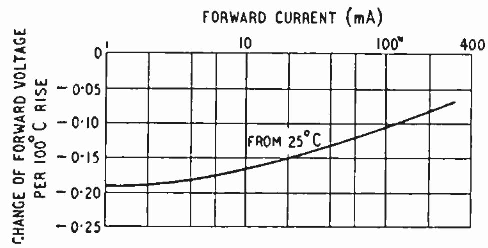


Fig. 7 Change of forward voltage for a typical Zener diode.

quoted in terms of the stud temperature. The following data may, for simplicity, be considered applicable to wire-ended diodes at the stated ambient temperatures.

Fig. 3 shows, for example, the variation of slope resistance with voltage for typical Zener diodes from a particular range. Since the slope resistance is also a function of the operating current, curves for several currents are given. The higher current curves are limited in voltage excursion by the allowable dissipation in the diodes. The slope resistance shows a minimum in the changeover region around 7 volts and rises steeply on the low voltage side of this point, but less steeply on the high voltage side. On the high voltage side, however, the slope resistance increases more rapidly than the voltage, so that if slope resistance is important better results can be obtained by using, say, five 7-volt diodes in series, instead of one 35-volt diode.

The variation of temperature coefficient of voltage against working voltage is shown in Fig. 4. It will be seen that diodes with breakdown voltages in the region of 5 volts are the most attractive from this point of view. However, approximately zero temperature coefficients can also be obtained by connecting a diode having a positive coefficient in series with one having a negative coefficient, although this

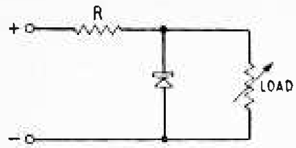


Fig. 8 Application as a voltage regulator or reference source.

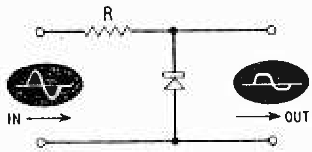


Fig. 9 Surge limiting circuit using a Zener diode.

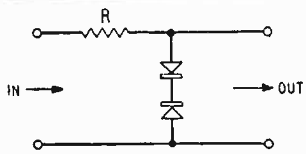


Fig. 10 Balanced clipping circuit using back-to-back diodes.

arrangement will probably give a higher slope resistance. In a similar way the negative temperature coefficient of the forward characteristic of a diode may be used to cancel a positive temperature coefficient of reverse breakdown voltage. The slope resistance in the forward direction is low (Fig. 5).

In making up series chains of Zener diodes to achieve approximately zero temperature coefficient, it should be noted that the calculations require curves showing actual change in voltage per °C (as in Figs. 6 and 7), and not the conventional values of temperature coefficient of voltage expressed as percentage change of voltage per °C.

The exact value of the temperature coefficient of a given diode is a function of the operating current, and of the precise temperature range over which the change in voltage is measured. Consequently, zero temperature coefficient of voltage will only be possible at one value of current for any one diode, and only over a limited temperature range. Where the very best performance as a voltage reference is required, care should be taken to keep the current constant, and if possible at that value which gives zero temperature coefficient.

As explained above, the manufacturer can design diodes to operate at any given voltage by adjustment of the resistivity of the base region of the diode; but this can only be done with limited accuracy. A given batch of diodes as manufactured has a certain spread of voltage values. Of the many varied uses of Zener diodes, some applications may call for the diode to have an accurately specified working voltage with a tolerance of, say, ±1%, while others may merely require a breakdown voltage between, say, 15 and 20 volts. In an application as a source of reference voltage, the working voltage of the diode may be quite unimportant; but extreme stability, coupled with low slope resistance and low temperature coefficient, will be desirable. As a result, if care is not exercised, there will grow up a vast proliferation of types, each differing only slightly from the next, and the manufacturer and the user will be faced with the problem of stocking reasonable numbers of each type, while the small demands for any one type will result in uneconomic manufacturing runs.

To deal with this problem, manufacturers in this country are at present marketing "general purpose" Zener diodes, which are available in ±5%, ±10%, and ±20% tolerances, using the same preferred numbers for nominal breakdown voltage which are familiar to users of resistors and capacitors, e.g. 3.3, 3.6, 3.9, 4.3, 4.7V, etc.

Applications.—The number of possible applications for these diodes appears to be extremely large. The most obvious applications are as voltage regulators and voltage reference sources (Fig. 8). For regulator application a low slope resistance and high power handling capacity are desirable features, while for reference purposes, stability of reference voltage with time and a low temperature coefficient are the most important factors. Suitably chosen voltage reference Zener diodes appear at this moment to be comparable with industrial standard cells in their voltage stability.

Another large field of application lies in the use of Zener diodes for surge limiting and waveform clipping, etc. Fig. 9 shows a circuit which gives both top and bottom clipping using only one diode. This circuit makes use of the fact that Zener diodes, being in other respects normal silicon rectifiers, have a forward characteristic which may be used on many occasions. The same circuit may also be used for protecting transistor circuits from line surges. If a balanced clipping action is required, two Zener diodes should be used, connected back to back (Fig.

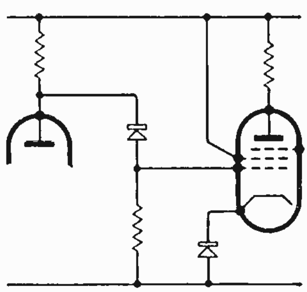


Fig. 11 Zener diodes used for coupling elements and cathode bias in a d.c. amplifier.

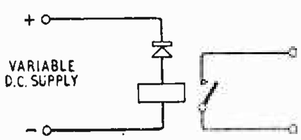


Fig. 12 Application as a voltage-sensitive relay.

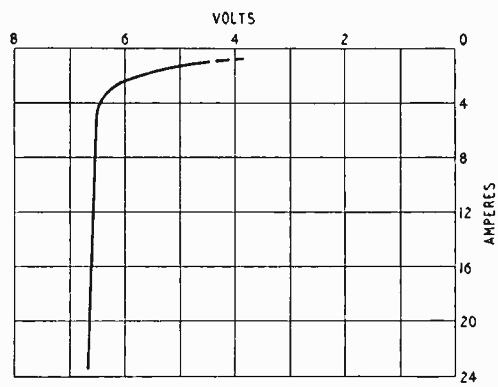


Fig. 13 Characteristic of an experimental high-power shunt regulator Zener diode for the region 2-20 amperes.

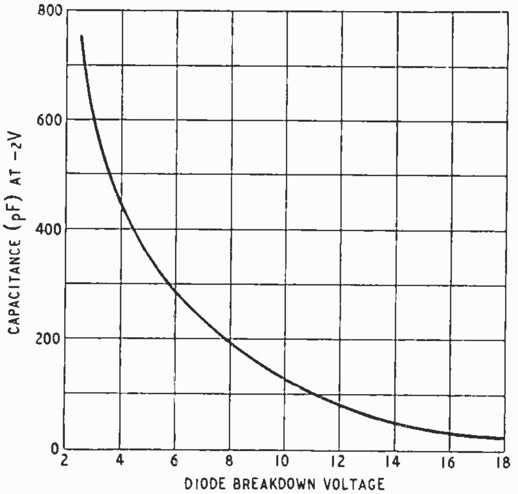


Fig. 14 Capacitance effect over a range of Zener diodes.

10). Some manufacturers now make special clipper diodes for this purpose.

Zener diodes have a much lower a.c. resistance than d.c. resistance (i.e. $\frac{dV}{dI} << \frac{V}{I}$) which means that they behave rather like a capacitor or battery. They are particularly useful for coupling and decoupling elements in d.c. amplifiers, where capacitors cannot be used because of the rise in impedance at low frequencies. Even in a.c. circuits at low frequencies the Zener diode may be more economical than a large capacitor, especially in space. Fig. 11 shows the use of a Zener diode as a coupling element and for fixed cathode bias in a d.c. amplifier.

Fig. 12 shows a method of obtaining a robust and inexpensive voltage sensitive relay; the relay should operate with a low voltage across it and thus the Zener diode used must be capable of passing a reasonably large current. Zener diodes can be made capable of handling quite large powers. Fig. 13 shows the characteristic of an experimental 150-watt unit intended for shunt regulation of power supplies, to operate between 2 and 20 amps.

A further useful property of silicon junction diodes (such as Zener diodes) is their "self capacitance." In addition to the electrostatic capacitance between the diode leads, or between the leads and metal case, there is a "self capacitance" associated with the junction itself; because the depletion layer is extremely narrow in a Zener diode, the junction capacitance is usually much greater than the case capacitance. This "self capacitance" is seen when the diode is biased in the reverse direction below the breakdown voltage. Fig. 14 shows the variation over a range of Zener diodes, the capacitances being measured at the same low voltage for all diodes in the range.

In addition, for any one diode, the capacitance depends upon the bias voltage applied. Increase of bias voltage up to the breakdown value causes a reduction of capacitance, as illustrated in Fig. 15. The voltage-dependent capacitance has applications in automatic frequency control. With an f.m. tuner, for example, the diode may be used as part of the tuning capacitance, whose value is controlled by the output from the discriminator.

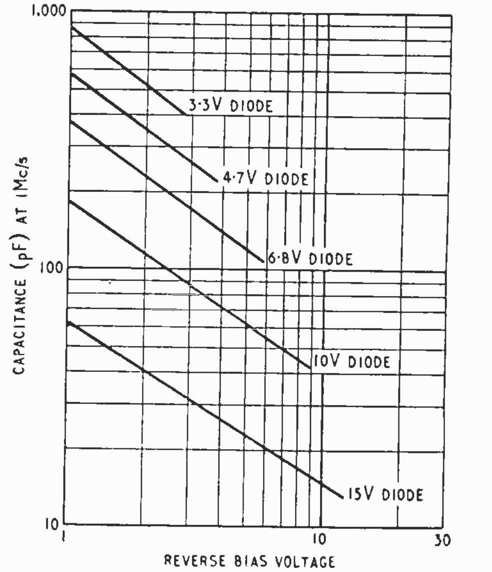


Fig. 15 Typical values of capacitance for reverse bias voltages before the breakdown region (at 25°C).

It is hoped that sufficient has been said about these new components to stimulate interest in their application and to give some guidance in their use. Much remains to be learnt of their characteristics and possible applications. Perhaps this article will help to speed the process.

Semiconductor Production *at the G.E.C. Semiconductor Division factory at Hazel Grove, Stockport, Cheshire, is now about 70,000 transistors and diodes per week. This automatic wafer measuring machine sorts germanium and silicon wafers according to thickness at the rate of 1,200 per hour. Another interesting technique uses a centrifuge to ensure good glass-to-metal seals in the housings. The glass and metal components are placed in jigs in an annular-shaped boat which is rotated and heated in an inert atmosphere, so that centrifugal force throws the molten glass into intimate contact with the metal parts. The method of operation, including control of temperature and cooling, is completely automatic. Using such methods the firm claims to have achieved an average yield of between 70% and 80%.*

LETTERS TO THE EDITOR

The Editor does not necessarily endorse the opinions expressed by his correspondents

Single-channel Stereo

HASN'T "Free Grid" (in the October issue) gone a bit wild over his one amplifier, two channels. If you sample (with rectangular wave) at 50c/s you get every frequency in the spectrum modulated by 50, 100, 150, etc., and that's a nasty noise. You should sample at something over twice the highest frequency in the wanted spectrum and put in a low-pass filter to get rid of higher-frequency unwanted modulator products. *But* the low-pass filters you would need have a reaction component in their impedances; they store energy and so forbid the clean cut that is essential for sampling as "Free Grid" wants it.

London, S.W.3. P. P. ECKERSLEY.

Editors and Editing

IN his article "Words, Words, Words" in the November "Wireless World," Mr. Eckersley very rightly calls for an improvement in the standard of writing of technical articles and papers. Victorian scientists, he says, wrote well, even excellently; many of them could be described as cultured. Nowadays, it is of no help to a scientist to be cultured and to write well, because the editors won't let him publish a paper as he writes it. Editors quite rightly tidy up[1] a badly-written piece of work, but when a paper is well written, they should leave it alone[2].

The interference frequently consists in making alterations to the style to bring it into line with editorial policy[3]. People who believe that it is possible to make small alterations in the style of a well-written piece of prose without ruining its effect—an effect that the author has probably worked hard to achieve—ought not to sit in editorial chairs. One famous Learned Society[4] will never allow an author of a paper to refer to that paper as "this paper," always substituting "the paper," to which a reader of any sensibility[5] reacts by asking "what paper?". The same Learned Society[4] recently allowed one of its vice-presidents to use the phrase "a whole diversity of new materials"[6]. If it is willing to allow such a phrase to appear in its Proceedings, by what right does it sit in judgment on the work of other authors? The Chairman of the Editorial Board of another Learned Society[4] is the author of several books from which it is clear that he does not know how to punctuate. Yet this Learned Society[4], like many others, dares to have an editorial policy on style—as if style can ever be a matter of policy.

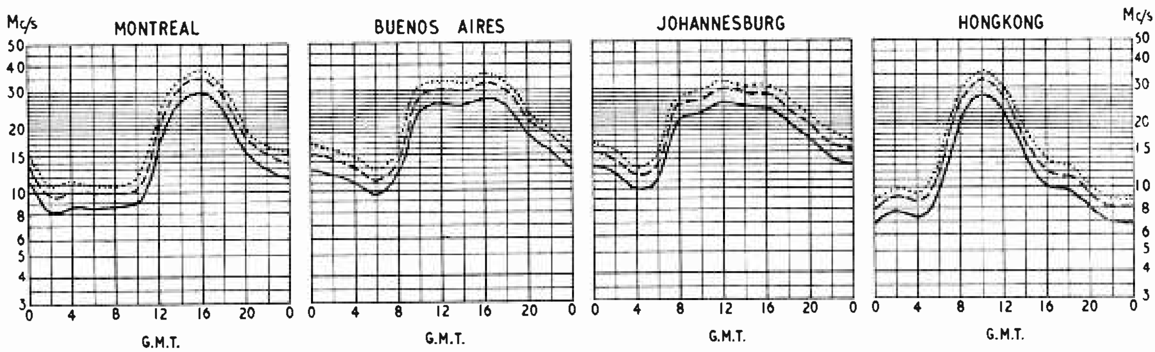
May I therefore make a plea that writers be allowed to publish their papers and articles in the language in which they were originally conceived? While the various Learned Societies[4] should do all they can to improve standards of writing, they should refrain from interference with a piece of work, once it is written, except on technical grounds—and even then, any alterations called for should be made by the author[7]. Let the editors confine their activities to editing—that is, to deciding the arrangement of the material on the printed page, to interpreting the author's intentions to the typographers, to correcting obvious errors, and to adding footnotes, e.g. "continued on page. . . ."[8] And, critics, please be a little more charitable to the author[9]. Why should he take all the blame, when things are done to his work over which he has no control, and of which he may even have no knowledge until his alleged work appears in print?[10]

Chelmsford. R. A. WALDRON.

[[1] Or decline to publish.
[2] Being busy men they are usually happy to do so.
[3] This journal welcomes diversity of style.
[4] Capitals for a common noun and its adjective?
[5] Sense is shorter than sensibility and does not involve the emotions.
[6] What is wrong with this? Collectively the materials are finite and although diverse can be comprehended as a whole.
[7] Who will then permit the editor's name to appear as co-author?
[8] This is the dull mechanic trade of *sub*-editing.
[9] Touché!
[10] Mr. Waldron's letter is printed as received with the exception of the interpolation of reference numbers to the rejoinders which the Editor feels compelled to make in defence of his vocation. He is nevertheless glad to publish this letter if only to show that he is mindful of the feelings of his contributors—present and future.]

SHORT-WAVE CONDITIONS

Prediction for January



THE full-line curves indicate the highest frequencies likely to be usable at any time of the day or night for reliable communications over four long-distance paths from this country during January.

Broken-line curves give the highest frequencies that will sustain a partial service throughout the same period.

•••••••••• FREQUENCY BELOW WHICH COMMUNICATION SHOULD BE POSSIBLE FOR 25% OF THE TOTAL TIME

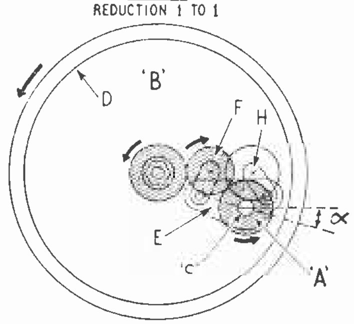
— — — PREDICTED MEDIAN STANDARD MAXIMUM USABLE FREQUENCY

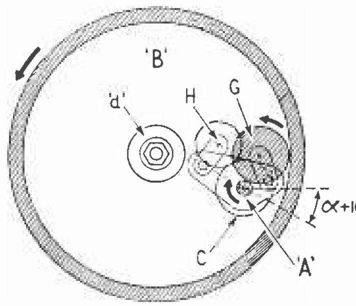
———— FREQUENCY BELOW WHICH COMMUNICATION SHOULD BE POSSIBLE ON ALL UNDISTURBED DAYS

Technical Notebook

Speed-Change Drive for magnetic tape data recording equipment has been devised by E.M.I. Electronics for applications where it is necessary to play back the data for analysis at a different speed from that at which it was recorded. It is a simple device giving a wide-ratio change of speed without mechanical complexity. Power is applied to one shaft carrying a stepped plain pulley A, and the output drive is taken from another shaft carrying flywheel B which also has two working surfaces of different radii, one external and the other internal. An idler carriage E is mounted on a plain bearing on the input shaft, so that it is dragged round by friction as far as it is free to move in whichever direction the input shaft is turned. If, in the diagrams, the drive shaft is turned anti-clockwise (State 1), the resulting anti-clockwise motion of the idler carriage will draw the idler wheel F, supported on E by the swinging arm H, into engagement with the larger diameter (C) of pulley A and the smaller diameter '*d*' of the flywheel B. B will move anti-clockwise, and

STATE 1
REDUCTION 1 TO 1





STATE 2
REDUCTION 1 TO 30

as in the figure C and '*d*' are approximately equal, there is no change of angular velocity in the mechanism. If the direction of the drive shaft is reversed (State 2), the carriage E will move clockwise until the alternative idler G engages between the smaller diameter ('*c*') of A and the larger diameter (D) of B. When this occurs the flywheel B will move anti-clockwise as before, but with a speed reduction determined by the ratio of D to '*c*.' In the case drawn this ratio is about 1 to 30. Thus it will be seen that by reversing the direction of the input shaft a large speed reduction may be obtained—the output shaft always revolving in the same direction. A large number of speed ratios may be obtained by suitable selection of diameters and positioning of components.

Magnetless Masers are possible according to an article by G. S. Bogle and H. F. Symmons in the *Australian Journal of Physics* for March 1959 (p. 1). Normally in the three level type of maser, three suitable spin quantum levels between which transitions are possible can only be obtained in certain paramagnetic salts in a magnetic field. The authors point out, however, that certain paramagnetic salts possess three suitable energy levels between which transitions are possible even in the absence of a magnetic field. Unfortunately, unlike ordinary masers, magnetless masers will not be tuneable over a wide frequency range. On the other hand, magnetless masers possess a number of compensating advantages over ordinary masers. For example, exacting requirements of magnetic field uniformity and stability are avoided and, since crystal orientation is no longer necessary, a single crystal is not required for a magnetless maser.

Directly Printed Circuits, as distinct from the usual etched variety, are made possible by a new copper-bearing paste developed by Bell Telephone Laboratories in the U.S.A. The paste is applied in the required circuit pattern to a ceramic base and the process is completed by heat treatment. The main advantage of the new system is the strong adhesion of the copper coating to the base material, compared with conventional etched circuits. Failure of bonding does not occur, it is claimed, until the pulling strength exceeds 2,000 lbs/sq. in. In preparation a paste is made from a finely ground mixture of copper oxide and a special glass "frit" (a term from glass-making), blended with a standard silk-screen printing material. After the pattern of paste is printed on the ceramic, the circuit card is dried to remove solvents. The card is then fired in air at 750°C for twenty minutes to burn off the screen-printing material. This operation leaves a non-conducting copper oxide pattern, ready to be reduced to metallic copper. The second firing operation is conducted at 850°C for thirty minutes, in an atmosphere containing hydrogen, nitrogen and oxygen. The hydrogen reduces the copper oxide to metallic copper, while the oxygen prevents reduction of other oxides in the system and promotes good wetting of the glass frit and the ceramic. Without the oxygen present, a poor bond results. Printed wiring cards prepared this way can be dip-soldered without bond failure, and without the use of corrosive fluxes. Resistivity of the copper film is said to be well within requirements for typical printed wiring applications. The process is suitable for automatic production techniques, and is expected to be competitive with other printed wiring methods in cost. Another possible application is in making metal-to-ceramic bonds.

Distortion Reduction in class-B amplifiers using biased diodes to switch in different signal potential dividing resistors at different signal levels to compensate for non-linearities in the class-B input/output characteristic is described in an article by B. Sklar in *Electronics* for May 22, 1959 (p. 54). One arm of the signal potential divider consists of a fixed resistor, and the other a number of branches in parallel, each branch containing a fixed resistor in series with a diode and biasing battery. Thus, at a signal voltage determined by the biasing battery voltage, the diode switches the fixed resistor into one arm of the potential divider. The resultant resistance in this arm thus varies with the signal level, and the consequent changes in the signal potential dividing ratio with the signal level can be used to compensate for non-linearities in the class-B input/output characteristic. A graphical method of determining from the input/output characteristic the resistance required in series with each diode for a given biasing voltage is described in the article. In a practical case the total harmonic distortion in a push-pull amplifier (mainly third harmonic) was reduced from 13 to 2·6%.

Physical Society Exhibition

Manufacturers and Research Establishments Exhibiting

ON the majority of the 140 stands at the 44th exhibition of scientific instruments and apparatus arranged by the Physical Society there will be equipment of interest to radio and electronic engineers. The exhibition will be held from January 18th to 22nd in both the Old and New Halls of the Royal Horticultural Society, at Westminster, London, S.W.1.

The opening ceremony will be performed by J. A. Ratcliffe, C.B.E., F.R.S., president of the Physical Society, at 11.0 on January 18th. On the opening day admission will be limited to members of the Society and the Press until 2.0. The times of opening are: 18th, 10.30 to 7.0; 19th, 10.0 to 9.0; 20th and 21st, 10.0 to 7.0; and 22nd, 10.0 to 1.0.

Tickets of admission are obtainable free from exhibitors or from the Society, 1, Lowther Gardens, Prince Consort Road, London, S.W.7.

A feature of the Society's exhibition each year has been the series of demonstration lectures. This year the lectures will be given on each of the first three days at 5.45. On the 18th the subject will be "Some reactions of the human body to the stresses of high performance flight" and the lecturer, Flt. Lt. J. Billingham (R.A.F. Institute of Aviation Medicine); on the 19th "Atomic Time" by Dr. L. Essen (N.P.L.); and on the 20th "Recent developments in solid state physics" by Dr. D. A. Wright (G.E.C. Research).

Name	Stand
Accles & Pollock	75
Admiralty Research Estab.	40
Advance Components	9
Armament Research and Development Estab.	1
Associated Electrical Industries	123
Atomic Energy Research Estab.	86
Atomic Weapons Research Estab.	86
Avo	90
B.T.H. Group Research Lab.	123
Baird & Tatlock	127
Baker, C., Instruments	79
Baldwin Industrial Controls	112
Barr & Stroud	51
Beck, R. & J.	80
Bellingham & Stanley	107
Birlec	123
Birmingham University Physics Dept.	137
British Physical Laboratories	20
British Scientific Instrument Research Association	77
Burndept	29
Cambridge Instrument Co.	97
Cambridge University	136
Cawkell Research & Electronics	36
Chance-Pilkington Optical Works	84
Chemical & Electrical Inspection Directorates	1
Cooke, Troughton & Simms	88
Cossor Instruments	103
Dawe Instruments	118
Decca Radar	18
Department of Scientific and Industrial Research and various research associations	44
Dobbie McInnes (Electronics)	14
Doran Instrument Co.	105
Dynatron Radio	24
E.M.I. Electronics	38
Edinburgh University	135
Edwards High Vacuum	125
Ekco Electronics	30
Electro Methods	109
Electronic Instruments	91
Electronic Technology	65
Electronic Tubes	49
Elliott Brothers	116
Engelhard Industries	45
English Electric Valve Co.	121
Ericsson Telephones	104
Evans Electroselenium	13
Explosives Research and Development Estab.	1
Ferranti	26
Flann Microwave Instruments	106

Name	Stand
Fleming Radio (Developments)	19
Furzehill Laboratories	5
G.E.C. Research Laboratories	115
Gallenkamp, A., & Co.	46
General Electric Co.	23
General Radiological	71
Grubb, Sir Howard, Parson & Co.	98
Guy's Hospital Medical Electronics Lab.	132
Harrison, W.	3
Hatfield Instruments	39
Hilger & Watts	95
Imperial College	133
Infra Red Development Co.	4
Institute of Physics	32
Isotype Developments	34
Johnson, Matthey & Co.	48
Joyce, Loebl & Co.	69
Kelvin & Hughes	108
Labgear	35
Lintronic	41
Locarte Co.	74
Lyons, Claude	37
Marshall of Cambridge Electronics	76
Medical Research Council	139
Megatron	16
Mervyn Instruments	99
Metropolitan-Vickers Electrical Co.	123
Mining Research Establishment	124
Ministry of Power Safety in Mines Research Establishment	128
Mullard	119, 129
Murex	52
Nagard	111
Nash & Thompson	101
National Physical Laboratory	44
National Research Development Corp.	31
New Electronic Products	7
Newport Instruments	89
Nuclear Enterprises	2
Oertling, L.	110
Oliver & Boyd	54
Optica United Kingdom	69
Optical Works	120
Ottway, W., & Co.	92
Panax Equipment	85
Paton Hawksley Electronics	78

Name	Stand
Perkin-Elmer	8
Physical Society	27
Physical Society Acoustics Group	140
Physical Society Colour Group	42
Planer, G. V.	53
Plessey Co.	28
Prior, W. R., & Co.	83
Pullin, R. B., & Co.	72
Pye, W. G., & Co.	93
Racal Instruments	17
Radio Research Station	44
Rank Cintel	113
Reading University Dept. of Physics	134
Royal Aircraft Establishment	1
Royal Meteorological Society	33
Royal Radar Establishment	1
Royston Instruments	10
St. Thomas' Hospital Electronics Dept.	131
Salford Electrical Instruments	22
Sangamo Weston	96
Science Museum	50
Services Electronics Research Laboratory	40
Servomex Controls	11
Shackman, D., & Sons	70
"Shell" Research	21
Siemens Edison Swan Research Lab.	123
Singer Instrument Co.	122
Solartron Electronic Group	94
Stanley, W. F., & Co.	114
Stanton Instruments	117
Sunvic Controls	123
Swiss Office for the Development of Trade	130
Techne (Cambridge)	126
Texas Instruments	43
Thompson, J., Langham	47
Thorn Electrical Industries	25
Towers, J. W., & Co.	15
Townson & Mercer	82
20th Century Electronics	6
Ultrasonoscope Co.	73
Unicam Instruments	87
Venner Electronics	12
Vinten	100
Watson, W., & Sons	81
Wayne Kerr Laboratories	102
Westminster Hospital Departments of Hæmatology and Physics	138
Wireless World	65

By
*ARTHUR R. BAILEY**,
M.Sc.(Eng.), B.Sc.(Eng.)

Economical High-Gain A.F. Amplification

MICROPHONE AND TAPE-REPLAY AMPLIFIERS USING UNUSUAL CIRCUIT

FOR many years engineers have been trying to obtain the maximum amplification from the minimum number of components. During research into precision three-phase a.v. stabilizers, the author came across a somewhat unorthodox phase-splitter[1] which gave an unusually large gain for the valves and components used. This circuit, which is shown in Fig. 1, utilizes the high input impedance of a concertina phase-splitter to provide a very high load impedance to the anode of a pentode amplifier. As the amplification factor for an r.f. pentode can be over 10,000 at low values of anode current (0.1mA) and the anode slope resistance may then be as high as 20MΩ, then it can be seen from the formula

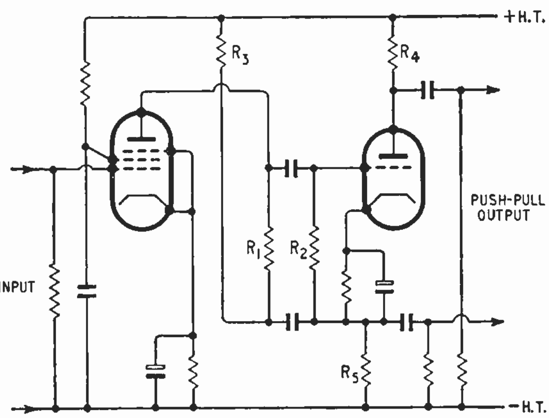


Fig. 1. Theoretical circuit of high-gain phase-splitter.

$A=\mu R_L/(r_a+R_L)$ that if the load resistance can be made greater than r_a then the amplification will be greater than $\mu/2$.

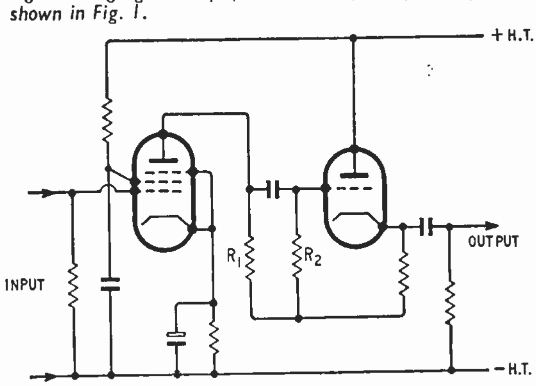
In the high-gain phase-splitter circuit the maximum amplification obtained is about 1,000 times. This compares favourably with the normal overall gain for a pentode amplifier (and "concertina" phase-splitter) of 100 to 300 times. Providing that a push-pull output is required, it is difficult to see how this circuit can be improved. If, however, a single-ended output is desired, then the circuit can be modified with advantage.

The first obvious step is to remove the anode load resistor R_4 of the triode valve: this is unnecessary as it merely provides the phase-inverted output. It will now be noted that the cathode load of the cathode-follower so formed consists of the pentode valve and its load resistor R_1 (in series) in parallel with the h.t.-feed resistor R_3 and the cathode resistor R_5 (in parallel). If the circuit is now rearranged, as shown in Fig. 2, it will be seen that the pentode valve now obtains its anode supply through the triode valve and the loading effects of resistors R_3 and R_5 (Fig. 1) are removed. The cathode-follower has now a very high effective load in its cathode circuit; thus it will generate a cathode-to-earth voltage of very nearly μ times the grid-to-cathode input voltage[2]. This grid-to-cathode input is developed across the anode-load resistor R_1 of the pentode valve. Hence for 1V of signal developed across this resistor there will be approximately μ_tV (where μ_t is the amplification factor of the triode) developed at the cathode of the triode. This means that the signal voltage on the pentode anode will be approximately $(1+\mu)$V. As 1V is developed across the pentode anode-load resistor R_1, the triode must therefore be acting as an additional a.c. load of approximately $\mu_t R_1$. To be accurate, both R_1 and R_2 should be considered; but as R_2 is over 10 times larger in value than R_1 its effect is very small.

The voltage drop in the triode valve need not exceed about 75V and so the triode will only slightly reduce the dynamic mutual conductance of the pentode valve. The triode therefore acts as a low resistance to d.c., but as a very high anode-load resistance. The pentode will give a very large gain due to this high anode load and the gain may approach the pentode amplification factor. For some pentodes this may be 10,000 times, and under these conditions the effective anode load may rise as high a value as 100MΩ. The effect of stray capacitances is then extremely serious and care has to be taken if a useful a.f. bandwidth is to be obtained.

Providing that the pentode anode-circuit components are physically small and sensibly arranged, the main capacitances in shunt with the pentode-anode circuit are the anode-to-grid capacitance of the

Fig. 2. High-gain amplifier derived from phase-splitter shown in Fig. 1.



* Bradford Institute of Technology.

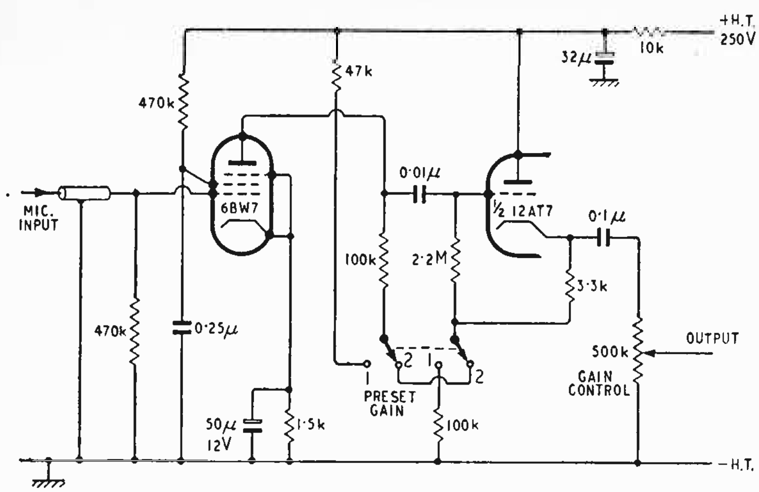


Fig. 3. High-gain amplifier used as microphone pre-amplifier. Preset gain switch positions: 1, low gain; 2, high gain.

triode and the output capacitance of the pentode. The anode-to-grid capacitance of a 12AT7 is only 1.5pF and is therefore hardly worth neutralising. The output capacitance of a 6BW7 is 3.5pF which is also quite small. The effect of these capacitances could be reduced somewhat by the "Cathoguard" circuit[3]. If the response is to be maintained up to 10kc/s with a maximum of 3dB fall in response, then the total capacitance of 5pF (ignoring stray and valve-base capacitances) will limit the effective anode output impedance to $10/\pi$MΩ. This value is composed of the anode load of the pentode in parallel with the anode slope resistance of the pentode valve. Assuming a dynamic anode-slope resistance for the pentode of 5MΩ, this gives a maximum pentode anode load in the order of 8MΩ. This was halved to allow for the stray capacitances that were ignored; thus a value of 4MΩ was obtained. With a 12AT7 valve a voltage amplification of 40 would be expected, hence a value of $4 \times 10^6/(40+1)$, or approximately 100kΩ, for the pentode load resistor R_1 was obtained.

The circuit has been used in a tape-recorder built by the author and has given very satisfactory results. The microphone amplifier of the recorder is shown in Fig. 3. This can be used at either high or low gain to allow for a wide range of input signals. In the high-gain position the circuit operates as previously described; in the low-gain position the pentode is re-connected as a "straight" amplifier driving a cathode-follower. The gain of the circuit is approximately 200 in the low-gain position and 3,500 in the high-gain position. The output is at low impedance, and providing that the output-voltage swing is restricted to several volts, loads of as little as 50kΩ can be placed across the output without giving rise to any measurable distortion.

The circuit used in the replay amplifier is shown in Fig. 4. A much higher value of anode load can be used in this case as the effect of stray capacitance is swamped by the tape compensating circuit, which is based on the C.C.I.R. recommendations for the 7½in/sec speed and on accepted practice (in the absence of a standard) for the 3¾in/sec speed. The output of the replay amplifier is in the order of 0.5V and is sufficient to drive most power amplifiers.

Hum and Microphony.—The use of high-slope r.f. pentodes in the early stages of a.f. amplifiers can give rise to bad microphony and hum troubles. The author has experienced little difficulty with microphony; anti-microphonic valve bases and selection of the valve to be used enable a very low microphony level to be achieved.

Hum, however, is apt to cause more trouble, due to the a.c. heater supply. There is no convenient means of obtaining enough d.c. to feed the heater of a 6BW7 unless a separate supply is used. An a.c. supply was therefore used and the hum level was not above the tape-noise level providing the following precautions were taken:—

(a) the valve heaters were fed from a centre-tapped supply, (b) the heater-transformer centre-tap was raised to a potential of about 20V positive with respect to earth by means of a decoupled potentiometer between h.t.+ and earth, and (c) a 1.5-Ω resistor was included in each heater lead to the valve.

If a loss of gain of some five times can be tolerated, then one of the low-noise pentodes such as the 6BR7 can be used. This valve has very low hum and noise figures but it suffers from the disadvan-

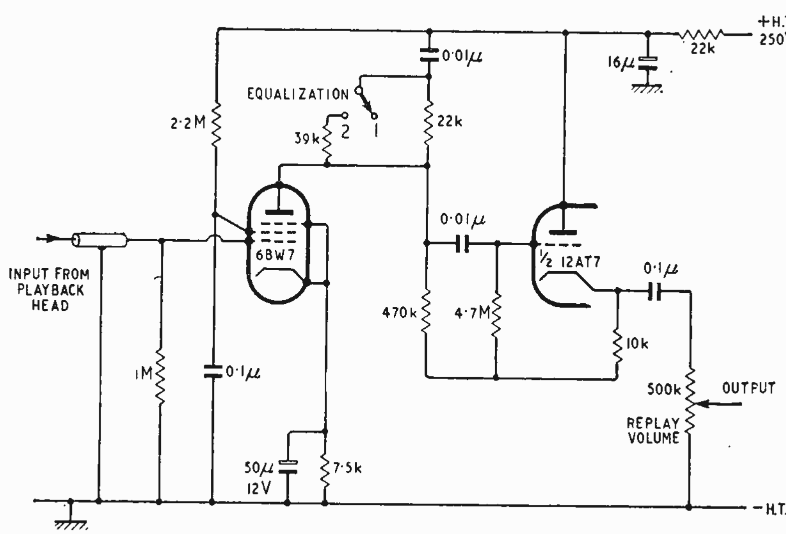


Fig. 4. Tape-playback pre-amplifier providing equalization facilities. Switch positions: 1, 3¾ in/sec; 2, 7½ in/sec.

tage of a relatively low amplification factor. When using a 6BR7 in place of the 6BW7 the value of the cathode-bias resistor must be decreased to 4.7kΩ for the tape-replay amplifier and to 1kΩ for the microphone amplifier.

Summing up, the advantages of the circuit are that few components are required and that all the amplification is obtained from the pentode valve. Due to this and the low output impedance of the circuit, the hum and noise introduced by the second valve is negligible, whatever valve type is used. The one disadvantage is that it is difficult to maintain a high amplification at supersonic frequencies; but this is not normally important.

Acknowledgement.—The author wishes to acknowledge the facilities provided by the Bradford Institute of Technology where most of the work on this circuit has been carried out.

REFERENCES

[1] Push-Pull Phase-splitter, by E. Jeffery, *Wireless World*, Vol. 53, p. 274 (August 1947), also "Amplifiers" (1st Edition) p. 101, by G. A. Briggs and H. H. Garner, Wharfedale Wireless Works.

[2] Radio Engineering (3rd Edition) by F. E. Terman, p. 308, McGraw-Hill Publishing Co., Ltd.

[3] The "Cathoguard" by L. G. White, *Wireless World*, Vol. 64, p. 312 (July 1958).

JANUARY MEETINGS

Tickets are required for some meetings; readers are advised therefore to communicate with the secretary of the Society concerned.

LONDON

6th. Brit.I.R.E.—"Some new possibilities in civil underwater echo-ranging—current research at the University of Birmingham" by Professor D. G. Tucker at 6.30 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

8th. I.E.E.—Discussion on electrical and electronic techniques in respiratory research at 6.0 at Savoy Place, W.C.2.

8th. Television Society.—"Problems of u.h.f. television: transmission, propagation and reception" by T. M. J. Jaskolsky (E.M.I.), R. A. Rowden (B.B.C.) and K. Moulding (Mullard) at 7.0 at the Cinematograph Exhibitors' Association, 164, Shaftesbury Avenue, W.C.2.

11th. I.E.E.—"A quadrature network for generating vestigial-sideband signals" by G. G. Gouriet and G. F. Newell; "The input impedance of rectifier modulators" by Professor D. G. Tucker; and "Rectifier modulators with frequency-selective terminations, with particular reference to the effect of even-order modulation products" by D. P. Howson and Professor D. G. Tucker at 5.30 at Savoy Place, W.C.2.

13th. Brit.I.R.E.—"A proposal for a space-charge-limited dielectric triode" by Dr. G. T. Wright at 6.30 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

15th. B.S.R.A. — "Stereophonic hearing" by Professor Colin Cherry at 7.15 at the Royal Society of Arts, John Adam Street, W.C.2.

20th. Physical Society Acoustics Group.—Symposium on "vibration" at 2.30 in the Physics Dept., Imperial College, Imperial Institute Road, S.W.7.

21st. Television Society.—Fleming Memorial Lecture on "Crystal Imperfections" by Professor R. King at 7.0 at the Royal Institution, Albemarle Street, W.1.

22nd. R.S.G.B.—Presidential address by W. R. Metcalfe (G3DQ) at 6.30 at the I.E.E., Savoy Place, W.C.2.

25th. I.E.E. Graduate and Student Section.—"Transistors in switching circuits" by M. Paskins at 6.30 at Savoy Place, W.C.2.

25th.—Radar and Electronics Association.—"The problems of technical reviewing" by J. C. G. Gilbert and R. S. Roberts at 7.30 at the Royal Society of Arts, John Adam Street, W.C.2.

27th. British Computer Society.—"Storage elements for very-high-speed computers" by Dr. G. G. Macfarlane (R.R.E.) at 2.30 at Northampton College of Advanced Technology, St. John Street, E.C.1.

27th. I.E.E.—"The oral presentation of scientific material" by Dr. A. Clow at 5.30 at Savoy Place, W.C.2.

27th. Brit.I.R.E.—"Training for operating and maintaining television broadcasting equipment" by Dr. K. R. Sturley and A. E. Robertson at 6.30 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

28th. I.E.E.—"Radio communications by means of satellites" by Dr. A. W. Lines at 5.30 at Savoy Place, W.C.2.

29th. I.E.E.—"Beam-type parametric amplifiers: some aspects of design and use" by R. B. Dyott and C. R. Russell at 5.30 at Savoy Place, W.C.2.

BIRMINGHAM

19th. I.E.E.—Faraday Lecture on "Electrical machines" by Professor M. G. Say at 6.30 at the Town Hall.

25th. I.E.E.—"Long-distance waveguide communication" by F. J. D. Taylor at 6.0 at the James Watt Institute.

BRISTOL

27th. Brit.I.R.E.—"An equipment for automatically processing time multiplexed telemetry data (Timtape)" by J. H. Russell, N. Purnell and T. Walters at 7.0 at the School of Management Studies, Unity Street.

BROADSTAIRS

26th. Association of Supervising Electrical Engineers.—"The Decca navigational system" by B. A. A. Smye-Rumsby at 8.0 at the Clarendon Hotel.

CARDIFF

21st. I.E.E.—Faraday Lecture on "Electrical machines" by Professor M. G. Say at 6.0 at Sophia Gardens Pavilion.

28th. British Computer Society.—"Basic principles of programming" by Dr. R. J. Ord-Smith (S.T.C.) at 6.30 at University College.

CHESTER

25th. I.E.E.—"The characteristics and protection of semiconductor rectifiers" by D. E. Corbyn and N. L. Potter at 6.30 at the Town Hall.

LEICESTER

19th. Television Society.—"The electrical synthesis of music" by A. Douglas at 7.30 at the College of Technology and Commerce.

LEEDS

4th. Association of Supervising Electrical Engineers.— "Radio control" by E. B. Hill at 7.30 at the Great Northern Hotel.

LIVERPOOL

11th. Brit.I.R.E.—"High frequency propagation—its present and future use for communication purposes" by A. F. Wilkins at 7.0 at the University Club.

14th. Institute of Physics.—"Electronic applications of superconductivity" by Dr. E. Mendoza at 7.0 at the University.

18th. I.E.E.—"Radio aspects of the International Geophysical Year" by Dr. R. L. Smith-Rose at 6.30 at the Donnan Laboratories, Vine Street.

MANCHESTER

18th. Institute of Physics.—"Recent developments in scintillation counting" by Dr. J. B. Birks at 7.0 at the University.

NEWCASTLE-UPON-TYNE

13th. Brit.I.R.E.—"Data processing machines" by J. Allen and J. Keating at 6.0 at the Institution of Mining and Mechanical Engineers, Neville Hall, Westgate Road.

TREFOREST

13th. Brit.I.R.E. — "Television broadcasting methods" by H. J. M. Hockley at 6.30 at the Glamorgan College of Technology.

WOLVERHAMPTON

13th. Brit.I.R.E.—"Electronics in medicine" by P. Styles at 7.15 at the Wolverhampton and Staffordshire College of Technology, Wulfruna Street.

Evolution of the Cathode-Ray Tube

A Survey of Developments over Three Decades

By MANFRED VON ARDENNE*

UNTIL the year 1928 the cathode-ray tube devised in 1897 by Ferdinand Braun only found application on rare occasions, despite the fact that Wehnelt (in 1905) and Westphal (in 1908) had already improved it considerably by the introduction of the incandescent cathode. In 1928 the cathode-ray tube emerged from its latent existence and rapidly gained in importance in two directions of development:

1. About this time the high-tension cathode-ray oscillograph with cold cathode and continuous evacuation made its appearance for the investigation of transient waves. The development of this instrument is linked with the names of Rogowski, Gabor, Dufour, MacGregor-Morris, von Borries and Binder.

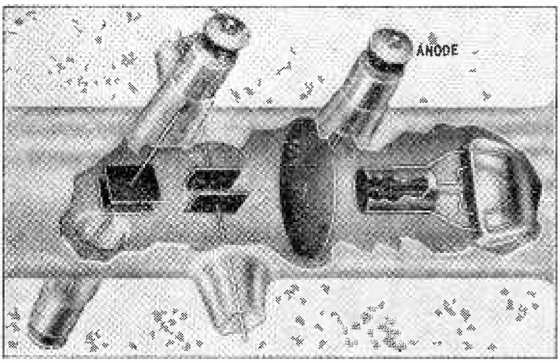


Fig. 1. The electron gun developed in 1928 with negatively-biased control electrode and beam cross-over. This gun, which is used in most present-day electron beam appliances, is shown here in an oscillograph tube for anode voltages above 1 kV, introduced by Leybold of Cologne in 1929.

2. The cathode-ray tube of modern design, which today plays important roles in the fields of oscillography, radar, and television, made its appearance.

A kindly fate has made it possible for me to collaborate actively in this second direction of development over a period of more than three decades. Today, perhaps, I may be permitted to look back over the field of my personal experience in this work.

Looking Back

The development of the modern cathode-ray tube received a decisive impetus in 1928 when it became possible, in my laboratory at Lichterfelde, to produce a fine electron beam with a current density of about 100μA and an acceleration of up to 3,000 volts as a result of a three-electrode system with a hot cathode and a control electrode with a negative bias. This electron gun was not only characterised by its construction from a thermal small-area cathode, a control electrode with negative bias and an anode, as well as by the geometry employed. Its most significant feature was the formation of an electron beam cross-over of small cross-sectional area and high current density. This emitting system differed from all earlier methods of operation of similar electrode arrangements in that the negative bias of the control electrode had a definite value somewhat below the initial voltage of the cathode-ray current. So far as can be seen from the literature available, these features were combined for the first time in the oscillograph tube[1] developed by me in 1928 and put on the market in 1929 by E. Leybold's Nachfolger of Cologne. Fig. 1 shows the structure of this tube with the type of electron gun characterised by the cross-over formation, as is used today in a great many electron devices.

Another branch of oscillograph technology which was making strides at that time, and which was later to achieve great significance in television engineering, radar engineering and high-frequency carrier telecommunications, was the wide-band amplifier or, as we called it in those days, the "aperiodic high-frequency amplifier." Together with Siegmund Loewe, we had begun in 1925 to combine several valve systems with their low-capacitance coupling units in a single evacuated glass envelope. In this way the Loewe dual valve, shown in Fig. 2, which had a space-charge grid system with a steep slope, was able to achieve a bandwidth of 1 Mc/s[2].

In order to change over from timebase deflection by mechanical/optical means (rotating mirror) to deflection by low-inertia electrical methods, relaxation oscillator devices were devised in that particular year in the

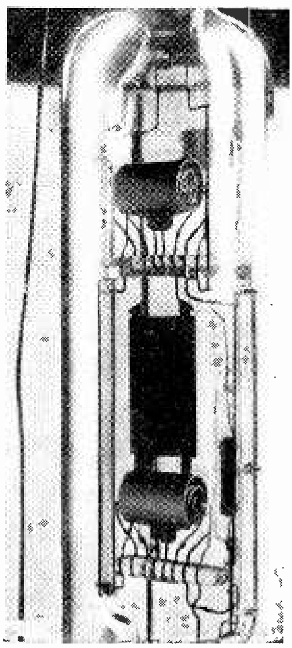


Fig. 2. The Loewe dual tube, developed in 1925, was in fact the first wide-band amplifier, in the modern sense of the term, and had a bandwidth of 1 Mc/s. This was obtained by the combination of a particularly low-capacitance circuit with high-slope valve systems.

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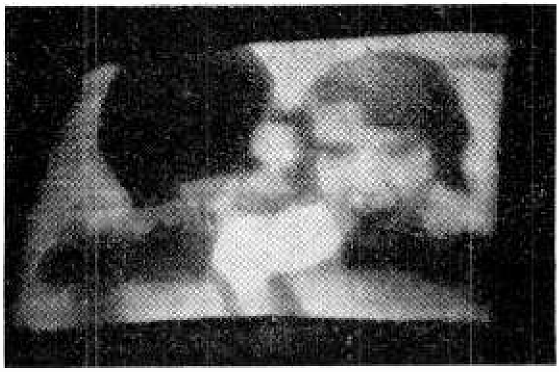
Lichterfelde laboratory, on the basis of publications by B. van der Pol and H. Frühauf[3] with the collaboration of I. Kammerloher. These gave triangular waveforms which could be synchronised by means of a cold-cathode thyraton with external control from the signal.

In the year 1930 there were available, in my laboratory in Lichterfelde, electron beam tubes with intensity modulation electrodes and high focal point brightness[4], relaxation oscillator devices to suit these and wide-band amplifiers in large numbers ready for operation. At that moment it was only a short step to the realisation of television on a purely electronic basis. The technical prerequisites for this purpose were so favourable as a result of the fact that the three basic elements were standing ready in one building, that this realisation, from the time of making the decision to the time of succeeding in an experiment, required hardly more than one day's wiring operations and experimental effort.

The stimulus for starting this work came in the main from outside. Since 1924 I had been following with great interest the reports of the pioneer experiments by J. L. Baird in England using mechanical scanning of the picture by means of a Nipkow disc[5]. This interest was considerably increased when D. von Mihaly demonstrated practical experiments at the Berlin Radio Exhibition of 1928, using an arrangement which was somewhat similar to a Baird televisor, and the demonstrations of mechanical television continued at the Radio Exhibitions of 1929 and 1930 with increasing quality. Finally, I received a particularly powerful stimulus to carry out this work from the experience of a personal meeting with Baird himself, and from the detailed discussions with him regarding the limits of the mechanical methods employed at that time.

Despite repeated indications of the advantages of the electronic method by Fritz Schröter and myself, in lectures and articles, television experiments continued to be conducted with mechanical scanning only. The time had become ripe for some experiments of our own. These experiments led to the achievement, on the 14th of December, 1930, of the first television pictures obtained on a purely electronic basis. One of the pictures, obtained in the year 1930, is shown in Fig. 3(a). A few months later the quality of the pictures had already been increased to the stage shown in Fig. 3(b).

An important factor in carrying out the television transmission experiment so quickly with electron ray tubes both at the transmitter and at the receiver, was the conception of the flying spot scanner[6]. Since then the flying spot scanner has been further developed for the scanning of colour films, for facsimile transmission of over 1 million words per minute (Ultrafax), for counting and sorting of particles on microscope slides, for optical auto-correlation measurements and many other purposes. As is known, this scanner works by deflecting a light spot over the screen of a cathode-ray tube with short after-glow so as to produce a bright raster which is focused by an object lens on the slide or film to be transmitted. The beam of light passing through the slide or film is then fed to a photoelectric cell. According to the optical density of the picture points encountered by the scanning spot a greater or lesser quantity of light is absorbed, so that the electron current emitted by the photoelectric cell is proportional to the brightness values of the picture points.



(a)

(b)

Fig. 3. Electron beam television pictures produced (a) in the year 1930 and (b) in 1931.

Soon after the first experiments with slides, the device used at that time was converted for the scanning of cinematographic films. The first public demonstration of the equipment as a whole was made in the autumn of 1931 at the Berlin Radio Exhibition. It had already been demonstrated to most of the leading technicians of the various European development centres. Because of the simplicity of the arrangement and the brightness of the pictures obtained, these demonstrations turned out to be such effective propaganda for the electronic method that, one year later at the Radio Exhibition of 1932, television receivers with cathode-ray tubes were exhibited by several radio firms. Today I still regard one of the great events of those days to be a visit to the Lichterfelde laboratory, of J. L. Baird, who unfortunately is no longer with us (see Fig. 4). During these demonstrations there had already been a display of the projection of television pictures from a cathode-ray tube on to a large screen of about 1 square metre, using a special optical system[6].

In the efforts to increase still further the brightness of the picture, and to increase the number of picture elements which could be transmitted for a given frequency band of the transmission channel, experiments were carried out in the Lichterfelde laboratory in 1932, partly with the collaboration of Kurt

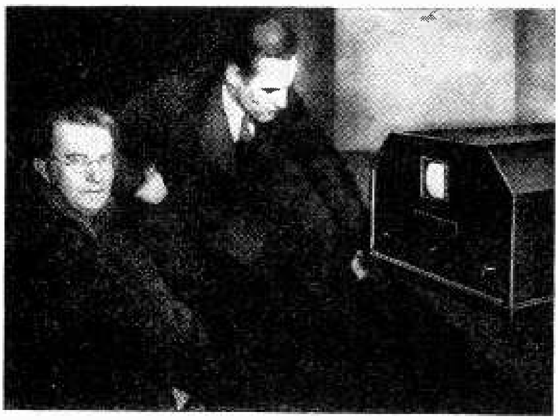


Fig. 4. The British television pioneer J. L. Baird (left) on a visit to our television laboratory in Berlin-Lichterfelde.

Schlesinger, using the so-called "variable speed scanning method" proposed shortly before by Richard Thun[7]. As is known, in this method the control of the brightness of the picture elements is effected by changing the speed of deflection of the light spot, so that at the receiving end the picture is reproduced always with the maximum possible spot brightness. Against this, in the modern television method only a mean spot brightness is effective.

In view of the advantages offered by the variable speed scanning process it is surprising that, up to the present time, nobody has tried out this process in industrial television, where there are no television standards which have to be observed. At that time, in 1932, our efforts with a system of television picture reproduction using variable speed scanning very soon found powerful support in the London laboratories of Cossor in the work of Bedford and Puckle[8]. These workers improved the quality of the picture by controlling the brightness not only by varying the line deflection speed, but also by using a certain amount of intensity control of the light spot.

In the year 1933 the demand for electron ray tubes began to increase at a tremendous rate. One of the largest customers in those days was the development centre at Slough in charge of R. A. (now Sir Robert) Watson-Watt, which often required deliveries of from 50 to 100 cathode-ray tubes. At the same time there arose an ever-increasing demand for the construction of complete cathode-ray oscillographs with built-in power packs and timebase units. It could be foreseen that the production possibilities of our small Lichterfelde laboratory would rapidly be exhausted. For this reason, working in collaboration with Leybold, the "Leybold-von Ardenne-Oszillographen-Gesellschaft" was founded which grew extremely rapidly in the years which followed. Even this company was no longer able to cope with the tremendous increase in the requirement for oscillographs, and shortly before the outbreak of the second world war it was taken over by the firm of Siemens and Halske of Berlin.

As a result of the development in Lichterfelde, the Leybold - von Ardenne company brought out the polar co-ordinate electron beam oscillograph in the year 1936[9]. In this apparatus, which made use of some of the radar techniques being introduced at that time, the timebase was described by an exactly circular movement of the light spot and the measuring deflection was carried out in a radial direction.

Already the transition from the gas-filled to the high-vacuum cathode-ray tube with beam concentration by electron-optical methods had been completed. Already, in the television tubes of 1930 and 1931, electrode arrangements had been used in the Lichterfelde laboratory[4] which are known today as electrostatic focusing lenses, and the control knob on the receiver for adjusting the voltage to these lenses was marked "Focusing." Based on the work of Busch[10], the electron-optical mode of operation had been developed by Calbrick-Davisson, Brüche, Knoll, Recknagel, Scherzer and others[11]. It was therefore soon possible in Lichterfelde, with comparatively few stages of experimentation, to develop high-vacuum cathode-ray tubes with a long cathode life and with anode voltages of up to more than 8 kV for mass production[12].

A parallel idea to my electron raster microscope came into being in 1938 in the form of the closely related electron-optical ray path of the electron micro-oscillograph[13]. In this type of oscillograph,

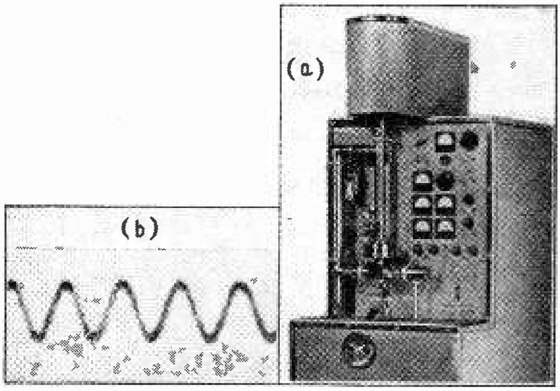


Fig. 5. (a) The electron micro-oscillograph devised in 1939 became well known, particularly through the equipment developed by Lee shown here. At (b) is a "one-shot" oscillogram of a wave with a frequency of 3,000 Mc/s, traced with a 10-micron scanning spot.

which was developed for Siemens with three or four scanning systems, the scanning spot was focused by means of a magnetic lens with a short focal length and a comparatively large beam aperture. In this way a scanning spot having a diameter of only about 10 microns was obtained, which gave an extraordinarily high current density at the anode voltage of 50 kV. This feature made it possible for the oscillograph to have an unusually high scanning speed. Since the deflection plates were also produced in "micro" construction and consequently the transit time effects were reduced, the instrument opened up possibilities of oscillographical investigation of transient phenomena at very high frequencies. This oscillograph principle has become known particularly through the Lee[14] equipment in Fig 5.

Very often certain inventive ideas occur quite independently of one another, and almost simultaneously, when the time for their conception is ripe. As an example of this I would like to recount here an incident from the early part of the second world war. H. E. Hollmann, a radio physicist also working in Lichterfelde, and I had decided in 1940 to work jointly on the development of a panoramic

(*Continued on page* 31)

radar apparatus with decimetric waves[15]. The basic concept was already pretty obvious to us as a result of the polar co-ordinate oscillograph I have already mentioned. We foresaw the tremendous importance of the panoramic radar principle for the future, and so the development proposal was taken direct to the German government minister, Goering, who was at that time responsible for aviation research. Goering's answer, that the war was already won and consequently there was no longer any need for a development which would not bear fruit for one or two years, characterizes the mental capacity of the system of government ruling in Germany at that time. Approximately at the same time as ourselves, Watson-Watt had begun the development of his panoramic radar system which found its way into the history of the second world war and, encouraged by the farsightedness of his Government, was brought to such a successful conclusion during the years which followed.

At the end of the war, the Lichterfelde laboratory, which had remained completely intact, was transferred, together with its staff, to the south of the Soviet Union. Here, in 1952, was the first opportunity for re-commencing our work in the field of electron beam devices. The result was the precision electron beam oscillograph with a scanning spot of about 3 microns diameter and a scanning area of almost 9×12 centimetres. Fig. 6 shows the apparatus[16] which was further perfected after the return to Dresden from the Soviet Union. The fine focusing of the scanning spot was carried out with the help of a grainless luminous screen, which was observed through an optical microscope. The photograph in the vacuum camera is taken on a 9cm $\times$ 12cm photographic plate with a fine-grain thin emulsion layer.

This oscillograph differs from the micro-oscillograph mentioned earlier in respect of the increased length of the deflected beam and the extreme sharpness of the spot. By virtue of the large deflected beam length and the extremely small convergence angle of the writing beam, the deflection errors with this system are reduced to the extent that nearly 10^9 image points can be accommodated on an oscillograph screen of the size mentioned. This figure is about four orders of magnitude higher than in the case of the usual cathode-ray oscillograph. Consequently, as a result of the smallness of the beam convergence angle ($2\alpha_L \approx 3 \times 10^{-4}$), the photographic scanning speed of this type of oscillograph (as also the scanning speed in relation to the diameter of the scanning spot) is necessarily small. Furthermore, as a result of the smallness of the scanning spot the oscillograms are not visible to the naked eye, so that in order to observe them it is necessary to use an optical microscope.

By means of this type of oscillograph, which is only at the beginning of its applications in research work, the fine structure of oscillograms is opened up to direct observation. Two sections of an oscillogram obtained with this apparatus, one highly magnified and the other very highly magnified, are shown in Fig. 7. These will perhaps serve to give an idea of the properties of this latest child of the electron beam oscillograph family. By recording the fine structure of characteristics in plasma investigations (characterizing the stability of the plasma), by making visible details of curves produced by the Barkhausen effect, by plotting fine details of transistor characteristics, the precision electron beam oscillograph has already introduced a new era in the graphical recording of electrical phenomena. The first results of this type of oscillographic recording have already shown great promise, particularly in studying the fine structure of electro-encephalograms, electro-cardiograms and nerve action potentials.

Looking Forward

It is perhaps a comforting thought for the younger generation that there are still many important problems in the science and technology of electron beam devices which remain to be solved in the future. Some of these problems can be clearly seen already, or are delaying the introduction of apparatus into practical use. Perhaps I may be permitted to conclude this article with a few remarks regarding such fields which so far have hardly been broached.

As far back as 1955 H. E. Kallmann[17] had mentioned a new deflection system by means of which the deflection sensitivity in the Y direction can be increased by about one order of magnitude. It is worthy of note that this system has found no application up to the present. A start was made at testing it out in conjunction with the precision electron beam oscillograph, because the new deflection principle could be a great step forward in this technique, where there is a very small beam cross-section in the deflection space. The relative deflection sensitivity of the precision oscillograph in terms of the diameter of the scanning spot is already more than one order of magnitude higher than that of the cathode-ray oscillograph tubes available on the market. One should therefore expect that this combination, at present in the development stage, should provide a total increase of more than two orders of magnitude of Y deflection sensitivity.

With very many measuring problems this advance would make it possible to manage completely without a deflection amplifier. This prospect is particularly valu-

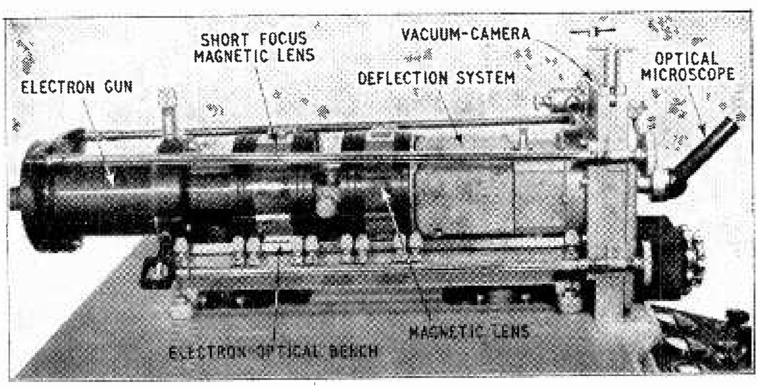


Fig. 6. Layout of the precision electron beam oscillograph developed during the period 1952-55. In this apparatus, built by VEB Vakutronik of Dresden, the scanning spot is only 3 to 5 microns and the scanning area is about 9 cm x 12 cm.

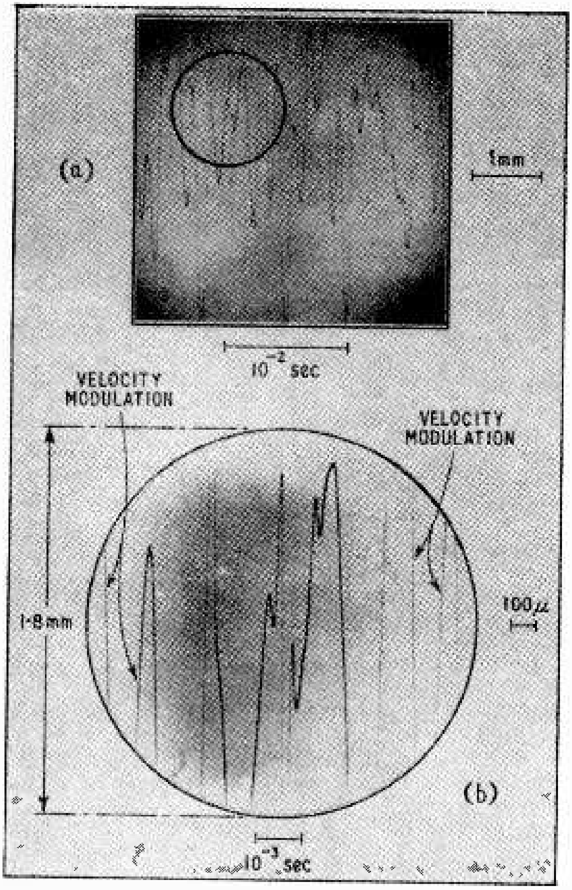


Fig. 7. Highly-magnified sections from a precision oscillogram of a music waveform at the output of a radio receiver: (a), section magnified 15 times (approx. 1/900 of the area of the 9 cm x 12 cm photographic plate); (b), section magnified 56 times, showing velocity modulation of the scanning line by residual i.f. signal from the receiver. (Approx. 1/4000 of the surface area of the 9 cm x 12 cm photographic plate!)

able in the case of the precision oscillograph, because the fine structure of the oscillogram would no longer be restricted by fluctuations in the deflection amplifier, and only the fine structure of the waveform under investigation would be made visible.

Closely related to the questions I have just touched upon is another line of development, in which low-noise amplifiers are used as deflection voltage amplifiers for oscillographs, especially for precision instruments. The future use of low-noise amplifiers in conjunction with precision oscillographs, for example, in the field of action-potential oscillography in medicine and physiology (observing the details of electro-cardiograms, electro-encephalograms and so on) should lead to interesting results.

Some of the tasks which face the precision oscillograph today will perhaps also be carried out by means of a special oscillograph tube with a very high spot sharpness (e.g. 5 to 10 microns), equipped with a suitable electron lens, with a grainless cemented luminous screen and with an anode voltage of 10 to 30 kV.

A wide field of application, especially in the field of medical electronics, should be claimed by the single-gun multiple oscillograph with television tube bulb, of which individual examples have already been constructed. With this 4 to 6 waveforms can be traced simultaneously on an after-glow screen with the help of an electronic switch.

Far greater efforts will be made than in the past to achieve the direct recording of oscillograms in single processes. Going beyond the recording tubes which have already been developed so far there should be wide use in practice for tubes with the facility of storing traces and also for instruments with xerographic recording of oscillograms developed from the old idea of Selényi[18].

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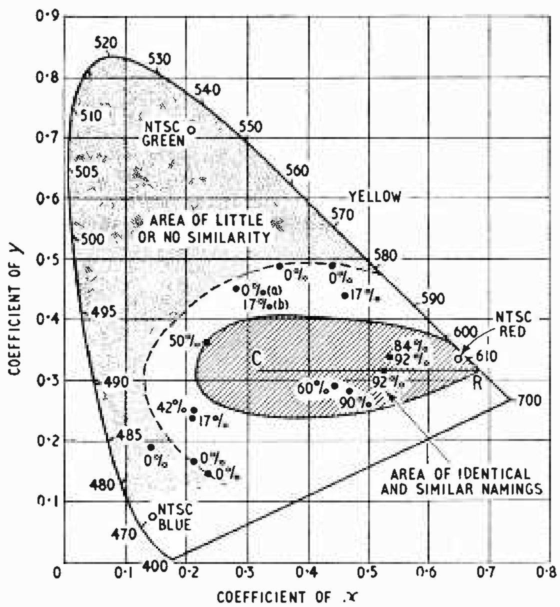
Subjective Colour Tests

MEASUREMENTS ON A REDISCOVERED "TWO-COLOUR" SYSTEM

TELEVISION engineers have recently been showing a good deal of interest in a system for reproducing pictures in colour which has the unusual feature of using white as one "colour" component and, say, red as the other. This phenomenon has been known for some time, but about a year ago was rediscovered and studied in detail by E. H. Land in the U.S.A.—as a result of which it has become popularly known as "Land colour." The feature of Land colour which would seem attractive for possible use in colour television is that it would only be necessary to transmit two simple signals carrying colour information. In the established N.T.S.C. colour television system it is necessary to transmit a luminance signal plus two colour-difference signals which, in a very complex way, contain information on the three primary-colour components of the picture. Even if Land colour did not offer an advantage in bandwidth economy it would apparently make things much simpler for the engineer.

Unfortunately, Land colour has a big drawback in that it depends on subjective effects to convey some of the colour information to the mind of the observer. And the extent to which the observer "sees" these colours, which are not presented physically to his eyes, depends very much on their positions and areas in the colour picture. At a recent meeting of the Physical Society's Colour Group some very fine examples of Land colour pictures were presented by M. H. Wilson and R. W. Brocklebank of the Goethean Science Foundation, Stourbridge. These, to most people, would have certainly passed muster as genuine three-colour reproductions, but it was pointed out that their success was very much a result of the careful composition of the coloured objects in the pictures. The effectiveness of the subjective colours cannot easily be determined, of course, but one speaker at the meeting, W. N. Sproson, described some subjective measurements for this purpose which had been conducted at the B.B.C. Research Department, using colour-matching procedures. Before giving details of the B.B.C. tests, however, it may be as well to recapitulate the basic method of producing Land colour pictures, for the benefit of those readers who may not be able to consult the relevant literature.*

Results of the B.B.C. tests plotted on the C.I.E. chromaticity diagram, which also shows the N.T.S.C. red, green and blue primaries for colour television. The figures around the spectrum locus are wavelengths in millimicrons (10^{-9} m). (a) and (b) are two different results for one colour.



Two photographs are taken of the scene to be reproduced; one through an optical filter passing only light of wavelengths longer than about 590 $\times 10^{-9}$ m (appears red when viewed by transmitted light) and the other is taken through a filter passing wavelengths shorter than this figure: this filter appears green or bluish-green. Processing to produce positive black-and-white images is then carried out—images in which the amount of light passed at any point represents the brightness of the scene at that point, within the pass-band of the filters used. These two records are thrown together on to a screen by two projectors, or otherwise superimposed additively (i.e., taking the electrical analogue, the images are in parallel, not series), the long-wavelength record being illuminated by light of a "longer" wavelength and the short record by light of the "shorter" wavelengths. The point on the wavelength scale about which the terms "longer" and "shorter" apply does not seem to be critical as the result is a picture in colour, even if two similar filters, such as orange and yellow, are used in projection. Also one positive may be illuminated by white light and the other by coloured light: Land concentrated on this latter method, using red light for the long record and white for the short.

"Simultaneous contrast" effects, in which the apparent colour of an area is influenced by its surroundings, have been known (and exploited) for a long time, especially in fields such as stage lighting.† However, the only result one would expect from the use of red and white lights would be the appearance of "minus red" (blue-green, the complementary colour to red). As Land's claims went far beyond this, *Wireless World* decided, as did many others, to repeat Land's experiments. Photographs of a test piece containing coloured cloths, china,

*E. H. Land. *Proc.Nat.Acad.Sci.* (U.S.A.), **45**, 1, p. 115, Jan. 1959; 4, p. 636, April 1959 (Parts I and II of three). Also *Scientific American*, **200**, 5, p. 84, May 1959, and **201**, 3, p. 16, Sept. 1959. A. Karp. *Nature*, **184**, 4687, p. 710, 29th August 1959. "Two Co-ordinate Colour" by "Quantum." *Electronic & Radio Engineer*, **36**, 8, August 1959.

†See, for instance, "The Technique of Stage-Lighting" (2nd Edn.), p. 151, by R. G. Williams. Pitman, 1958.

fruit and flowers were taken through Ilford filters Nos. 204 and 404 and these were processed to form positive transparencies for projection with red and white light. The colour rendering varied over the scene, being fair on small areas, such as the fruit, good on one or two points of fine detail such as the yellow centre of a white daisy, and poor in large areas. Another interesting point was that a suggestion of blues appeared in the right places in the reproduction, but, in fact, little blue light could have been registered on the film, for the pair of filters used were the red and green from a set of three designed to split the spectrum into three parts centred on the three primary colours in light; red, green and blue. Also, *Wireless World* was invited to view some work being done by J. P. Wilson, of the Information Systems Group, King's College, London, where similar effects were noted. An interesting side-issue of this visit was a demonstration which seemed to indicate that the simultaneous-contrast effects occur not in the retina, but in the brain. The experiment consisted of displaying one positive transparency to each eye, the long record having also the appropriate filter included in the light-path. In this way, each retina was presented with only one picture, but the result was still a Land-colour rendering of the scene.

In the B.B.C. tests the object was to form an estimate of the range of chromaticities given by Land colour reproduction, and the results were plotted on the standard C.I.E. chromaticity diagram‡ as shown in Fig. 1. A triple projector was used. Two-colour and three-colour versions of the same slide were shown to the observers individually. The three-colour version used red, green and blue positive separations projected through the same coloured filters. The two-colour version used the red and green separations projected in red and white lights.

A colour-naming technique was used to assess the accuracy of the two-colour version in terms of the three-colour version. Specific areas of a given picture were named by the observer; no restriction was placed on the actual colour names to be used by the observers but consistency of naming was requested. The same areas were named in both a two-colour and a three-colour reproduction. The colour namings were then analysed into the three classes: "identical," "similar" and "different." Chromaticities of the colours were estimated by comparison with the Munsell Colour Atlas.

On the C.I.E. chromaticity diagram in Fig. 1 are shown the results of the colour namings. The numbers at specific chromaticities are the percentages of observers giving "identical and similar" namings to the two-colour and three-colour versions. On the basis of these few results a central area has been shaded in, over which 50% or more of the observers gave "identical" and "similar" namings. The diagram shows a straight line CR (joining Illuminant C standard white to red) which represents the "objective" range of colours produced. A further, outer area is also shaded in, and over this there is little or no similarity in the colours produced by a two-colour and a three-colour reproduction.

The effect of the size of colour patch is important, and the C.I.E. diagram gives the results for fairly large colour patches. The tests have shown that the range produced by this two-colour process is definitely greater when the colour patch is somewhat smaller. Yellows, greens and blues have been reported in small areas, although the C.I.E. diagram indicates, correctly, that in larger areas these colours are not accurately reproduced. This fact has been confirmed by the *Wireless World* experiments.

Thus, in view of the subjective nature of the colours and the fact that they depend a great deal on the composition of the pictures, it does not seem that Land colour has much to offer for a practical system of colour television. One has only to compare the limited range of chromaticities indicated by the central area in Fig. 1 with the wide range enclosed by the N.T.S.C. primaries to see the disadvantage of Land colour for large-area reproduction. It has been suggested that the phenomenon might be valuable in prompting us to revise our orthodox ideas on colour vision, but at the above-mentioned meeting Professor W. D. Wright, the eminent authority on optics, expressed the view that the established theories are not likely to be affected by it.

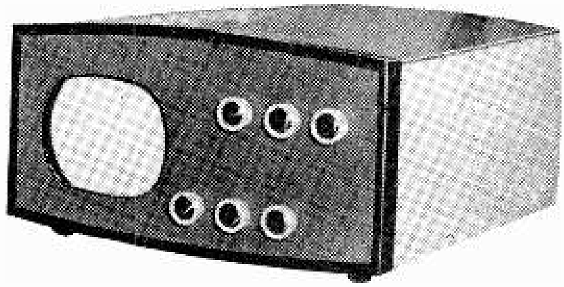
‡ For an explanation of the C.I.E. (Commission Internationale de l'Eclairage) chromaticity diagram and its *x* and *y* co-ordinates, see "Colour Fundamentals," by H. Henderson, *Wireless World*, August 1956.

Doctors' Hobbies Exhibition

DIVIDED into 22 classes covering activities ranging from the collection of antiques to photography, this exhibition included an Electrical Class in which the winning entry was a small television receiver described on the accompanying card by its maker, Dr. M. J. Ball, as "... suitable for the invalid's bedside or the bureaucrat's desk". The set is housed in a cabinet made by resin-bonding Formica to a wooden frame and it uses a 5-in magnetically deflected and focused c.r.t. (Type 5FP7). The long-persistence afterglow of the screen phosphors had been partly destroyed by exposure to ultraviolet light. Providing for the reception of both B.B.C. and I.T.A. programmes on its attached 16-in rod aerial, the receiver consists, in the main, of sections of commercial receivers modified and adapted to suit the 5-in tube. In all, 17 valves of various heater-current ratings are used and these are interconnected in a series-parallel configuration to provide a 0.3-A heater chain.

As the receiver is made up from units and components of normal size, their close packing inside the case caused difficulties due to deflection of the c.r.t. beam by stray magnetic fields and the heat produced by the 120W or so of mains power consumed. The use of Mumetal screening and careful orientation of iron-cored components overcame the first problem, whilst ventilation through the loudspeaker grille in the top of the cabinet, coupled with the use of an aluminium deflector assisted in the removal of heat.

The exhibition was oganized by Benger Laboratories, Ltd., and held at the London headquarters of the British Medical Association.



Small television receiver seen at recent exhibition.

Electromechanical Analogies

By
"CATHODE RAY"

Some Further Details of How to Represent Mechanical "Works" as Electrical Circuits

LAST month we agreed that developing the analogy between electrical circuits and mechanical (and acoustical) devices was a very nice idea, and most instructive and useful if correctly handled. But it was easier to go wrong with it than might seem at first sight.

On the electrical side, we all understand how to represent a piece of equipment as a circuit diagram, made up of standardized graphic symbols joined up by lines representing wires. Our difficulties begin when we try to represent a piece of mechanical equipment by an analogous type of diagram. Even when that part of the job is done for us in a book, we may not be quite clear how the various components are "connected." Not clear enough, anyway, to apply a foolproof rule for translating the diagram into its equivalent electrical circuit.

That was the part of the problem we dealt with last time. Before going on let us recapitulate.

The analogy we considered was the familiar "direct" one in which force is represented by e.m.f., velocity by current, mass by inductance, compliance by capacitance and resistance, reactance, impedance, etc., are terms common to both. Mechanical links such as rods (assumed massless, or their masses represented separately in lumps) correspond roughly with wiring, but if we treat them in the same way as electrical connections we can hardly fail to go wrong. In particular, the order in which they are connected—unimportant in electrical circuits—makes all the difference. If an applied "a.c." force gives two mechanical elements the same linear vibratory velocities, reckoned between their "terminals," they are by definition analogous to corresponding electrical elements in series, though visually they are "in parallel." Whereas the two "terminals" of a mechanical resistance (represented conventionally by two flat surfaces sliding across one another frictionally, or by the piston and cylinder of a dashpot) and of a compliance (represented by a coil spring) can easily be located, a mass has only one connection to the force. But it can be regularized by "completing the circuit"—drawing a dotted line back to the other "terminal" of the source of force. To avoid uncertainty as to whether the description of a mechanical "circuit" as "parallel" refers to arrangement or to behaviour, Dr. A. Bloch* suggested the term "co-resistive" for both it and an electrical series circuit. And because the analogue of an electrical parallel circuit is one in which the same force comes across each mechanical element equally, which happens when they are apparently in series, he uses the description "co-yielding" for both. So to transform a mechanical system into its equivalent electrical circuit in accordance with the direct analogy, first draw it as a mechanical "circuit" by the foregoing conventions, to bring out the points of application of forces and to show whether elements are connected in what we electrical people would call series or parallel; then convert it to the "dual" *arrangement* (in which series and parallel are all interchanged), and at the same time—or as a separate step if we aren't sufficiently adept—exchange the mechanical symbols for the corresponding electrical ones.

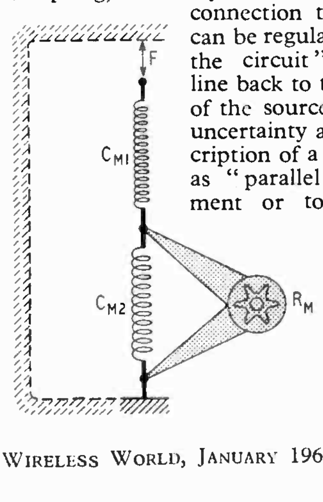


Fig. 1. Mechanical "circuit", in which an alternating force F is applied to two springs, to one of which is connected a frictional damper.

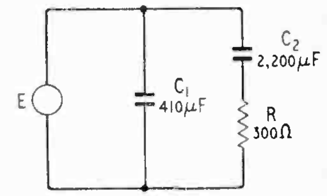


Fig. 2. Direct electrical analogue of Fig. 1.

If you are new to all this, not having read the last instalment, you may have found its condensation into a single paragraph rather bewildering. If so, a simple example should make it clearer. We might at the same time make some progress towards the practical side by working in numerical values.

Fig. 1, then, shows a mechanical system consisting of two springs with a frictional damper across one of them. When the springs are tested separately, a 1-kg. weight (about 2¼ lbs.) compresses C_{M1} 0.4 cm. and C_{M2} 2.15 cm. The same force applied between the ends of the damper arms makes the distance between them change steadily at 3.3 cm/sec. We shall assume that this velocity varies exactly in proportion to the applied force. (In practice it probably wouldn't, but we don't want to involve ourselves in non-linear resistances right at the start.) The masses of these parts are supposed to be negligible. We can now calculate the compliances and mechanical resistance, and if we do so in m.k.s. units they will be in mechanical farads and ohms, which will at least make us feel partly at home straight away. Capacitance is equal to charge/voltage, so compliance is displacement/force; and mechanical resistance is force/velocity. The m.k.s. unit of force is the newton, which is enough to give a mass of 1 kg. an acceleration of 1 metre/sec.^{2}. The force of gravity at sea-level gives a mass of 1 kg. an accelera-

* "Electromechanical Analogies and their Use for the Analysis of Mechanical and Electromechanical Systems", *Journal I.E.E.*, Part 1, April 1945, pp. 157-169.

tion of 9.81 m/s² ("g"), so 1 kg. weight is equal to 9.81 newtons. Therefore

$$C_{M1} = \frac{0.004}{9.81} = 0.00041 \text{ mech. farad} = 410 \text{ mech. } \mu F$$

$$C_{M2} = \frac{0.0215}{9.81} = 0.0022 \text{ mech. farad} = 2{,}200 \text{ mech. } \mu F$$

$$R_M = \frac{9.81}{0.033} = 300 \text{ mech. ohms.}$$

With such a simple arrangement there is really no need to draw a separate diagram to show the "circuit"; the only thing to remember is that in order to impart the force F to the springs the source of the force must be rigidly attached to the framework or "earth" to which the bottom spring is anchored. So we have to imagine, if we don't dot in, this completion of the circuit.

There should be no difficulty in arriving in one stride at the equivalent electrical circuit. Capacitances take the place of compliances, and resistance the place of mechanical resistance. C_{M1} being (visually) in series with F and the combination of C_{M2} and R_M, its analogue C_1 in Fig. 2 must be in parallel with them. And the analogues of the parallel pair C_{M2} and R_M appear in series with one another. The translation into electrical units consists simply in deleting the prefix "mechanical."

Note that frequency hasn't come into this at all. So Fig. 2 should be valid for any waveform. But we must not forget that such conclusions are true only so far as our assumptions are true. For instance, we neglected the mechanical masses entirely. While that might be justifiable at very low frequencies, it could hardly be so at high. A rough way of deciding whether it was significant or not would be to suppose that something of the order of half the total mass was concentrated at the junction of the three mechanical elements. This, being subjected to the same velocity as C_{M2} and R_M, would appear in Fig. 2 as an inductance of 1 henry per kg. in the C_2R branch. The resonant frequency of this branch could then easily be calculated.

Confining ourselves to the simple Fig. 2, we can find the frequency at which the impedance of C_2 equals that of R:

$$\frac{1}{2\pi f C_2} = R$$

$$\therefore f = \frac{1}{2\pi C_2 R} = \frac{1}{2\pi \times 0.0022 \times 300} = 0.24 \text{ c/s.}$$

At this frequency, the impedance of C_1 would be several times greater than that of C_2 and R combined, so would take that much less current. We conclude that at the same frequency the upper spring would be relatively stiff, flexing only a fraction as much as the other. At much higher frequencies (short of mass being important) the impedance of C_{M1} is relatively low, so it flexes most.

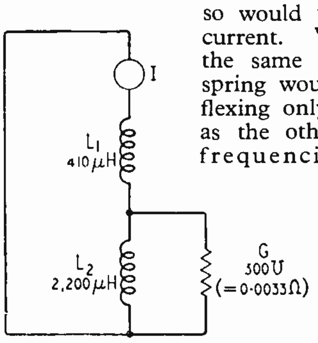


Fig. 3. Inverse electrical analogue of Fig. 1 and dual of Fig. 2.

If the exercise is confined to paper, the question of rate of exchange between mechanical and electrical quantities need hardly arise. So far we have made it one-to-one in every case, and because we have worked in a single system of units throughout (m.k.s.) we can be sure the analogy can be relied upon throughout. For instance, the amount of power needed to make a point on the machine vibrate with an r.m.s. velocity of 0.01 m/s would be the same as that needed to make 0.01 amp r.m.s. flow through the corresponding part of the circuit at the same frequency.

With mechanical systems complicated enough to make this sort of study worth while, however—and expecially when distributed masses, etc., are involved —it may be more convenient to measure the performance of the electrical circuit than to calculate it. If so, you may ask, why not measure the performance of the mechanical system direct and save all the trouble of translation? The answer is that it is usually easier and more accurate to measure electrically, and *much* easier to vary circuit quantities continuously during test than machine quantities.

When it comes to building actual electrical models, the 1 : 1 scale may be awkward. We may not have a 2,200µF fixed capacitor, for example; much less a variable one for trying other values. The solution is to use some other scale, but we must take care to keep it consistent.

We can decide to represent a velocity of 1 metre/sec by a amps, and a force of 1 newton by b volts. That is to say

$$\frac{I}{V} = a \text{ and } \frac{E}{F} = b \quad .. \quad .. \quad (1)$$

$$\text{Therefore} \quad \frac{R}{R_M} = \frac{E}{I} \cdot \frac{V}{F} = \frac{b}{a} \quad .. \quad .. \quad (2)$$

and similarly for impedance and reactance. So, as inductive reactance is proportional to inductance and mass reactance to mass,

$$\frac{L}{M} = \frac{b}{a} \quad .. \quad .. \quad (3)$$

and inversely

$$\frac{C}{C_M} = \frac{a}{b} \quad .. \quad .. \quad (4)$$

Frequency of resonance is proportional to $1/\sqrt{LC}$ and therefore to $1/\sqrt{MC_M}$, so the analogue works in "real time."

Power is proportional to EI and FV, and

$$\frac{EI}{FV} = ab \quad .. \quad .. \quad (5)$$

so 1 mechanical watt is represented by ab electrical watts, and the same for energy. If you want watts to be the same size in both domains, you must choose $b = 1/a$.

If it would suit us to make C_2 in Fig. 2 2.2µF, then from eqn. (4) $b/a = 1{,}000$, and if we make $b = 1/a$ we have $b^2 = 1/a^2 = 1{,}000$. Substituting these in eqns (1)–(5) we find our scale factors to be:

1 newton is represented by $\sqrt{1000}$ volts

1 metre/sec is represented by $1/\sqrt{1000}$ amp.

1 mech. watt	,,	,,	1 electrical watt
1 mech. c/s	,,	,,	1 electrical c/s
1 mech. ohm	,,	,,	1000 electrical ohms
1 kg. mass	,,	,,	1000 henries
1 mech. farad	,,	,,	by 0.001 farad

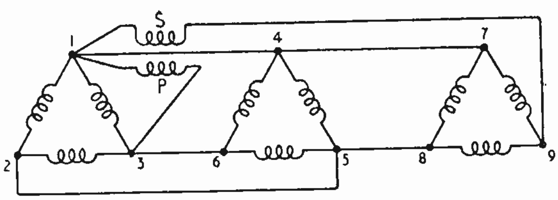


Fig. 4. Use of an ideal 1:1 transformer (PS) to enable a circuit to be drawn without crossing wires. This brings such exceptional circuits within the scope of the rules for drawing dual circuits.

It would be advisable to make a table like this whenever the model is not life-size throughout.

Having (let me optimistically assume) made the effort of mastering this electromechanical analogy chiefly for the sake of avoiding the sweat of learning mechanics, making double use instead of our knowledge of electrical circuits, you may feel very strongly that it is superfluous, not to say positively confusing, to add to it another type of analogy in which everything is upside down and clean contrary to all our technical upbringing. If you add " and common sense " I can hardly blame you, as that was how I used to feel. Now, as Bloch's latest disciple, I am going to try to put across what I was at first extremely reluctant to buy from him, namely the " inverse " analogy (which is the same as the " mobility " analogy invented by F. A. Firestone in 1933). I fear I lack the masterly salesmanship with which he converted my hostility into enthusiasm, but here goes.

In the inverse analogy, force is represented by *current* and velocity by *voltage*. I need hardly explain that this necessitates everything else being upside down; mass is represented by capacitance, compliance by inductance, mechanical resistance by conductance, mechanical impedance by electrical admittance, etc. It follows that co-resistive mechanical arrangement is represented by co-yielding electrical arrangement. In fact, the inverse electrical analogue is the " dual " of the direct electrical analogue. And if you don't know what " dual " means in this context and haven't got last month's *Wireless World* or " Second Thoughts on Radio Theory " (Chap. 35) handy for looking up, it means the whole upside-down relationship between the two electrical analogues of any mechanical system.

Before you say rash things about not listening a moment longer to such nonsense as making voltage analogous to velocity and inductance to compliance, may I point out that in the first case they both begin with a " v " and in the second both are shown in diagrams as a curl. Small points, but quite useful for a taxed brain to hang on to.

More important is the fact that in translating from mechanical to electrical circuit diagram the arrangement is the same—there is no interchanging of series and parallel, which can be quite tricky with complicated systems. The translation of symbols is relatively easy, especially as they are much more like one another than in the inverse analogy. Thus instead of Fig. 2 to represent Fig. 1 we would have Fig. 3. (" G " is the symbol for conductance.)

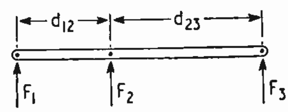
So far, then, all is well. The disadvantage is that when one comes to study the mechanical behaviour on a basis of familiarity with circuit behaviour, one's familiarity is found to be of the wrong kind. It may be hard at first to interpret the increase in voltage across L_1 with rise in frequency as an increase in vibrational velocity of the upper spring in Fig. 1. But a little practice soon gets one into the way of it. If it doesn't, there is always the alternative of converting Fig. 3 into its complete electrical dual, as explained last month. The result is Fig. 2.

When Bloch advocated the inverse analogy he did so with the argument that just as in some situations a current can be regarded as the cause of a voltage (e.g., in the anode circuit of a line-scan pentode) so a velocity can be regarded as the cause of a force. While this is quite true, it seems to me that the question of cause and effect confuses the issue of direct versus inverse analogies. As we have just seen, it is possible to use either, according to one's whim, without any interchange of cause and effect.

But I am particularly grateful to him for unconsciously putting the finishing touch to the system of vector diagrams I praised so conceitedly only a month or two ago. Hitherto I had to admit one little flaw—that as regards current vectors it broke down if the circuit diagram couldn't be drawn without crossing wires. Actually there are very few practical circuits, for which one might want to draw vector diagrams, where this difficulty arises. I have never come across any, but the possibility irked me. The same difficulty occurs when drawing the dual of such a circuit, as one may want to do when changing over between inverse and direct analogies. Bloch showed that this difficulty can be overcome by bringing in an ideal 1 : 1 transformer.

One of the " impossible " circuits, though not of much interest to most of us, is a 3-phase source connected to two loads, Fig. 4. There is always one lead that can't be run without crossing; in this case, the one from 3 to 9. But there is no rule against an invisible magnetic field crossing, so the transformer PS solves the problem. This enables a vector diagram to be drawn according to my rules (*Wireless World*, August 1954, p.383), and enables the dual circuit diagram to be drawn according to the rules given last month.

Fig. 5. Diagram of a simple lever. One of the forces F_1—F_3 represents the support given by the fulcrum.



Some things still remain to be said in favour of the inverse analogy, and as space is running out I won't go into detail again about units and scale factors for it; the principles are the same as for the direct analogy.

One much-used mechanical component which I have held back until now is the lever, because (notwithstanding what Dr. Bloch seems to say to the contrary) it needs the inverse analogy to link it with its electrical counterpart—the transformer. Ideally, a lever is perfectly rigid and without mass, so is incapable of storing mechanical energy in itself, and it has a frictionless fulcrum, so dissipates no energy. What it does do is vary the ratio of force to velocity (mechanical impedance), gaining say force at the expense of velocity. In the same way, an ideal transformer stores and dissipates no energy, but changes the voltage/current ratio.

A lever must have at least three forces acting on it, as for example in Fig. 5. The sum of the three

$(F_1+F_2+F_3)$ must be zero, otherwise it would go flying off. Also to conform to the ideal conditions mentioned, the total power going into it $(F_1 V_1 + F_2 V_2 + F_3 V_3)$ must be zero. Finally, and obviously the angular velocity $\frac{(d\phi)}{dt}$ of both parts of it (d_{12} and d_{23}) must be the same:

$$\frac{d\phi}{dt}=\frac{V_1-V_2}{d_{12}}=\frac{V_2-V_3}{d_{23}}$$

Compare this with an auto-transformer, Fig. 6. The clearest analogue of lever length is number of turns, N. To this, voltage is proportional. Voltage per turn is proportional to the rate at which the magnetic flux in the core (also denoted by ϕ) is changing:

$$\frac{d\phi}{dt}=\frac{E_1-E_2}{N_{12}}=\frac{E_2-E_3}{N_{23}}$$

So voltage is analogous to velocity. This fits the other conditions too. Suppose F_3 in Fig. 5 is an upward (positive) force of 10 kg., and the lever is hinged at the F_1 end. Then, if $d_{23}=2d_{12}$, F_3 can lift 30 kg. at F_2 (which is therefore negative). To balance these two, the upward pressure F_1 must be 20 kg. If forces were represented by voltages, as in the direct analogy, the transformer figures would be wrong. But if force is analogous to current we

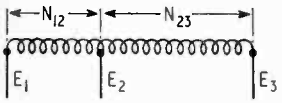


Fig. 6. Electrical analogue of Fig. 6—an autotransformer.

have as the first condition $I_1+I_2+I_3=0$, which is true. The second condition would be true either way.

Our interest in all this is likely to be in connection with "transducers" which are partly electrical and partly mechanical, such as loudspeakers, microphones, pickups, motors, and relays. In early treatises, separate circuit diagrams were shown for the electrical and mechanical portions of these. The reaction of the mechanical portion on the electrical circuit was represented in the electrical circuit diagram as a single element called "motional impedance". One can go further than this, however, and make a single circuit diagram in which all the mechanical elements are separately represented along with the purely electrical. The thing can then be studied as a whole.

You will probably foresee that in order to do this we must accept some restrictions on choice of scale factors. Otherwise the mechanical and electrical portions won't join up properly. For one thing, the law of conservation of energy must be observed. It may be less obvious that there is no longer freedom to choose between the direct an inverse analogies. Bloch deals with this, but unfortunately I couldn't follow his proof and had to satisfy myself on the following lines.

Suppose first we have a device, such as a moving-coil loudspeaker, in which the cause of the mechanical force on a wire is the reaction of a magnetic field on current flowing through the wire. (This is sometimes known as the electric motor effect.) Assuming the wire carrying current I is at right angles to the field of flux density B, and the length of the wire is l, the fundamental equation is:

$$F=B\,l\,I \qquad (6)$$

If the wire is free to move, this force will move it and cause an e.m.f. to be generated in it (dynamo effect):

$$E=B\,l\,V \qquad (7)$$

where V is the velocity of the wire, assumed to be at right angles to the field and current.

If the electrical impedance of the wire is either negligible or separately represented, its only impedance is due to the back e.m.f. generated by its motion, so is called the motional impedance, Z_{EM} It can be derived from equations (6) and (7):

$$Z_{EM}=\frac{E}{I}=(B\,l)^2\frac{V}{F}$$

$(B\,l)^2$ is a constant, and force/velocity (F/V) is a mechanical impedance—in this case the mechanical impedance of the wire and all that moves with it. So the electrical impedance is *inversely* proportional to the mechanical impedance, and consequently we are bound to use the inverse analogy. And the scale factor is also fixed for us—$(B\,l)^2$.

The same result, except for the details of the constant, emerges from corresponding calculations of other magnetic types of electromechanical transducer.

But now compare the electrostatic type. (I don't like the term "electro*static*" for something that moves, but it will probably be better understood than just "electric".) Suppose we have a pair of parallel plates, each of area A, separated by a dielectric of thickness d and permittivity ϵ, and supplied with a fixed polarizing voltage E_0. Then if E is a relatively very small "signal" voltage, the force caused by it can be shown to be

$$F=\frac{E_0\,\epsilon\,AE}{d^2} \qquad (8)$$

If free to move as a result of this incremental force, with velocity V, the capacitance will vary. If at the same time E_0 is kept constant, the charge must vary, giving rise to a current

$$I=\frac{E_0\,\epsilon\,AV.}{d} \qquad (9)$$

Deriving the motional impedance from (8) and (9) we get

$$Z_{EM}=\frac{E}{I}=\left(\frac{d^2}{E_0\,\epsilon\,A}\right)^2\frac{F}{V}$$

so it is *directly* proportional to the mechanical impedance, and we must use the direct analogy, and of course the scale factor specified.

This, of course, is only the beginning of the subject. So far it has been idealized to make the basic principles clear. Extending the thing to distributed masses, etc., is more or less routine stuff, like extending r.f. theory to microwaves.

Since writing these two articles I have had my attention drawn to "Notes on Electro-Mechanical Equivalents" by H. Jefferson in *Wireless Engineer*, December 1944. He deals throughout with both "direct" and "inverse" analogies, which he calls "*b*-equivalent" and "*a*-equivalent" respectively; and shows that the "wrong" equivalent can be made to fit a lever or an electro-mechanical transducer by use of an "inverting transformer" with a ratio of $1:\sqrt{-n^2}$. While this is mathematically feasible, it does rather spoil one main purpose of these analogies —to assist easy visualization—and he naturally recommends the other equivalents.

MIDGETS AND FIDGETS

—Or Bifocals Anyone?

By JACK DARR*

AMONG the many unpleasantnesses the American radio-TV repairmen have to put up with is the increasing tendency of the setmakers toward miniaturization of their products. These gentry are evidently firmly convinced of the truth of the old saw about "Good Things Coming In Small Packages!" While this might conceivably be quite useful in the small transistor portable radio field, where we have already seen a 4-transistor set reduced to the size of a packet of cigarettes, to fit into the shirt pocket, it can lead to uncounted confusion in others! Not *too* much trouble is encountered, always providing you have a good supply of very high-powered jeweller's loupes, a soldering-iron with a *very* small bit, and immeasurably good eyesight. (If you do, cherish it: it won't last long!)

The poets sigh for the halycon days of yore. So, too, do some of us "old gaffers" who remember the radio business "away back when." In this instance the phrase refers to the early 1930s, when the radio business was only beginning to grow into the giant of today. This was the period which saw the biggest home radios ever built. Housed in cabinets faintly reminiscent of grand pianos, in both size and construction, they were filled with masses of chasses (Sorry! Shan't do it again) which were separate power supplies, audio amplifiers, tuners, and so on.

This decade also witnessed the birth of the first "midget" radio. This happy event took place about 1931, with the advent of the Model 6 "Echophone." It was about 12 × 14 inches, and about 15 inches high. It had a round-topped cabinet of veneer plywood, a 6-valve circuit, and was famed far and wide as being the only radio set made that one could pick up with only one hand! These sold like hot cakes, and soon every major manufacturer had his finger in the pie, making "midgets."

The classic example was the original Majestic Company (Grigsby-Grunow) who built the immortal Model 50. This was classified as a midget, although there were many who expressed doubt as to the validity of the classification. It was about the same size as the "Echophone," although a bit taller, rather square-topped, with a sort of Corrupt Gothic pilaster effect on the front of the cabinet. Its principal feature, though, was its weight. This hefty little giant was so heavy that servicemen with ordinary sized feet often found themselves sinking hock-deep into lawns, and asphalt paving in midsummer, while attempting to carry it to their trucks! The cabinet, while not too large, was reputed to be filled with solid iron. This was a base canard; there *were* a few air-spaces left here and there, albeit not too many! The heft was accounted for by some of the design practices common to that period; massive mains transformers, input and output transformers, and a 10-inch electrodynamic loudspeaker with a tremendous field coil furnished a goodly share of it. A large cast-iron-framed tuning condenser and large components did the rest. Even the i.f. transformers were about 2 inches square, 3 high, and filled solidly with tar! True! Each i.f. can weighed about two pounds! Incidentally, these were *not* tunable!

For a final touch, these sets were sold with a "matching table," to which they were somewhat insecurely fastened. This consisted of a heavy framework (1 × 2-in lumber!) at the top, and slender, tapered legs; from a scant inch at the top, they wound up less than a half-inch diameter at the bottom! Much to our surprise these tables, despite their decidedly unsafe appearance, never collapsed under their tremendous load. Of course, we did find, now and then, the tiny ends of the legs sunk completely through the lino, or into a soft pine floor, but somehow or other they never did quite completely let go, like the proverbial One-Hoss Shay.

Modern science has once again leaped into the breach, though. From "midgets" that were so heavy we couldn't lift 'em, they have given us radios that are so tiny we can't see 'em! The customer now comes into the shop, saying, "Can you fix my radio?" Upon receiving an affirmative reply (although with certain unspoken reservations), he begins frantically searching his person. Claiming that he certainly had it when he left home, he finally digs it out of his shirt pocket, where it has gone to earth behind a packet of Pall Malls. The difficulty, of course, is occasioned by the fact that the radio is smaller than the fags!

The Tool Kit

Our brave technician gingerly accepts it, turns on a very bright light over his bench, and rounds up a group of tools filched from local jewellers, surgeons, and the like: tiny tweezers, hæmostats, picks, screwdrivers, and that essential appendage, a jeweller's loupe of at least four power. Screwing this firmly into his eye, he at last attacks the plastic case. Opening this, he discloses a mess of miniaturized components which would be far more at home in the nose of a proximity-fused anti-aircraft shell. (This is where most of them came from, and at the moment he fervently wishes they were back!) At one end is a wee battery. Hopefully, he measures its voltage, in the faint thought that it might be low. No luck; he must work on the thing!

Printed circuits? Oh, definitely, old boy. There isn't room inside the thing for a normal wire! One couldn't close the case! By cleverly mounting all the transistors and parts on one side of the board, and printing the wiring on the other, the designer has managed to render the gadget almost immune from normal maintenance procedures. However, our braw laddie removes a few minute screws, about the size of those securing the balance-staff in a

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medium-sized pocket-watch, and gets the thing out into the light. Now, by holding it up between his eyes and the powerful light, he can see through the translucent board. (In the process, he also manages to acquire a mild sunburn on the tip of his nose from the actinic rays, but this is quite incidental.)

A standard test-prod looks rather like a telegraph pole beside the space available for insertion of same. By contrast, the older radios and TV sets had enough space to park a good-sized lorry between components! Nevertheless, Our Hero finally manages to pick up a voltage here, a resistance reading there, and, after a while, he locates the trouble: it is, as usual, a minuscule break in the printed wiring. (Due, no doubt, to the mistress dropping it off the dresser the night before, or bunging it at the master's head!) Flowing solder over this with his special needle-nose bit, it works! He reassembles it and hands it back to the customer, who, as is customary in such cases, has left his wallet in his other coat. Now, in America, would be the ideal time for a coffee break (a "cuppa" in England?).

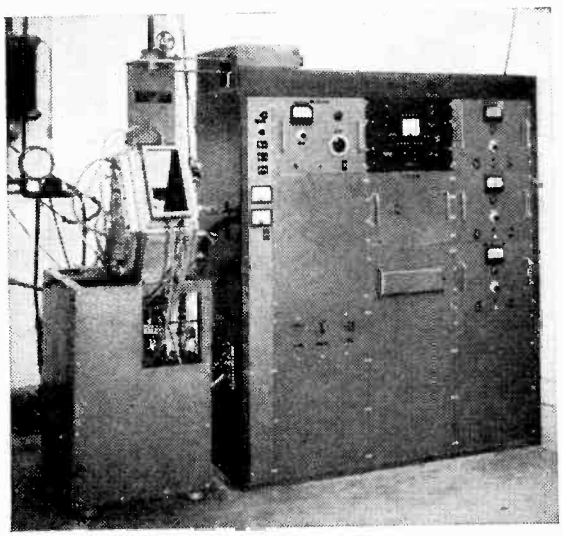
We were getting by with these Minute Marvels until the setmakers decided that too much of a good thing was not enough, and began their shrinking techniques upon TV receivers! Now, the average TV set, even some of our mail-order marvels, need quite a few more parts than a 4-transistor radio. Still, these electronic Jivaros seem to be making an earnest effort to cram all of them into a space of about the same size! This has some quite ridiculous results, at times. Upon opening the back of a modern portable TV, which by this time measures some eight inches in depth, one finds a wee blobby object sticking out in the centre: this is the neck of the picture tube. Upon a perfectly flat wall of glass is apparently pasted some peculiar-looking coils, etc.: these comprise the deflection yoke! Upon looking up the spec's for the picture tube, he finds that it has a deflection angle of 110 degrees! Wondering how long it will be until someone succeeds in making tubes with deflection angles *greater* than 180 degrees, so that the tubes could be built in the shape of inverted ice-cream cones, he begins to look for the chassis. Here the words "look for" are used advisedly. Of the chassis as we knew it, there ain't no such no more. Scattered here and there about the case are odd bits of metal, with valves sticking out at odd angles. A few resistors and capacitors may be seen, and from this evidence, he deduces that this weird assembly is intended to be "the works".

The printed circuits, which were the subject of an earlier diatribe**, abound in these little monsters. Because of their space-saving characteristics, they have been seized upon with glee by the sadists who are in charge of Design. In some cases, they have been cleverly arranged in the form of a box, enclosing the picture tube. This enables the designer to enclose almost totally all parts and valves (Oh, didn't I tell you? The valves are on the *inside* of the box, with their sockets indecently exposed on the outside!) rendering the whole thing something like 89% inaccessible for normal maintenance work! The edges of the PC boards comprising the major part of the assembly are firmly tied together by the wiring and interconnecting leads. To get it out of the "box" so that it can be checked, it is necessary to spend at least half an hour totally disabling the set, by disconnecting the major part of these. Of course, if the technician has unlimited time on his hands, he may make the set operative in this odd condition by reconnecting the edges with scraps of flex, test leads, etc. This, of course, induces some strange and wonderful feedback lops, aiding no end in the diagnosis of the original defect!

Be that as it may, we *are* learning to live with them, in a resigned sort of way. Patience and fortitude can do wonders when applied to such instances. Really, some of the PC boards are not too difficult to work on, provided the maker has not rendered things too hard, by concealing one side of the board completely with a heavy steel plate, as has been the case in some recent models. Practice will do wonders!

As to radios, one never knows what will come up next. With hearing-aids fitted into the bows of a pair of eyeglasses, one can scarcely blame the unfortunate technician involved in this incident. A customer came into the shop, and said, "Could you fix my radio?" Upon receiving the usual affirmative answer, he began trying to remove a large ornate ring from his finger. The technician turned, saw this, and swooned! When revived, the customer explained that he only wanted one of the prongs of the ring resoldered: the radio was still out in his car! The technician, remembering the article he had just read about future trends in micro-miniaturization, had been under a completely wrong impression!

** *Wireless World*, November 1957.



This crystal-pulling furnace *is made by Nash and Thompson, Ltd., Chessington, Surrey, to the design of the Services Electronics Research Laboratory, Baldock. The temperature of the molten semiconductor material in the crucible, which is heated by a graphite element, is judged by looking into the vacuum chamber (left) at the liquid surface. The meniscus formed is an extremely sensitive indicator, as it depends on surface tension which changes widely with temperature near the melting point of the material. The equipment rack contains the pumps, instrumentation and control apparatus for the heater and pulling motors.*

Loudspeaker Magnet Design

With Special Reference to Capped Cylindrical Slugs of Alcomax III

By A. E. FALKUS*, B.Sc. (Eng), M.I.E.E.

THE development of a process for making production quantities of Alcomax magnets with a semi-columnar structure has placed in the hands of loudspeaker designers a material which, while having a better performance than any used hitherto, yet has certain limitations of shape.

The figure of merit of a permanent magnet material is the maximum value of the product BH, where B is the flux density in the magnet and H the magnetomotive force per unit of length that the magnet can exert when carrying B in a magnetic circuit. The BH (Max.) value for semi-columnar Alcomax III is 5.8 mega-gauss-oersteds whereas for normal cast Alcomax III the value is 5. Thus the process whereby longitudinal crystal growth, i.e., semi-columnar structure, is induced increases the performance of a given weight of alloy by 16% for a small extra process cost.

There is, however, a limitation on the shape of the magnet in that the semi-columnar structure can only be obtained when the magnet consists of a solid cylinder.

However, this feature of semi-columnar material, the limitation of the shape to a plain cylinder,

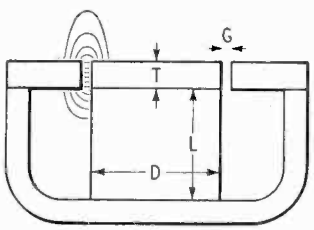


Fig. 1 Dimensions and stray fields in the capped cylindrical-slug magnet design.

leads to a simplified method of design. It will be shown later that for a given load (i.e., mass of cone to be driven) a given input impedance, and given weight of magnetic alloy, there is one optimum value for the pole diameter and depth of gap.

Although semi-columnar Alcomax III is the magnet material considered, the design methods suggested can be applied to any magnet material by using the appropriate values of the magnetic constants.

Basic Design.—The best basic design for a loudspeaker magnet of semi-columnar material is that of a capped slug. The magnet consists of a cylindrical slug of a diameter equal to the inside diameter of the voice coil less the working clearances. This slug is capped by a disc of mild steel which forms the pole piece. This disc is of the same diameter as the magnet and of a thickness equal to the desired depth of air gap.

The design is shown diagrammatically in Fig. 1, where the magnet slug has a diameter D and length L. It is capped by a disc of mild steel also of diameter D and thickness T. The radial width of the air gap is G.

Since the magnet slug may not have a central hole, it is best fixed to the yoke and pole piece by some form of adhesive, such as Araldite, which will provide a satisfactory bond.

The capped slug design is well known as an efficient design for small sizes of magnet. It will be shown that it may be used for any weight of magnet and, when the proportions are correct, will give high magnetic efficiencies.

Gap Flux.—To design a loudspeaker magnet satisfactorily it is necessary to be able to calculate what proportion of the total flux carried by the magnet passes usefully through the air gap and what proportion leaks across above and below the gap.

Referring to Fig. 1 and assuming that the magnet is working at its BH (Max.) point, the magnetomotive force across the gap, neglecting losses in the yoke, will be LH. The flux density in the air gap will therefore be LH/G. Now the gap cross-sectional area is πDT.

The total useful gap flux is therefore $LH \pi DT/G$ (1)

Leakage Flux.—The leakage flux is also driven by the magnetomotive force LH. The total admittance of the leakage paths will be proportional to a factor which depends on the configuration of the magnet, multiplied by the circumference of the pole piece. That is, the total leakage flux may be expressed as $LHC \pi D$.

The factor C will be constant for all capped slug designs. Measurements of a number of different capped slug magnet designs all give a value for C of 3.5 when L and D are measured in cm and H in gauss.

The total leakage flux is therefore $3.5\, LH \pi D$ . . (2)

It should be noted that the value for C of 3.5 takes into account only the leakage flux in the vicinity of the gap.

The top leakage between the flat end face of the pole piece and the front plate near the gap will be a constant for a given pole diameter and a given magnetomotive force across the gap. It will be the same for all types of magnet construction, i.e., capped slug, skirted pole piece, ring magnet, etc. It will be a little greater where the front plate is chamfered down in thickness at the gap so that the leakage surfaces are at less than 180° to each other. In general, however, the effect of a chamfer may be neglected.

The internal leakage between the cylindrical surface of the pole piece or magnet below the gap and the under side of the front plate will always be greater than the top leakage because the average leakage path is approximately halved as the surfaces are only at 90° to each other. In the case of the capped slug design, however, the leakage falls off rapidly with increasing distance from the gap. This is

* Fane Acoustics, Ltd.

because not only is the leakage path increasing, but the magnetomotive force operating is decreasing because the flux is coming from a point below the top of the magnet.

In the case of the skirted pole piece construction of Fig. 2, the magnetomotive force driving the internal leakage increases with increasing distance below the gap due to the drop of magnetomotive potential

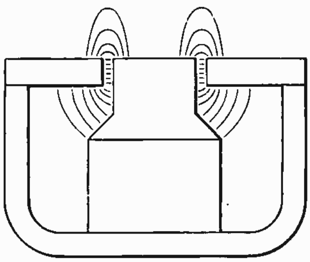


Fig. 2 Skirted pole piece magnet construction showing stray fields.

in the cylindrical portion of the pole piece which is usually working near saturation point. Further, the conical surface of the skirt, which is running nearly parallel to the under side of the front plate, adds considerably to the total leakage. The leakage factor C will thus be considerably greater than 3.5 for this design and will also depend on the ratio of the skirt diameter to the pole diameter and on the length of the nearly parallel portion of the pole piece.

Magnetic Efficiency.—The ratio of useful gap flux to leakage flux may be found from equations (1) and (2) as:

$$\frac{LH\,\pi\,DT/G}{3.5\;LH\,\pi\,D}$$

This simplifies to $T/3.5G$ .. .. .. (3)

It is interesting to note that the ratio of gap flux to leakage flux is directly proportional to the depth of the air gap and inversely proportional to its width.

The magnetic efficiency of a loudspeaker magnet system may be defined as the percentage of the total flux supplied by the magnet which passes usefully through the air gap. This may be written as:

$$\frac{\text{Gap flux}}{\text{Gap flux} + \text{Leakage flux}} \times 100\%$$

From equations (1) and (2) this becomes:

$$\frac{LH\,\pi\,DT/G}{LH\,\pi\,DT/G + 3.5\,LH\,\pi\,D} \times 100\%$$

This simplifies to

$$\frac{T}{T + 3.5G} \times 100\% \quad .. \quad .. \quad .. \quad (4)$$

Magnet Diameter.—The total flux in the magnet is B times the cross sectional area, i.e., $B\pi D^2/4$. This must equal the sum of the gap flux and leakage flux. Thus, from equations (1) and (2):—

$$B\pi D^2/4 = LH\pi DT/G + 3.5LH\pi D$$

Dividing out by πD, this becomes:—

$$BD/4 = LHT/G + 3.5\;LH$$

$$\text{Hence, } D = \frac{4\;LHT}{BG} + \frac{14\;LH}{B}$$

$$= L\left(\frac{4\;HT}{BG} + \frac{14\;H}{B}\right) \quad .. \quad .. \quad (5)$$

If the volume of the magnet slug is V, then:—

$$V = \pi D^2 L/4$$

Hence $L = 4V/\pi D^2$

Substituting for L in equation (5) we have:—

$$D = \frac{4V}{\pi D^2}\left(\frac{4\;HT}{BG} + \frac{14\;H}{B}\right)$$

Multiplying out by D^2 this becomes:—

$$D^3 = \frac{4V}{\pi}\left(\frac{4\;HT}{BG} + \frac{14\;H}{B}\right) \quad .. \quad (6)$$

Air Gap Required to Accommodate the Voice Coil.—For optimum acoustic response, the voice coil weight must bear a certain relation to the weight of the cone that it drives.

The required impedance of the voice coil is determined by the matching load of the output circuit to which the speaker will be connected. Assuming the impedance to be 10% higher than the d.c. resistance, which it normally is over the middle-frequency range, the required d.c. resistance of the coil may be found.

Knowing the weight and resistance of the voice coil winding, the wire diameter and its total length can be found with the aid of standard wire tables. Let this diameter be d and the total length of wire be w.

Then the number of turns in the coil will be $w/\pi D$ and the total length of the winding, assuming two layers, will be $wd/2\pi D$.

This neglects the slight increase of the coil diameter over the magnet diameter.

For maximum sensitivity, particularly where large excursions of the coil are not expected, the voice coil winding may be made equal in length to the depth of the air gap, i.e., $T = wd/2\pi D$.

Hence $D = wd/2\pi T$ .. .. (7)

In the case of a speaker required to handle considerable power, particularly at low frequencies, the coil should be longer than the gap to reduce harmonic distortion at large amplitudes. In this case T will be less than the coil length by twice the over-hang and equation (7) must be modified accordingly.

Magnet Dimensions.—It will be seen from equations (6) and (7) that we have two expressions for

TABLE 1: Magnet Designs For Small Commercial Loudspeakers

Weight of magnet	Diameter of pole and magnet		Depth of gap		Length of magnet		Flux density in gap	Magnetic efficiency
oz	cm	in	cm	in	cm	in	gauss	%
½	1.742	0.686	0.445	0.175	0.810	0.319	6,080	62.2
1	2.112	0.832	0.367	0.144	1.102	0.434	8,270	57.6
2	2.565	1.011	0.302	0.119	1.494	0.588	11,220	52.8
4	3.127	1.232	0.248	0.098	2.008	0.791	15,070	47.9

D in terms of T for a given volume of magnet material of known characteristics and a given cone and input impedance.

The gap width G which occurs in equation (6) may be calculated as 2*d* plus the thickness of the voice coil former plus twice the working clearance between voice coil and pole piece.

B and H for semi-columnar Alcomax III may be taken as 10,000 and 580 respectively when the magnet is working at its BH (max.) point. The specific gravity of Alcomax III may be taken as 7.35. The value of V will therefore be its weight in gm divided by 7.35.

By substituting numerical values for V, H, B, G, *w*, and *d* in equations (6) and (7), we are left with two simultaneous equations involving D and T which may then be evaluated.

To illustrate the design methods outlined above, a range of designs have been worked out:—

(A) For a small commercial speaker which is to have maximum sensitivity for small power handling and magnet weights of ½ oz to 4 oz.

(B) For a 12-in speaker to handle 20 W at low frequencies and with magnet weights of ½ lb to 1½ lb.

These two series of speakers have been chosen as being near the extremes likely to be met in practice.

Design of Small Commercial Speakers: Voice Coil.—It has become standard for this type of loudspeaker to have an input impedance of 3 Ω. The d.c. resistance of the voice coil may therefore be taken as 2.7 Ω.

Experience has shown that the average 5 in, 6 in × 4 in, or 7 in × 4 in cone requires a voice coil weight of about ½ gm to provide a good tonal balance.

From the standard wire tables we find that the wire gauge which most nearly meets this is 38 s.w.g. which has 2570 Ω per lb; since 2.7 Ω will weigh 2.7 × 454/2570 = 0.48 gm.

Now, 38 s.w.g. copper wire has 864 Ω per 1000 yd. The length for 2.7 Ω is therefore 2.7 × 1000 × 91.4/864 = 286cm = *w*.

The overall diameter of 38 s.w.g. wire, enamelled, is 0.0067 in = 0.01703 cm = *d*.

Substituting for *w* and *d* in equation (7), we have:—

$$D = \frac{286 \times 0.01703}{2\pi T} = \frac{0.775}{T} \quad \ldots \quad \ldots (8)$$

Magnet.—The values for B and H for semi-columnar Alcomax III are 10,000 and 580 respectively.

The voice coil wire diameter, *d*, is 0.0067 in. If we assume a thickness for the former of 0.003 in and gap clearances of 0.007 in, we arrive at a gap width G of 2 × 0.0067 + 0.003 + 2 × 0.007 in = 0.0304 in = 0.0772 cm.

Substituting these values of B, H, and G in equation (6), we have:—

$$D^3 = 1.273\ V \left(\frac{4 \times 580\ T}{10{,}000 \times 0.0772} + \frac{14 \times 580}{10{,}000}\right)$$

$$= V\,(3.83\ T + 1.034) \quad \ldots \quad \ldots (9)$$

Now, the specific gravity of Alcomax III is 7.35 and 1oz is equal to 28.4gm. Then, if W is the weight of the magnet slug in oz:—

$$V = W \times 28.4/7.35 = 3.86\ W$$

Substituting this value of V in equation (9), we have:—

$$D^3 = 3.86W\,(3.83\ T + 1.034) \ldots \quad \ldots (10)$$

From equation (8) we have T = 0.775/D. Substituting this value of T in equation (10), we have:—

$$D^3 = 3.86W\,(2.97/D + 1.034)$$

Multiplying both sides by D and simplifying, this becomes:—

$$D^4 - 3.99\ WD = 11.44\ W \quad \ldots \quad \ldots (11)$$

We may now insert any required value for W in equation (11) and solve for D by trial and error.

When D is known, the values of T, L, the gap flux density and the magnetic efficiency may be found from the various equations given previously.

These operations have been carried out for magnet weights of ½, 1, 2, and 4 oz and the results are given in Table 1. The dimensions are given in the table in inches as well as in centimetres.

It should be noted that in these calculations no allowance has been made for the magnetomotive force required to drive the flux through the iron circuit between the bottom of the magnet and the air gap. This may be allowed for by adopting a value for H some 5 or 10% less than that given by the magnet manufacturers.

In this country, there are no standard sizes for loudspeaker magnets and one weight of slug may be purchased as easily as another. It will therefore probably be preferred to make the pole diameter a standard size of steel rod for ease of production, rather than to have the magnet an exact number of ounces. For this reason curves are given in Fig. 3 showing pole diameter, gap depth, magnet length and gap flux density in terms of magnet weight. From these curves, for instance, it will be seen that a 1-in pole may be used with a 1.95 oz magnet to give a flux density of 11,100 gauss in a gap of 0.120-in depth.

The suggestion of using a 1-in. pole or larger for a small commercial speaker may seem strange at first. Provided a non-perforated dome is used for an internal dust cover, however, there will be no acoustic disadvantage. In fact, there is an improvement in response to be obtained by partially filling the apex of the cone. The gain in sensitivity and

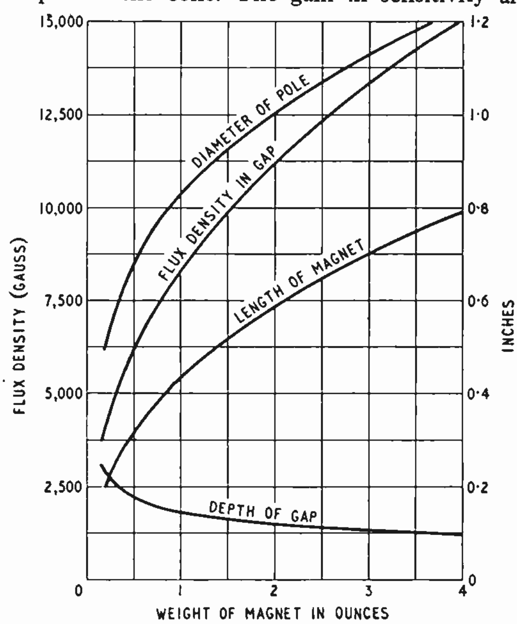


Fig. 3 Magnet designs for small commercial loudspeakers showing diameter of pole, flux density in gap, length of magnet, and depth of gap in terms of weight of magnet.

TABLE 2: Magnet Designs for 12-in Low-frequency Loudspeakers

Weight of magnet	Diameter of pole and magnet		Depth of gap		Length of magnet		Flux density in gap	Magnetic efficiency
oz	cm	in	cm	in	cm	in	gauss	%
8	4.663	1.837	0.872	0.343	1.786	0.703	9,050	68.5
16	5.500	2.165	0.644	0.253	2.598	1.023	13,180	61.7
32	6.478	2.505	0.452	0.178	3.748	1.477	19,000	53.0

reduction in overall depth of the speaker as compared with a skirted pole or ring magnet design for magnet weights of 2 or 3 oz is considerable.

Design of 12-in Low-frequency Speakers: Voice Coil.—For speakers for public address or high-fidelity reproduction it has become standard to use an input impedance of 15 Ω. For a speaker to be used as the bass unit of a multi-speaker combination the most important region is that part of the range below 100c/s because, since the cone diameter is much smaller than the sound wavelength in air at the lowest frequencies, everything possible must be done to off-set the drop in radiation efficiency.

Below 100c/s the impedance will depend on the method of loading and will be considerably more than the d.c. resistance, so that the best compromise is to make the voice coil 8 to 10 Ω rather than 15 Ω less 10%. For this design we shall take 9 Ω.

Again, in order to obtain the best performance below 100c/s, it is best to use a voice-coil weight heavier in proportion to the cone than for a small general purpose speaker. For a 12-in. bass speaker the best coil weight is 6 to 7 gm.

From the wire tables we find the nearest gauge is 35 s.w.g. of which 9 Ω has a weight of 6.1gm. This gauge has also 441 Ω per 1,000 yd. The length for 9 Ω is thus $1000 \times 91.4 \times 9/441 = 1840$ cm $= w$. The overall diameter of 35 s.w.g. enamelled wire is 0.0094in $=$ 0.0239cm. $= d$.

A speaker to have a good low-frequency performance must be capable of considerable voice-coil excursion without undue distortion due to the coil moving out of the gap. This is achieved by making the coil longer than the gap depth. For a 12-in. speaker to be used primarily as a bass unit it is desirable for the coil to extend some ⅛in. above and below the gap. Thus the coil will not commence to leave the gap until the amplitude of movement exceeds ⅛in.

The gap depth may therefore be taken as ¼in or 0.625 cm less than the coil length. Thus

$$T = wd/2\pi D - 0.625.$$

$$\text{Whence } D = \frac{wd}{2\pi\,(T+0.625)} \quad \ldots\ldots\ldots\ldots (12)$$

Substituting for w and d in equation (12), we have:—

$$D = \frac{1840 \times 0.0239}{2\pi\,(T+0.625)}$$

$$= \frac{6.98}{T+0.625} \quad \ldots\ldots\ldots\ldots (13)$$

Magnet.—The voice coil wire diameter, d, $=$0.0094in. If we assume a thickness for the former of 0.0045in and gap clearances of 0.011in, we arrive at a gap width, G, of $2 \times 0.0094 + 0.0045 + 2 \times 0.011$in $=$0.045in$=$0.1143 cm.

Substituting for B, H, and G in equation (6) we have:—

$$D^3 = 1.273\ V \left(\frac{4 \times 580\ \ T}{10{,}000 \times 0.1143} + \frac{14 \times 580}{10{,}000} \right)$$

$$= V\ (2.58\ T + 1.034)$$

Substituting 3.86 W for V we have:—

$$D^3 = 3.86\ W\ (2.58\ T + 1.034) \quad \ldots\ldots\ldots\ldots (14)$$

From equation (13), $T = 6.98/D - 0.625$

Substituting this value of T in equation (14) we have:—

$$D^3 = 3.86\ W\ (2.58\ [6.98/D - 0.625] + 1.034)$$

$$= 69.6\ W/D - 2.24\ W$$

Thus $D^4 = 69.6\ W - 2.24\ WD$

Or, $D^4 + 2.24\ WD = 69.6\ W$

We may now insert various values for W and solve for D. This has been done for magnet weights of ½ lb, 1 lb, and 2 lb and the various details of the design worked out. The figures are given in Table 2.

As for the previous examples, the results are presented graphically in Fig. 4.

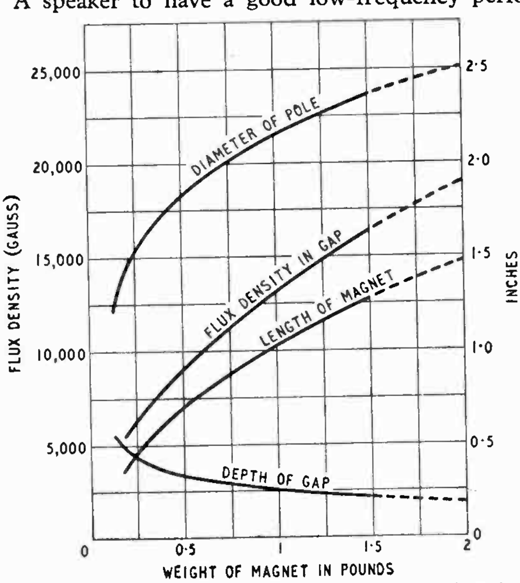


Fig.4 Magnet designs for 12-in low-frequency loudspeakers showing diameter of pole, flux density in gap, length of magnet, and depth of gap in terms of weight of magnet.

In considering these designs, it must be remembered that one requirement was that the voice coil must extend for ⅛-in above and below the gap. A result of this is that, as the pole diameter increases with increasing magnet weight, a smaller proportion of the coil is within the gap. For magnet weights above 1½ lb therefore, it is considered that it would be better to increase the wire gauge and thus the length of wire for 9 Ω.

Elements of Electronic Circuits

9.—TRIGGERED TWO-STATE CIRCUITS

By J. M. PETERS, B.Sc. (Eng.), A.M.I.E.E., A.M.Brit.I.R.E.

THE freely running multivibrator, as described last month, can be locked on to an applied wave of fixed repetition frequency as shown in Fig. 1. Conditions for an asymmetrical multivibrator are illustrated here. The frequency of oscillation will

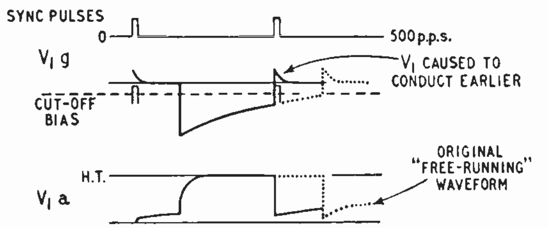


Fig. 1.

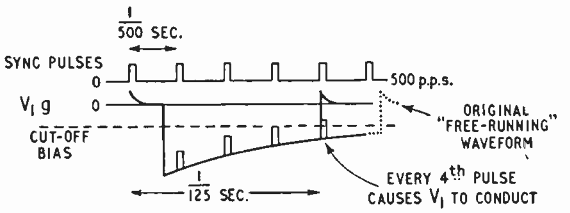


Fig. 2.

increase until it becomes a multiple or a sub-multiple of the frequency of the injected signal.

Positive-going synchronizing pulses are applied to the grid of one valve of the circuit—say V_1 in Fig. 1 of last month. Let us assume that the repetition frequency of these pulses is greater than that of the freely running multivibrator and let us consider a single pulse. It will be seen that when the pulse arrives at the grid of V_1 the potential of the grid, discharging to zero with time constant C_2R_3, has not quite reached the valve cut-off voltage. The application of the positive pulse carries it over this level, so accelerating the transition of V_1 to its conducting state. In effect it causes V_1 to conduct before it would have done under normal C_2R_3 discharging conditions (shown by the dotted line in Fig. 1). As each positive input pulse causes this to happen, the multivibrator becomes synchronized to the input wave.

Instead of making every synchronizing pulse trigger the multivibrator, it is possible to arrange for the circuit to be triggered by each n^{th} pulse. This will mean that the multivibrator frequency is then $\frac{1}{n}$th of the input frequency. For example, an input with a repetition frequency of 500 pulses per second can cause the multivibrator to oscillate at 125 pulses per second by arranging for it to be triggered by every 4th pulse; this is shown in Fig. 2. Frequency division therefore takes place, and it is possible to make $n=10$ or more by careful choice of component values. It will be noted that the amplitude of the sync pulse will to a large extent govern the frequency of oscillation of the multivibrator.

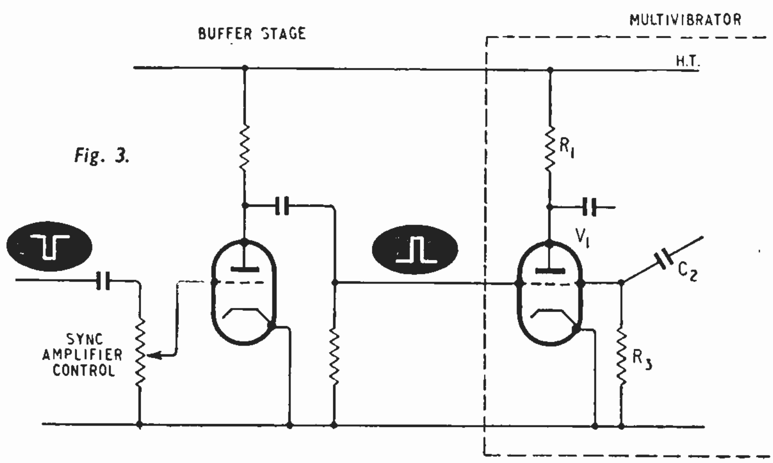
In the example shown, only the duration of the positive portion of the anode voltage waveform is affected by the triggering action. If the duration of both positive and negative portions of the waveform are to be controlled, it will be necessary for both valves to be triggered. A convenient method is by applying negative trigger pulses between the common cathode and earth.

On account of the possibility of the multivibrator grid voltage changes reacting back on the source of sync voltage, it is often necessary to isolate the oscillator from the source by means of a buffer amplifier stage, as shown in Fig. 3. Sync amplitude can be controlled at the amplifier grid as indicated.

Fig. 4 shows a development of the basic multivibrator in which two pentodes, V_1 and V_2, are used instead of triodes, and a further refinement is the incorporation of a diode clamp V_3.

From Fig. 5 we will assume that V_1 is conducting and V_2 is cut off. A negative sync pulse applied to the control grid of V_1 becomes an amplified positive pulse on the control grid of V_2, and V_2 conducts. This results in a fall in voltage on V_2 screen grid, which is transferred to the suppressor of V_1 by C_2. As C_2 discharges through R_3 and V_2, the g_3 of V_1 rises through the suppressor cut-off

Fig. 3.



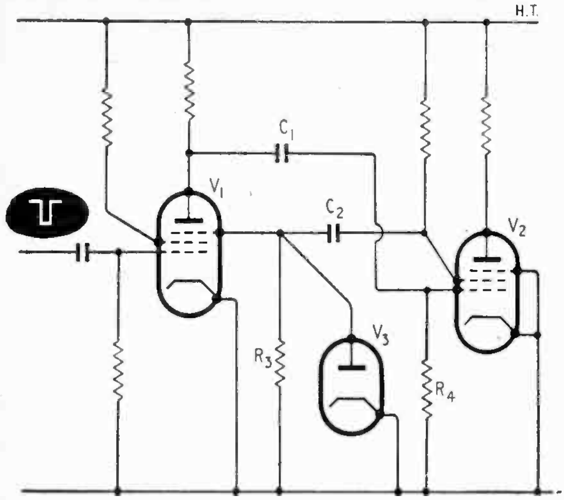


Fig. 4.

voltage, causing anode current in V_1 to flow again and the anode volts of V_1 to fall. This fall in voltage is transferred to V_2 control grid by C_1, causing V_2 to be cut off. As C_1 discharges through R_4 the voltage on V_2 control grid rises through cut-off, V_2 conducts again and the cycle continues on similar lines, as has been described previously.

It is important to note the advantages gained by making the circuit connection in this manner:—

First, since V_1 control grid is isolated from the operation of the circuit there is no need for a buffer amplifier, i.e. the sync input is decoupled from the oscillator. Secondly, V_2 anode is unaffected by the charging of C_2 as is the case in the simple multivibrator. A squarer output waveform therefore

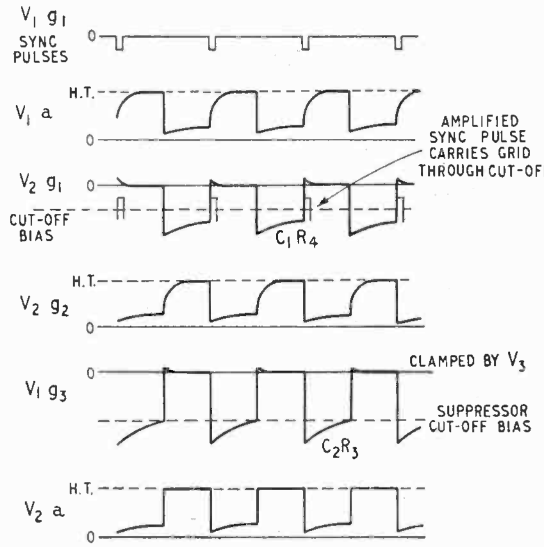


Fig. 5.

results. A further improvement is the incorporation of diode V_3, the function of which is to clamp the voltage on V_1 suppressor to zero.

Speedier Component Assembly

SHOWN in the illustration is one of the new rotary dispensing machines for small components, known as the Rotasembler. It consists of 19 vertical hoppers, each divided longitudinally to provide two compartments each 3in wide and 1½in deep. The front one is 20in and the rear one 24in high, the difference being accounted for by the adjacent positions of the two feed lips, as shown in the illustration. Up to 38 different parts can be accommodated in one machine, and about 2,000 small components in each of the 38 hoppers.

One of several Rotasembler component dispensing machines in use in the Regentone factory at Romford, Essex.

The Rotasembler is rotated by compressed air being operated by a foot-controlled valve. As the hopper next in sequence always stops in exactly the same place as the previous one operator time and fatigue in identifying and selecting the next part for assembly is reduced, and it is claimed that the assembly work is considerably speeded up with assembly errors reduced to a minimum.

The machine, which costs £87 10s, is made by Work Study Equipments, 4, Montalt Road, Woodford Green, Essex, from whom further details can be obtained.

Printed Wiring Practice

IN order to make known as widely as possible the current practice in designing and producing printed circuits the Electronic Engineering Association has issued a report covering design considerations, general standards (materials, conductor sizes, etc.), production practices and special components. The object of this document is —"(a) To promote the adoption of such design and production practices as have proved to date to be justified as a result of common experience. (b) To make a contribution to any national standards that may be prepared on the subjects covered. Such national standards are considered urgently desirable in order to co-ordinate the numerous documents already in preparation by various sectional interests." Copies may be obtained from the Secretary, E.E.A., 11 Green Street, London, W.1.

CONFERENCES AND EXHIBITIONS

Latest information on forthcoming events both in the U.K. and abroad is given below. Further details are obtainable from the addresses in parenthesis.

UNITED KINGDOM

Physical Society Exhibition, Royal Horticultural Society's Halls, Victoria, London, S.W.1 .... Jan. 18-22
(Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7).

Managerial and Engineering Aspects of Reliability and Maintenance of Digital Computer Systems (Conference), I.E.E., Savoy Place, London, W.C.2. .... Jan. 20-21
(British Conference on Automation and Computation, c/o I.E.E.,)

Engineering Materials and Design Exhibition and Conference, Earls Court, London, S.W.5. .... Feb. 22-26
(Industrial & Trade Fairs Ltd., Drury House, Russell Street, London, W.C.2.)

Electrical Engineers Exhibition, Earls Court, London, S.W.5 ...... April 5-9
(A.S.E.E. Exhibition, Museum House, Museum Street, London, W.C.1).

Solid State Microwave Amplifiers (Conference), University of Nottingham
(Institute of Physics, 47 Belgrave Square, London, S.W.1). April 6-8

Audio Fair, Hotel Russell, Russell Square, London, W.C.1.......... April 21-24
(Audio Fairs Ltd., 22, Orchard Street, London, W.1.)

Production Exhibition and Conference, Olympia, London, W.14 .. April 25-30
(The Production Exhibition, 11 Manchester Square, London, W.1).

Mechanical Handling Exhibition, Earls Court, London, S.W.5 .... May 3-13
(*Mechanical Handling*, Dorset House, Stamford Street, London, S.E.1).

Instruments, Electronics and Automation Exhibition, Olympia, London, W.14. May 23-28
(Industrial Exhibitions Ltd., 9 Argyll Street, London, W.1.)

Medical Electronics Conference and Exhibition, Olympia, London, W.14. July 21-27
(I.E.E., Savoy Place, London, W.C.2.)

National Radio and Television Show, Earls Court, London, S.W.5. Aug. 24-Sept. 3
(Radio Industry Exhibitions Ltd., 49 Russell Square, London, W.C.1.)

Farnborough Air Show .... Sept. 5-12
(Society of British Aircraft Constructors, 29 King Street, London, S.W.1.)

Industrial Photographic and Television Exhibition, Earls Court, London, S.W.5. .... Nov. 21-25
(Industrial and Trade Fairs Ltd., Drury House, Russell Street, London, W.C.2.)

Radio Hobbies Exhibition, R.H.S. Old Hall Victoria, London, S.W.1 Nov. 23-26
(P. A. Thorogood, 35 Gibbs Green, Edgware, Middx.)

OVERSEAS

Reliability and Quality Control in Electronics (Symposium), Washington, D.C. .... Jan. 11-13
(R. Brewer, G.E.C. Research Laboratories, Wembley, Middx.)

Instrument-Automation Conference and Exhibition, Houston. Feb. 2-4
(Instrument Society of America, 313, Sixth Avenue, Pittsburgh 22, Pa., U.S.A.)

Solid-State Circuits Conference, Philadelphia .... Feb. 10-12
(Tudor R. Finch, Bell Telephone Laboratories, Murray Hill, N.J., U.S.A.)

French Components Show (Salon International de la Pièce Détachée Electronique), Paris .... Feb. 19-23
(Fédération Nationale des Industries Electroniques, 23 rue de Lubeck, Paris 16e).

Non-Destructive Testing (Conference), Tokyo .... Mar. 15-21
(Secretary, British National Committee for Non-Destructive Testing, c/o the Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.)

I.R.E. National Convention, New York .... Mar. 21-24
(E. K. Gannett, I.R.E., 1 East 79th Street, N.Y.21.)

German Industries Fair, Hanover.......... April 24-May 3
(Schenkers Ltd., 13, Finsbury Square, London, E.C.3.)

Instrument-Automation Conference and Exhibition, San Francisco May 10-12
(Instrument Society of America, 313, Sixth Avenue, Pittsburgh 22, Pa., U.S.A.)

International Congress on Microwave Tubes, Munich .... June 7-11
(Prof. Dr. W. Kleen, Balanstrasse 73, Munich 8.)

British Exhibition, New York .... June 10-26
(British Overseas Fairs Ltd., 21 Tothill Street, London, S.W.1.)

Nuclear and Electronic Congress and Exhibition, Rome.......... June 15-29
(Fairs and Exhibitions Ltd., 2, Dunraven Street, London W.1.)

Automatic Control Congress, Moscow .... June 27-July 6
(British Conference on Automation and Computation, c/o I.E.E., Savoy Place, London, W.C.2.)

Physics of Semiconductors (Conference), Prague .... Aug. 29-Sept. 2
(International Union of Pure and Applied Physics, 3 Boulevard Pasteur, Paris 15)

Instrument-Automation Conference and Exhibition, New York Sept. 26-30
(Instrument Society of America, 313, Sixth Avenue, Pittsburgh 22, Pa., U.S.A.)

Firato—International Radio Show, Amsterdam .... September
(Firato Secretariat, Emmalaan 20, Amsterdam, Z).

General and Applied Phonetics Congress, Hamburg .... September
(Dr. H.-H. Wängler, Alsterglacis 3, Hamburg 36, Germany).

Interkama—International Congress and Exhibition for Measuring Techniques and Automation, Dusseldorf .... Oct. 19-26
(Nordwestdeutsche Ausstellungs-Gesellschaft m.b.H., Ehrenhof 4, Dusseldorf)

RANDOM RADIATIONS

By " DIALLIST "

The Tenth Million

BY this time the total of British television receiving licences must have reached the ten million mark. The latest figures available at the time of writing were those for the end of October. There were then 9,844,365 licensed TV receivers and there's always a big increase at the end of the year. And to help things on new transmitters and small local boosters have been coming into action. An astonishing business—isn't it?—that progress should have been so rapid since the restart of television in 1946. Ten years ago there were only half a million sets. It's bound to continue and one wonders what the saturation point will be. I'd put it at well over fifteen million, for that's the present number of homes with either sound or television sets in them. As TV coverage increases and improves many —maybe most—of the homes that are now equipped for sound only are bound to go in for television. New homes, too, are being built apace in TV service areas and it looks as if television manufacturers will be kept busy for a long time to come both in supplying the needs of new viewers and in providing sets to replace old ones.

International Standardization

SOMETHING very badly needed, particularly now that the import restrictions on various kinds of electrical gear have been relaxed, is the adoption of an international colour code for three-wire flex mains leads. A dealer to whom I was talking not long ago told me that he'd seen appliances of foreign origin with mains leads with green covered phase wires! As green is now the colour for the earth lead here, this could have unfortunate consequences should a serviceman not look before he leaps and test carefully before wiring up a 3-pin plug. Another bit of international, or at any rate N.A.T.O., standardization I'd like to see is in the screws, bolts and nuts used in things electrical. During the war the fact that American sizes and threads weren't the same as ours cost this country a pretty penny. You couldn't get American replacements for any which were lost or suffered from stripped threads. The quickest method of replacement we found in radar was to re-drill and re-tap screw holes so that they'd take our own sizes. The loss of a nut usually meant replacing a bolt. Now that the world is growing more and more metric in outlook, the answer might be for everyone gradually to adopt metric sizes and threads.

Do You Crane?

SHOULD people whose sight is normal or who wear correct glasses find it tiring to the eyes to watch television? That's a question often asked and to me the answer seems to be something like this: No, provided your set is properly adjusted, that the signal is good, that you sit at the proper viewing distance, that you don't switch off the room lighting and that you don't keep your eyes glued to the screen for hours on end. This summarizes the seven simple rules laid down by the Association of Optical Practitioners to avoid eyestrain when viewing. Neglect all or any of these provisions and you needn't be surprised if in time you find watching TV a trying business. Our 405-line system probably gives the best balance between horizontal and vertical definition that can be obtained on the 5-Mc/s channels now used in this country; but it has one drawback which, to my mind, is a serious one. That is that to avoid lininess you must sit quite a way from the screen. As I've mentioned before, a useful rule of thumb is: minimum viewing distance (feet)=half the screen diameter or diagonal (inches). Now, at 8½-feet from a 17-in screen, or 10½-feet from one of 21in it's difficult to feel that you aren't missing something. That's why people watching TV have a tendency to crane forward, thus reducing the effective viewing distance and so increasing the effects of lininess.

Let's Have The Best

That's the reason why I've always been so keen that when u.h.f. channels are assigned to TV we should use them for transmissions of much higher definition. Eugène Aisberg, editor of *Toute la Radio*, after seeing television here, in the U.S.A. and in other Continental countries than his own, wrote that he was indeed thankful that he lived in France with its 819-line system. Any readers who have had the chance of comparing French television pictures with ours will, I am sure, bear me out when I say that they are enormously better than our own. You can view them, for instance, at a much smaller distance, without being conscious of the lines. I don't just want our new system to be as good as the French; I want it to be better still. We'll soon have the chance to make our u.h.f. television the best in the world and it's a chance that may not come again.

Bewitched?

HAVE you ever come across a receiver of first-rate make which seemed to have a hoodoo on it? They're rare, as you'd expect them to be; but just once in a blue moon one of these turns up which seems to be bewitched. A friend was so delighted with the appearance and the performance of a particular set which he'd seen and heard in another house and so impressed by the enthusiastic reports that other owners gave of its utter freedom from trouble of any kind that he promptly ordered one for himself. It came; it was installed; all went well on the first evening; but on the second it just faded into silence. His dealer, who employs first-class servicemen, had it attended to at once. But hardly was the man out of the house when a valve went phut and all was silence again. And so it went on week after week—a day or perhaps two days of perfect listening, and then something always went wrong. At length, he wrote to the makers, adding that he knew from experience how good their sets of that type were—with the unhappy exception of his own. At once, they sent down one of their engineers who having seen this particular set's record in the dealer's files, fitted a new chassis free of charge. The set has been in regular use for nearly a year now and there's been not the slightest sign of any trouble. Queer, isn't it?

Good Work

IT'S good news that C.R.T., Ltd., of Baldock, who specialize in rebuilding c.r. tubes, are now giving an eighteen month's guarantee on all their products. To my way of thinking every bit and piece in sound and television sets should be covered in the same way. I'm glad to see that Siemens Edison Swan have made a move in the right direction, by giving a twelve month's guarantee on their transistors used in any proprietary set of which it is a standardized part. By the time this note appears other makers may have followed suit. There should, after all, be nothing to go wrong in a properly sealed transistor provided that it isn't badly overloaded.

UNBIASED

By FREE GRID

Pedagogic Pedantries

IN his interesting article entitled "Words, Words, Words" in the November issue, P. P. Eckersley, as one of the old guard of the B.B.C., naturally tries to continue the almost hopeless task of educating us, which the B.B.C. started nearly forty years ago when it tried to get us to use the pedantically pedagogic plural violincelli.

I do, however, heartily endorse most of what P. P. Eckersley says but I was a bit surprised that a writer, who rightly chides those who speak of "spectrums" when they mean "spectra," should have used the barbaric adjective "ionic" when he ought to have tried to lead us to better things. The pedantically correct word is, of course, "iontic" as we were all reminded by D. J. Bataimis, of Athens, in a letter published in *Wireless World* of September, 1954. We must, at least, credit Mr. Bataimis with knowing his own language.

"I was a bit surprised"

It is true that the word "ionic" has an ancient history dating back as it does to the issue of *Nature* for October 9th, 1890, but so also has the word "ain't." But antiquity doesn't make ain't correct unless used with its proper meaning of "am not" as Queen Victoria used it. Similarly the word "ionic" has its proper usage in a phrase like "ionic capitals" such as are to be found on the supporting columns of certain public buildings of classical architecture.

As for the Ionians being wanderers, this may well have been so but they took their name from the Greek god Ion from whom they are said to be descended; incidentally, many scholars have tried to identify Ion with Noah's grandson Javan whose sons certainly did a bit of colonizing after the flood (Gen. X 4, 5).

Of course, the real culprit in this "ionic" business is Faraday, who in 1839 coined the word "ion" in connection with electrolysis and made its plural "ions" instead of "ionta." I have a sneaking sympathy with him but regret that he spoke of "cations" and not "cathions." In any case, it would be a pedagogic pedantry to try to do anything about it now, and so we shall have to put up with it; it ain't possible to do otherwise.

Hypnagogic Hum

IN pre-war years I frequently used to chide the B.B.C. for the dull and feeble programmes it put out, especially on Sunday afternoons. They usually resulted in sending me into a profound sleep. Some of the B.B.C. programmes were particularly feeble, and I recollect one occasion when I happened to be chatting with a water diviner. We were standing rather near to my loudspeaker when suddenly his dowsing rod flew into the air owing to the programme being even more wet than usual.

But I was very puzzled when sometimes I found my head nodding even in the middle of a bright and breezy programme. The mystery is explained now. I recollect that the receiver I was using then had a low-pitched hum which seemed incurable no matter how many times I juggled with the smoothing circuits of the power pack and, I learn now, it was this hum which was causing me to fall asleep, and not the B.B.C. programmes. It appears that this mains hum is so strongly hypnagogic that it is now being used therapeutically in the U.S.A. to produce sleep in restless patients.

Walkie-Tapie

IT seems astonishing that none of the participants in the new long-distance marching craze has, at the moment of writing, carried a portable radio set to relieve the boredom. It is true there are no B.B.C. programmes on the air during the night when walkers would be in most need of musical good cheer. There are, of course, plenty of programmes to be picked up on short waves in the night, but I suppose what is really needed is a lightweight battery-driven walkie-tapie loaded with some of Sousa's famous marches. I have a good mind to try out the idea myself with the walkie-tapie strapped to my chest rather than on my back in order to facilitate reel changing.

Peak for Pain

WAY back in 1890 when the electric chair was first installed in Sing Sing there were two rival companies supplying electric power to New York according to a book written by a retired warder of the famous prison. Naturally a.c. was chosen for the chair as it was an easy matter to step up the e.m.f. to provide the necessary 2,000 volts.

This fact was immediately seized upon by the d.c. supply company who pointed out to potential users of electricity that the very fact that a.c. was chosen for the chair proved the product of the rival company to be highly dangerous and unsuitable for domestic use. This ingenious bit of propaganda had a very profound effect on electricity users of that time, and I sometimes wonder if it doesn't do so to a small extent even today.

The reason I say this is because recently when I was going over a house with a friend who was its potential purchaser I said I hoped for his sake that the electricity supply was a.c., otherwise a lot of appliances like synchronous clocks and fan heaters would be denied him. To my surprise he immediately switched on a light, removed the bulb and stuck his thumb in the socket. With scarcely a moment's pause he announced triumphantly that it was a.c. When I asked how he knew, he at once replied cryptically "Peak for Pain", and went on to explain that with a.c. the shock was considerably greater, as one received the benefit of the peak voltage.

Dr. Crippen

THIS issue of *Wireless World* ushers in the year 1960 and this reminds me of the unique event of 50 years ago which first put wireless on the map in the eyes of the general public. I refer, of course, to the arrest in July, 1910, of Dr. Crippen as a result of a radio message sent by Captain Kendall of s.s. *Montrose* saying he believed the doctor was on board in the guise of a Mr. Robinson. As a result of the message Inspector Dew sailed in late July on the *Laurentic* which overtook the *Montrose* in mid-Atlantic.

I have always thought we radio people have been rather remiss in not putting up a monument to Dr. Crippen to acknowledge his undoubted great service in publicizing radio.

Those who would acclaim Jack Binns, wireless operator of s.s. *Republic*, as the one who first demonstrated the value of wireless when his vessel was in collision with s.s. *Florida* in January, 1909, must remember that his name is unknown today whereas everybody has heard of Dr. Crippen.