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DECEMBER 1956

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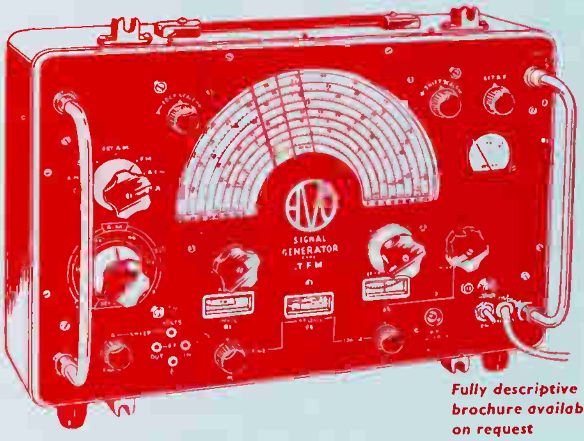

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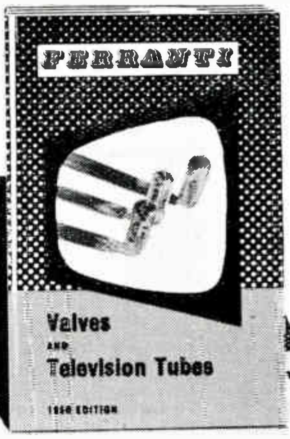

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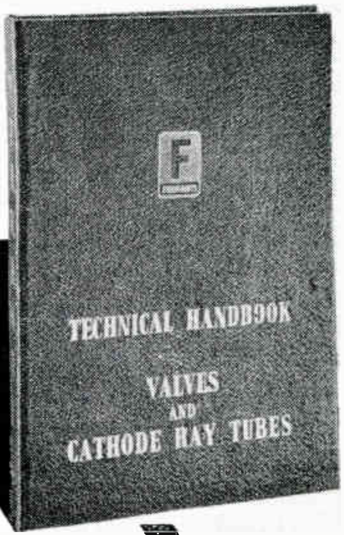

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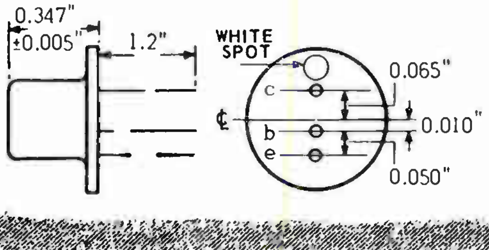

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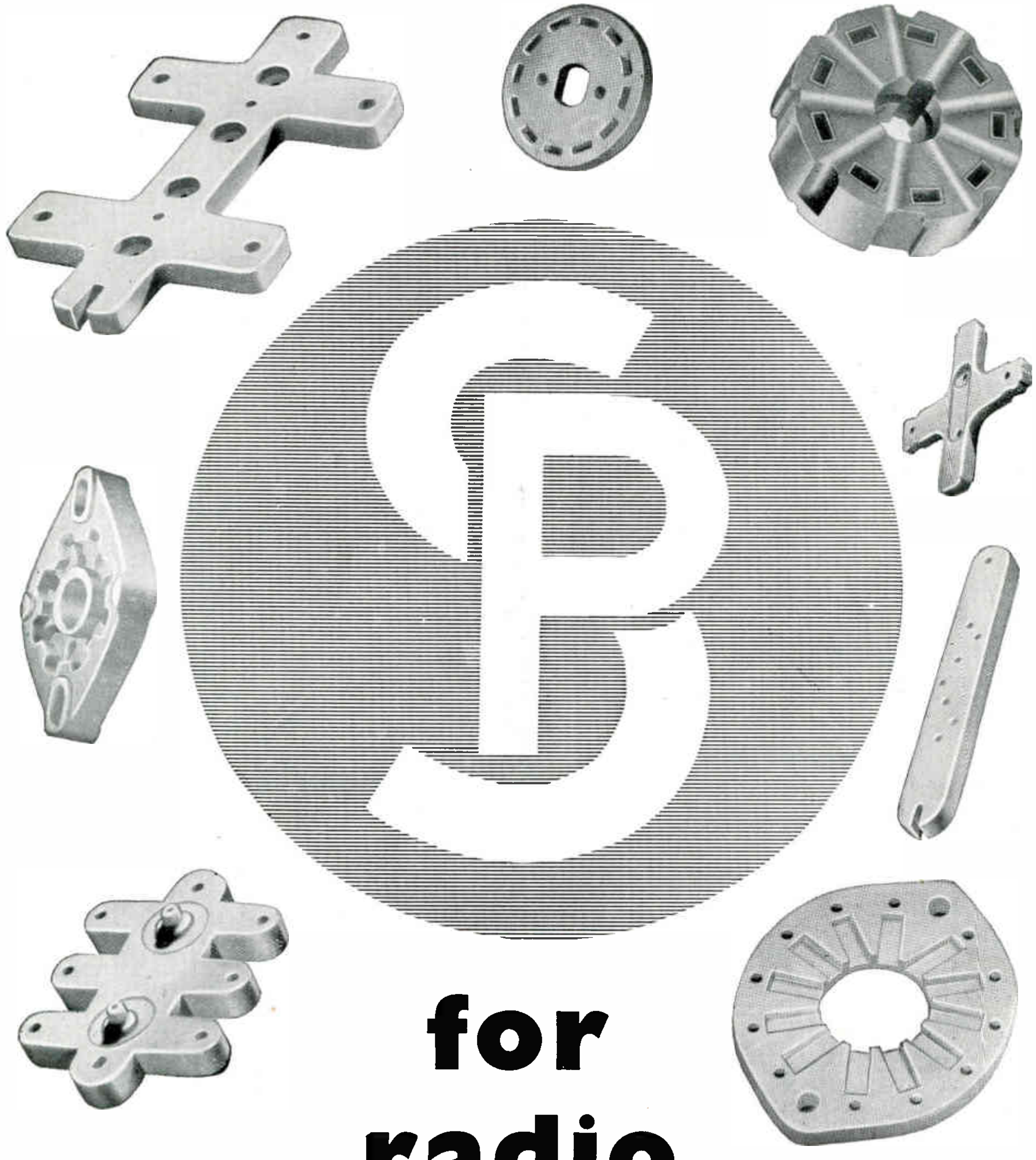


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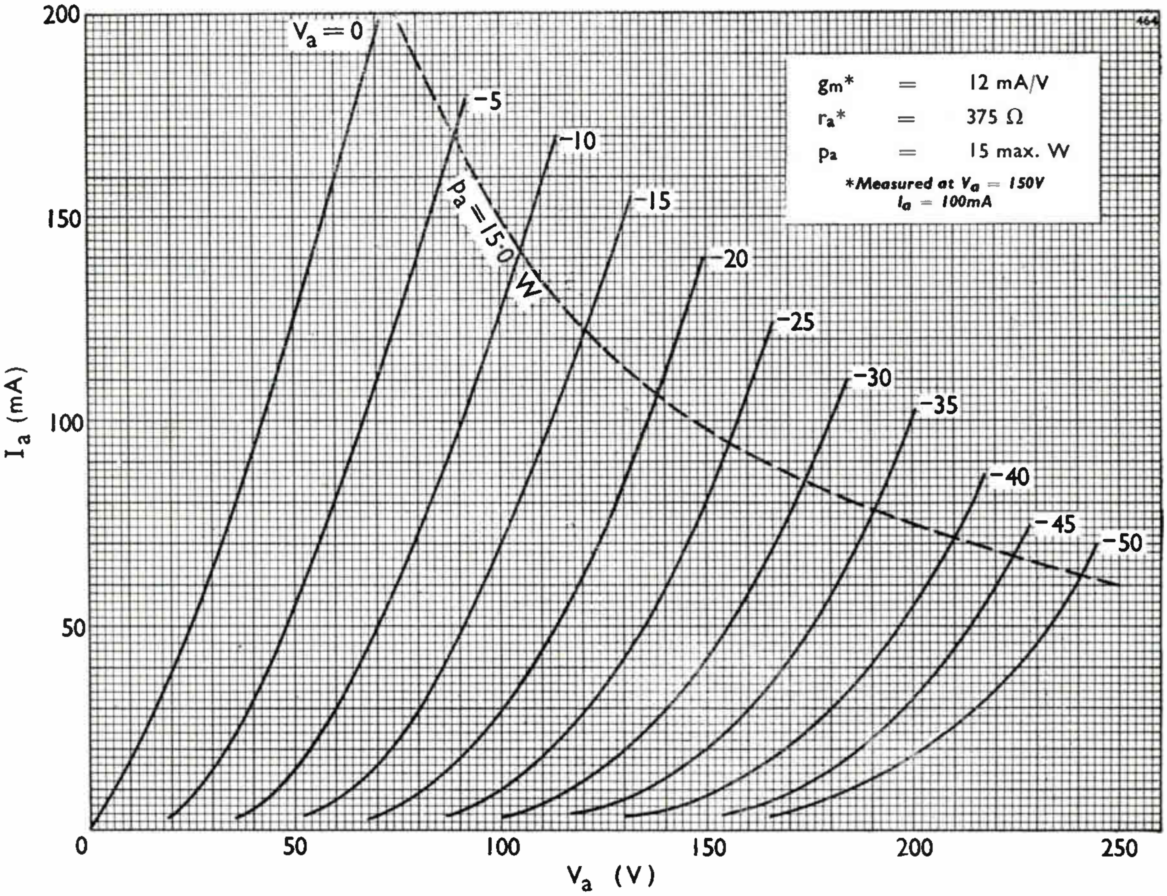

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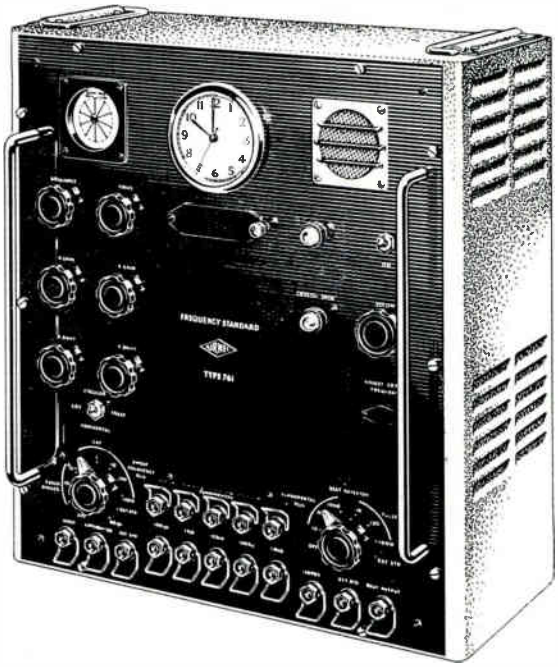

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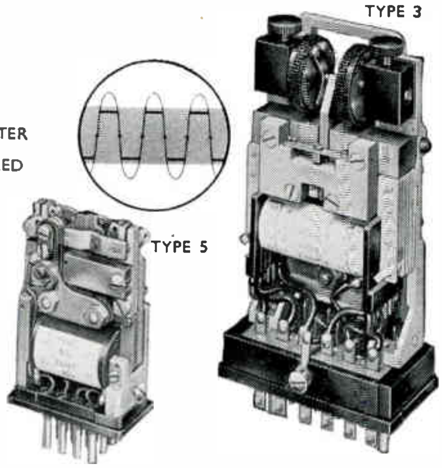

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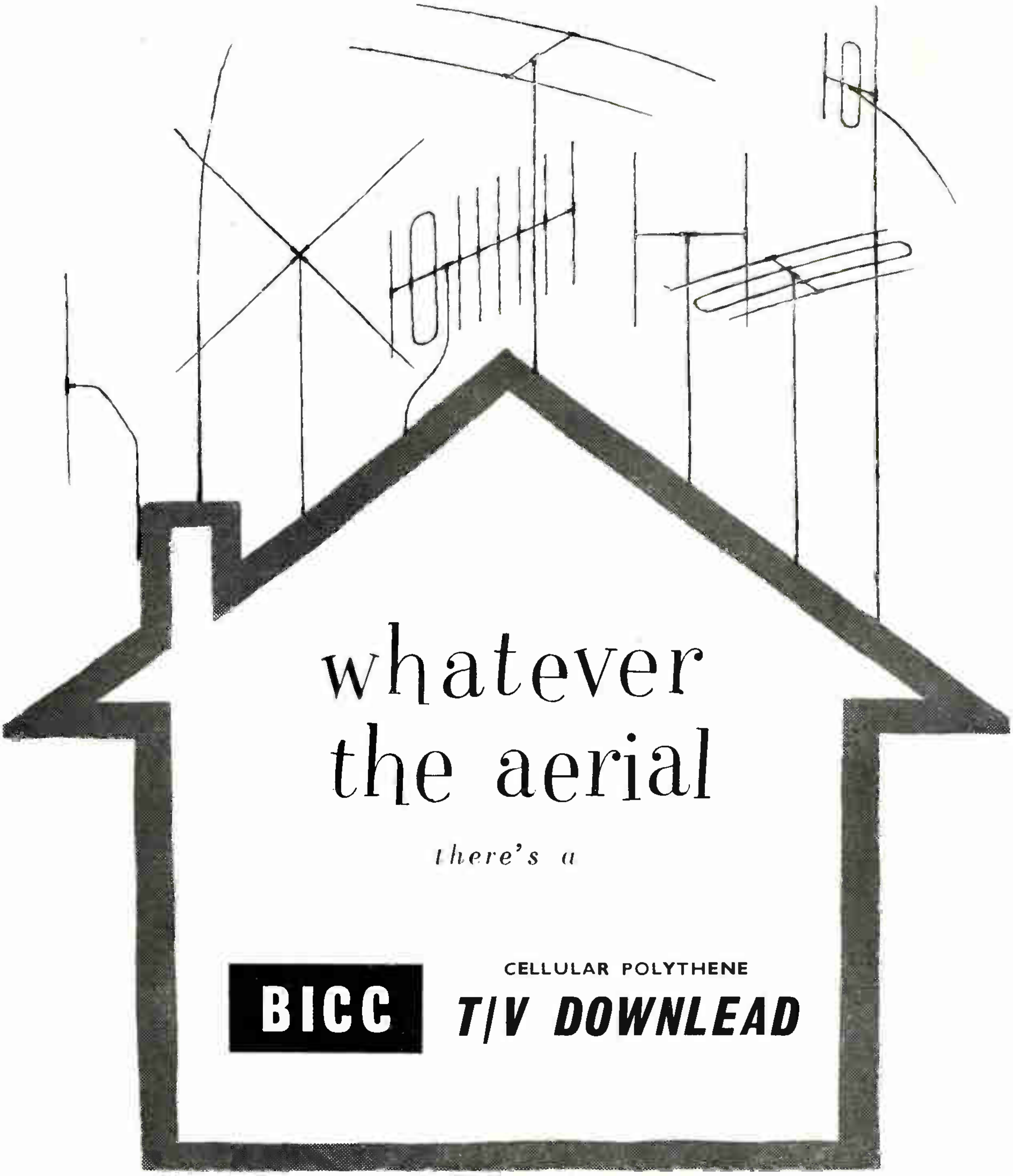

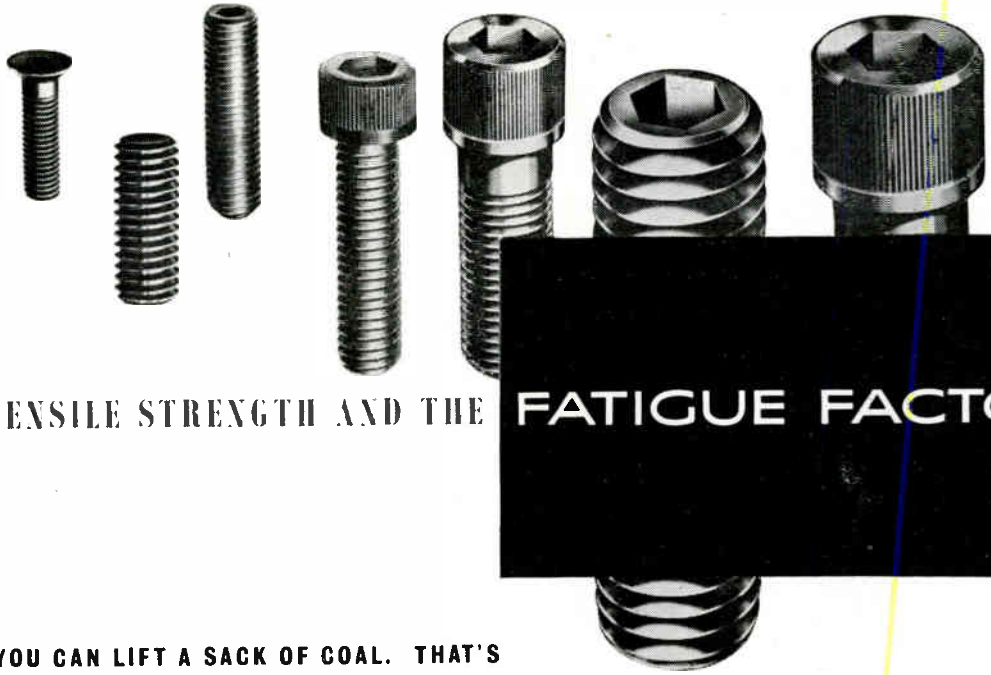

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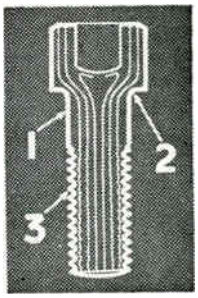

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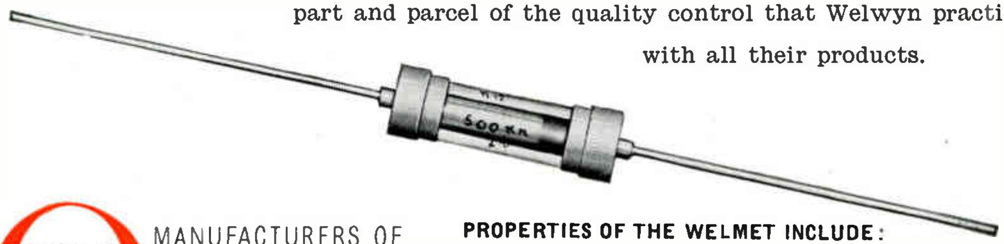

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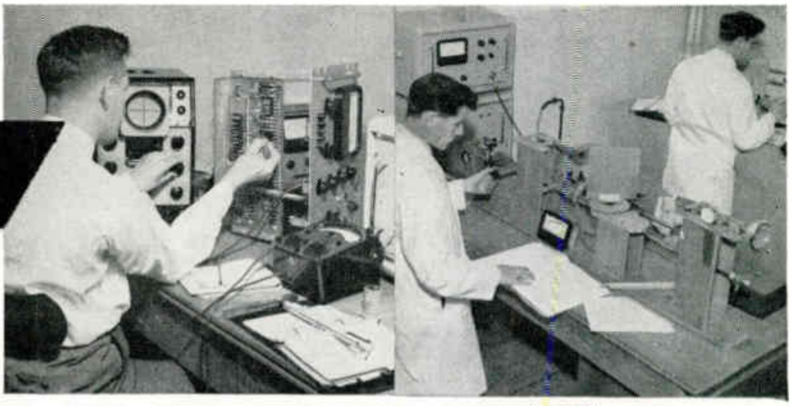

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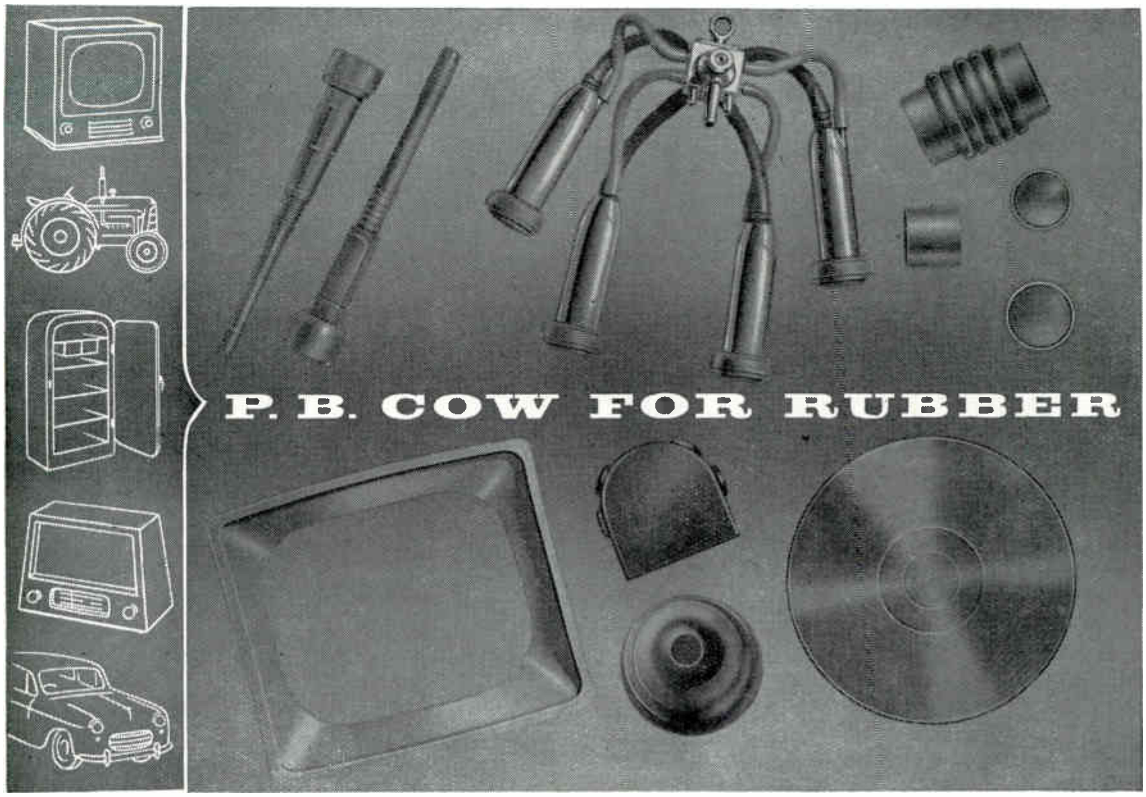

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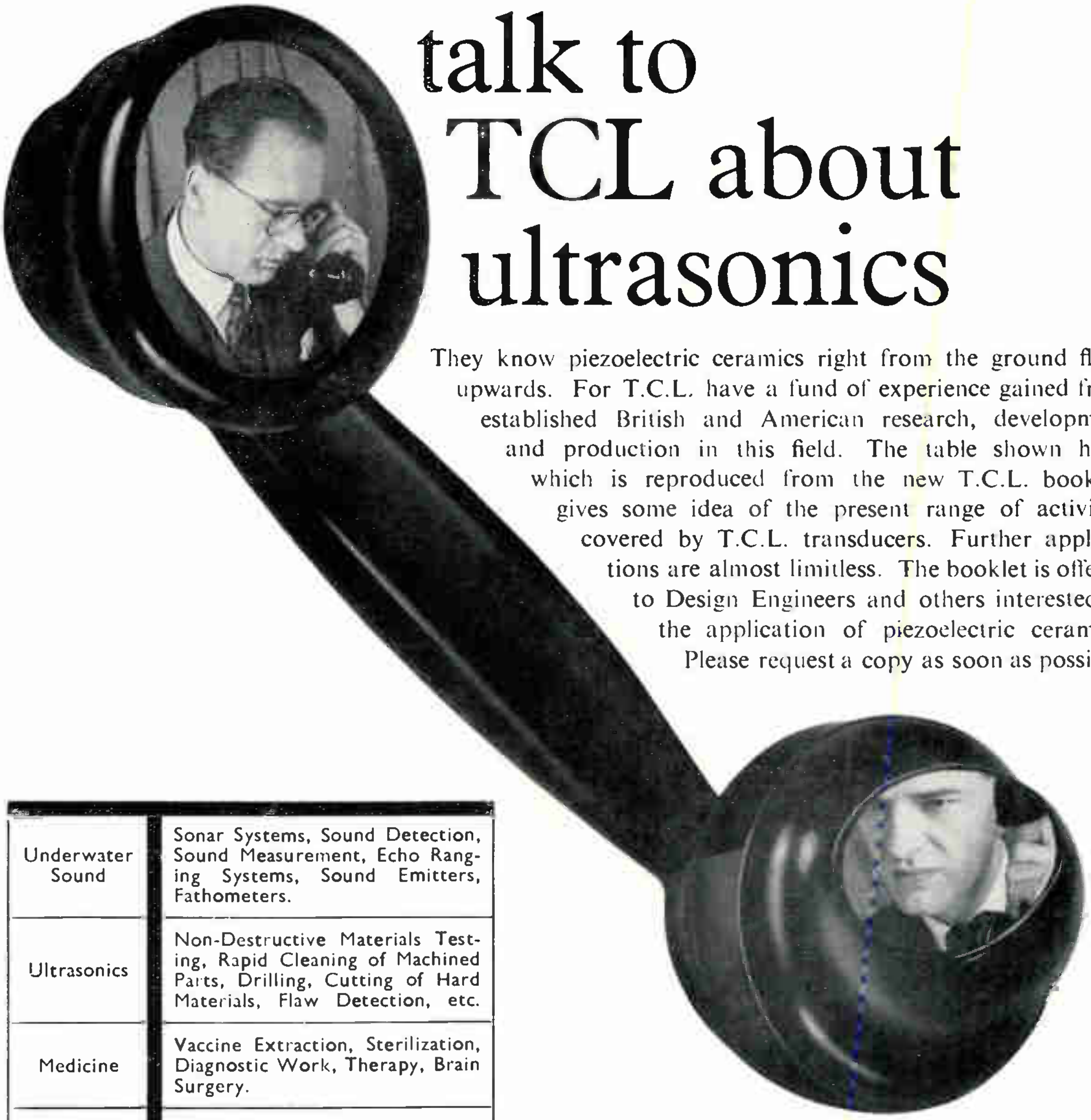

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N.1005M	Low Noise	4000	1mW	11	22	360	200μA	350
N.1013	Voltage Amplifier	2000	200mW	20	32	650	4mA	300
N.1017M	Low Noise	1200	1mW	10	20	700	200μA	200
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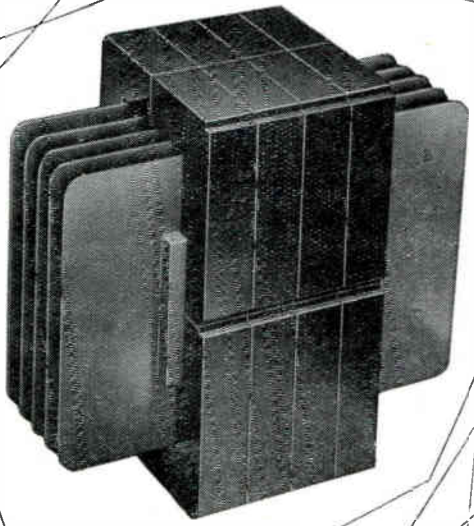

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Vol. 33 DECEMBER 1956 No. 12

FREE OSCILLATIONS IN SIMPLE DISTRIBUTED CIRCUITS

By **A. B. Hillan,** M.Eng., A.M.I.E.E.

(*The Atomic Weapons Research Establishment, Aldermaston*)

SUMMARY.—The paper deals with the calculation of waveforms which occur when a progressive wave in a transmission line impinges on a terminating circuit. The method of calculation is used to determine the waveforms occurring in certain simple distributed circuits when in free oscillation.

1. Introduction

MUCH contemporary work involves the study and measurement of phenomena occurring in circuits containing distributed elements. It is clear that a knowledge of the behaviour of simple distributed circuits is a prerequisite for such work. The object of this paper is to outline the basic principles governing the behaviour of uniform transmission lines and to illustrate their application by the study of the behaviour of some distributed circuits when in free oscillation.

In the general sense, a distributed circuit may be taken to mean any circuit in which transit times cannot be neglected. In a lumped or point circuit an analysis can be carried out on the assumption that the effect of a voltage or current impressed in any branch of the circuit will be felt instantaneously in all other branches, without introducing errors greater than a required maximum. When this assumption introduces excessive errors, the transit times of the effects must be considered and the circuit is then regarded as being distributed. Aerial systems and transmission lines are examples of such circuits, but it will be realized that, under certain conditions, other circuit elements such as valves must be included.

In this paper, attention will be confined to the study of a linear passive distributed circuit consisting of a finite length of uniform transmission line terminated at each end by a simple point circuit. If such a network is driven at some point by a sinusoidal source, the voltage and current everywhere are sinusoidal and can be readily reproduced at any point by substituting an appropriate lumped circuit. This similarity in behaviour of lumped and distributed circuits when in forced sinusoidal oscillation is due simply to the property of sinusoids that the sum of any number of sinusoids of the same frequency is sinusoidal, regardless of the phase relations of component waves. If the driving waveform is other than sinusoidal no such correspondence in behaviour results.

The fundamental differences between lumped and distributed circuits are well illustrated by considering free oscillations in the systems. As is well known, a simple lossless lumped circuit of inductance and capacitance, when in free oscillation, produces sinusoidal voltage and current waveforms, independently of how the energy was initially stored in the circuit. A corresponding form of simple lossless distributed circuit when in free oscillation produces more complicated waveforms dependent on the manner of storage of energy initially. The calculation of waveforms in such a circuit is the basic problem considered, but the method used is applicable to more complicated circuits.

Attention is given to two basic forms of distributed circuit, to be referred to as circuits A and B. These are:

Circuit A: A uniform lossless transmission line with a pure inductance at one end and an open-circuit at the other.

MS accepted by the Editor, June 1956

Circuit B: A uniform lossless transmission line with a pure capacitance at one end and a short-circuit at the other.

As the behaviour of the circuits is affected by the manner of storage of the energy initially, a further distinction will be made as follows:—

Case I: Energy initially stored in the lumped-circuit component (i.e., inductance for circuit A and capacitance for circuit B).

Case II: Energy initially stored in the distributed-circuit element (i.e., the transmission line).

Finally, the effect of circuit losses introduced by the insertion of resistances will be given for certain simple cases. The extension of the method of analysis to deal with more complicated circuits is discussed briefly.

Before proceeding to the first analysis a brief résumé of the properties of transmission lines relevant to the problems considered will be given.

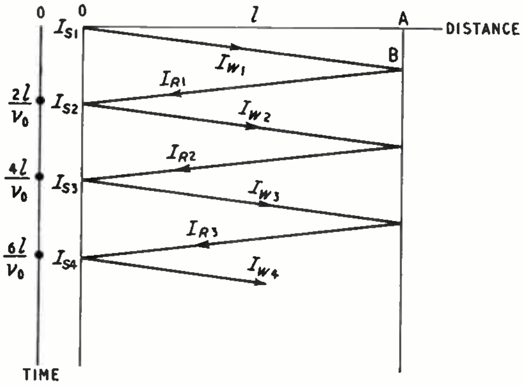


Fig. 1. *Diagrammatic representation of transmission line. The left-hand side is taken as the origin and I_W, I_R indicate successive reflections.*

2. Some Properties of Uniform Transmission Lines

2.1. *Nomenclature*

The nomenclature adopted in the following notes and analyses can be explained with the help of Fig. 1. The left-hand end of the line, where the inductance or capacitance is situated, is taken as the origin; the line extends for its length OA $= l$ in the direction of the x axis. The negative ordinate of the graph is time.

The oscillation is initiated at the origin at time zero and a current I_{S1} is produced in the termination. At the same moment a progressive current wave I_{W1} leaves O and travels with a finite velocity v_0 towards the right-hand termination. The progress of the wave is represented in Fig. 1 by the line OB. This first wave reaches the right-hand termination at time l/v_0, and a current wave I_{T1} is then set up in the termination. At the same time, a reflected current wave I_{R1} travels back towards the left-hand termination, which it reaches at time $2l/v_0$. As a result of the arrival of this reflected wave, a further current wave I_{S2} is set up in the termination and a re-reflected wave, called the second progressive wave I_{W2}, starts down the line.

The process is cyclic, and in a lossless circuit is repeated endlessly. In general terms I_{Sn} is the nth current wave in the left-hand termination from which I_{Wn}, the nth progressive wave, is derived. I_{Tn} is the current in the right-hand termination due to I_{Wn}, while I_{Rn} is the resulting current reflection, which sets up the I_{Sn+1} wave on reaching the left-hand end of the line. The voltage wave corresponding to any given current wave is indicated by replacing I by V.

Applying Kirchhoff's law to the terminations, it follows that the following relationships are true:—

$$\left.\begin{aligned} I_{W1} &= I_{S1}{}^{*} & I_{R1} &= I_{T1} - I_{W1} \\ I_{W2} &= I_{S2} - I_{R1} & I_{R2} &= I_{T2} - I_{W2}\text{ etc.} \end{aligned}\right\} \qquad (1)$$

and in general

$$I_{Wn} = I_{Sn} - I_{Rn-1} \quad I_{Rn} = I_{Tn} - I_{Wn}$$

The convention adopted in this paper is that current circulating in a clockwise direction is taken as positive; voltage increasing in the same direction is taken as positive.

2.2. *Progressive Waves*

A uniform lossless transmission line is characterized by distributed inductance, L_0 henrys/metre, and distributed capacitance, C_0 farads/metre. Energy can be transmitted along the line in either direction at a finite velocity v_0 metres/second given by the equation

$$v_0 = \frac{1}{\sqrt{L_0 C_0}}\,\dagger \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Energy is transmitted along the line in magnetic and electrostatic fields produced by a progressive current and voltage wave. At any instant in a progressive wave the current and voltage waveforms along the line are linearly related by the equation

$$\left.\begin{aligned} V &= Z_0 I \\ \text{where} \quad Z_0 &= \pm\sqrt{\frac{L_0}{C_0}}\text{ ohms}\dagger \end{aligned}\right\} \quad \ldots \quad \ldots \quad (3)$$

is called the characteristic impedance of the line and is a pure resistance.

The two signs attributable to Z_0 refer to the reversible nature of the flow of energy. In this paper, a progressive wave travelling from left to right is associated with the positive sign; in a reflected wave either the current or the voltage must be reversed relative to the other, so that

---

* Except for circuit B, Case II (Section 4.3.2).

† It is assumed that L_0 and C_0, and hence v_0 and Z_0, are independent of frequency. The error involved in this assumption is not serious except for very accurate calculations.

the negative sign applies.

$$\left.\begin{aligned}\text{Thus}\quad V_{Wn} &= Z_0 .\, I_{Wn}\\ \text{and}\quad V_{Rn} &= (-\,Z_0).\, I_{Rn}\end{aligned}\right\} \quad .. \quad (4)$$

2.3. *Reflection*

When the line is absorbing power from a source, it accepts energy at the same rate as would a physical resistance $+Z_0$. This energy is propagated along the line at the appropriate rate and delivered to the termination. Hence at the termination the line acts as a source of energy having an internal impedance of Z_0 ohms.

Now consider the effect of an open-circuit termination: it cannot accept power and, hence, all the incident energy must be reflected. This means that the reflected wave must be equal in magnitude to the incident wave. For an incident current wave I_{Wn}, the incident voltage wave is $V_{Wn} = Z_0 . I_{Wn}$. Since the termination is unable to support a current wave, the current in the reflected wave must reverse; i.e.,

$$I_{Rn} = -\,I_{Wn} \quad .. \quad .. \quad .. \quad .. \quad (5)$$

The voltage in the reflected wave is then

$$V_{Rn} = (-\,Z_0).I_{Rn} = V_{Rn} = V_{Wn} \quad (6)$$

Thus the voltage wave is reflected without reversal of sign and so the voltage at the termination is

$$V_{Tn} = V_{Wn} + V_{Rn} = 2V_{Wn} \quad .. \quad (7)$$

2.4. *Thévenin's Theorem*

It can now be seen that at the above termination the line behaves as a source of power having an internal impedance Z_0 and open-circuit voltage $2V_{Wn}$, V_{Wn} being the voltage in the wave arriving at the termination. The waveforms in any termination can be determined by applying Thévenin's theorem and deriving the equivalent circuit shown in Fig. 2. The use of this equivalent circuit enables I_{Tn}, and hence all other waveforms, to be calculated. The same considerations apply to the calculation of I_{S2}, I_{S3}, etc., from the reflected waves returning to the left-hand end.

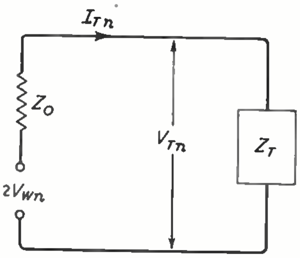


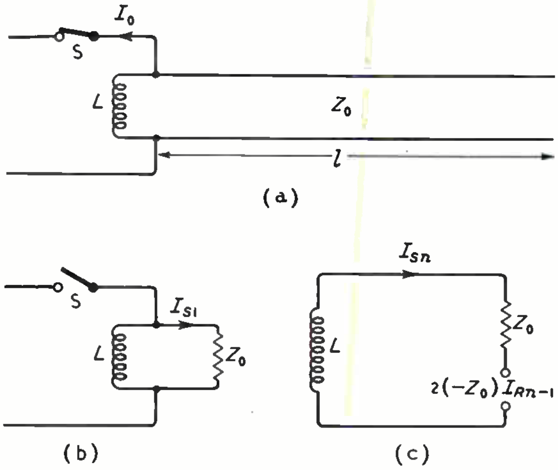
Fig. 2. *Equivalent circuit of line.*

2.5. *Attenuation*

The effect of losses in a physical line on its characteristic impedance can usually be neglected. The voltage–current relationship in every progressive wave is thus unaffected. It is then possible to base calculations on a lossless line and later to take the attenuation into account by introducing it as a correction factor.

The attenuation constant of a line is expressed as α nepers/metre, and a progressive wave travelling along l metres of line is attenuated by a factor $e^{-\alpha l}$, which is therefore the correction factor to be introduced to take line losses into account. Thus the first reflected wave returning to the left-hand end of the line is attenuated by a factor $e^{-\alpha(2l)}$ relative to the lossless case.

For a progressive wave in the form of a steady sinusoid, it is known that the attenuation constant increases with frequency. It follows that to calculate the precise effect of line attenuation on any transient waveform would involve a great deal of labour. The best that can be done simply is to choose the attenuation constant at a frequency dependent on the waveform considered and assume this value to be independent of frequency. Thus a first approximation to the effect of attenuation is obtained, and, provided the primary approximation is borne in mind, no serious errors should result.



(a)

(b) (c)

Fig. 3. *A line terminated in inductance L with stored energy is shown at (a), with an equivalent circuit for the calculation of I_{s1} at (b). A Thévenin equivalent is indicated at (c).*

3. Case I: Energy Stored Initially in Lumped Circuit Element

3.1. *Analysis of Circuit A*

3.1.1. *Simplifications in Procedure*

In the circuit to be analysed [Fig. 3(a)] the initial energy is $\frac{1}{2}LI_0{}^2$, stored in the inductance termination at the left-hand end of the line. Free oscillation begins when the switch S is opened. The termination at the right-hand end of the line is an open-circuit. This permits a simplification of the analysis, since it follows from Section 2 that

$$\left.\begin{aligned} I_{Rn} &= -\,I_{Wn}\\ V_{Tn} &= 2Z_0 I_{Wn}\\ I_{Sn} &= I_{Wn} + I_{Rn-1}\\ &= I_{Wn} - I_{Wn-1}\\ V_{Sn} &= Z_0 I_{Wn} + (-\,Z_0) I_{Rn-1}\\ &= Z_0(I_{Wn} + I_{Wn-1})\end{aligned}\right\} \quad .. \quad (8)$$

From the above equations it can be seen that the waveforms in any part of the circuit can be specified simply in terms of I_{Wn}. Hence if I_{Wn} is calculated the circuit analysis is complete. The following sections are devoted to this calculation.

3.1.2. *Calculation of I_{W1}*

In Section 2 it was shown that $I_{W1} = I_{S1}$; the equivalent circuit for the calculation of I_{S1} is shown in Fig. 3(b). At time zero the switch S is opened and the behaviour of the circuit is governed by the following differential equation:—

$$L\frac{dI_{S1}}{dt} - Z_0 . I_{S1} = 0 \qquad .. \qquad .. \qquad (9)$$

The complete solution of this equation is

$$I_{W1} = I_{S1} = I_0 e^{-Z_0 t/L} \qquad .. \qquad .. \qquad (10)$$

3.1.3. *Recurrence Formula for I_{Wn}*

Fig. 3(c) shows the circuit obtained by the use of Thévenin's theorem to enable I_{Sn}, the nth current wave in the inductance, to be calculated. It must be remembered that by the principle of superposition for all values of n other than 1, the inductance is regarded as having no magnetic energy initially. Taking as positive a voltage increasing in a clockwise direction, the following equation is obtained from Fig. 3(c)

$$-L\frac{dI_{Sn}}{dt} - Z_0 . I_{Sn} - 2(-Z_0) . I_{Rn-1} = 0 \quad (11)$$

Since $I_{R1} = -I_{W1} = -I_0 e^{-Z_0 t/L}$,

Equ. 11 can be used to evaluate I_{S2} and hence I_{W2}. It is found that

$$I_{W2} = I_0 e^{-Z_0 t/L}\left\{1 - 2\frac{Z_0 t}{L}\right\} \qquad .. \qquad (12)$$

The equation for I_{Wn} then takes the form

$$I_{Wn} = I_0 e^{-Z_0 t/L}\{P_n\} \qquad .. \qquad .. \qquad (13)$$

where P_n is a polynomial in $\{Z_0 t/L\}$.

Equ. (11) can be used to obtain a recurrence formula for P_n, thus enabling successive equations for I_{Wn} to be obtained with the minimum difficulty.

If Equ. (11) is transformed by writing the dependent variables in terms of I_{Wn} and I_{Wn-1}, while at the same time changing the independent variable from t to $\{Z_0 t/L\}$, the following equation is obtained:

$$-Z_0 . D\{I_{Wn} - I_{Wn-1}\} - Z_0\{I_{Wn} - I_{Wn-1}\} = +2Z_0 I_{Wn-1} \qquad .. \qquad .. \qquad (14)$$

where $D \equiv \dfrac{d}{d\left\{\dfrac{Z_0 t}{L}\right\}} = \dfrac{L}{Z_0} . \dfrac{d}{dt}$

Substituting Equ. (13) into (14), the result is

$$D\{P_n - P_{n-1}\} = -2P_{n-1} \qquad .. \qquad .. \qquad (15)$$

Hence $P_n = \text{constant} + P_{n-1} - 2\int P_{n-1}$ (16)

The values of P_1 and P_2 obtained from Equs. (10) and (12) show that the constant is zero, so that the recurrence relation for P_n is

$$P_n = P_{n-1} - 2\int P_{n-1} \qquad .. \qquad .. \qquad (17)$$

3.1.4. *Summary of Results*

Using Equ. (17) the successive expressions for I_{Wn} can be readily built up; the first 10 equations are tabulated in Table 1, where x is written for $\{Z_0 t/L\}$. These equations have been evaluated in the range of x from 0 to 2 and the results are tabulated in Table 2. The results given in Table 2 have been plotted in Figs. 4 and 5 to show the shape of the waveforms that occur.

3.1.5. *Example*

Tables 1 and 2 and Figs. 4 and 5 are generalized results applicable to any values of l, I_0, L and Z_0, so that the evaluation of any specific case requires little work. As an example, suppose it is required to calculate the voltage–time curve at the open end of the transmission line for the following case:

$I_0 = 2$ amps
$L = 10^{-3}$ henry
$Z_0 = 100$ ohms
$v_0 = 2 \times 10^8$ metres/second

TABLE 1

$$I_{W1} = I_0 . e^{-x}$$

$$I_{W2} = I_0 . e^{-x}(1 - 2x)$$

$$I_{W3} = I_0 . e^{-x}(1 - 4x + 2x^2)$$

$$I_{W4} = I_0 . e^{-x}\left(1 - 6x + 6x^2 - \frac{4}{3}x^3\right)$$

$$I_{W5} = I_0 . e^{-x}\left(1 - 8x + 12x^2 - \frac{16}{3}x^3 + \frac{2}{3}x^4\right)$$

$$I_{W6} = I_0 . e^{-x}\left(1 - 10x + 20x^2 - \frac{40}{3}x^3 + \frac{10}{3}x^4 - \frac{4}{15}x^5\right)$$

$$I_{W7} = I_0 . e^{-x}\left(1 - 12x + 30x^2 - \frac{80}{3}x^3 + \frac{30}{3}x^4 - \frac{24}{15}x^5 + \frac{4}{45}x^6\right)$$

$$I_{W8} = I_0 . e^{-x}\left(1 - 14x + 42x^2 - \frac{140}{3}x^3 + \frac{70}{3}x^4 - \frac{84}{15}x^5 + \frac{28}{45}x^6 - \frac{8}{315}x^7\right)$$

$$I_{W9} = I_0 . e^{-x}\left(1 - 16x + 56x^2 - \frac{224}{3}x^3 + \frac{140}{3}x^4 - \frac{224}{15}x^5 + \frac{112}{45}x^6 - \frac{64}{315}x^7 + \frac{2}{315}x^8\right)$$

$$I_{W10} = I_0 . e^{-x}\left(1 - 18x + 72x^2 - \frac{336}{3}x^3 + \frac{252}{3}x^4 - \frac{504}{15}x^5 + \frac{336}{45}x^6 - \frac{288}{315}x^7 + \frac{18}{315}x^8 - \frac{4}{2835}x^9\right)$$

$$l = 200 \text{ metres}$$

$$x = \frac{Z_0 t}{L} = 10^5 t$$

$$\frac{2l}{v_0} = 2 \times 10^{-6} \text{ second}$$

From Section 2.1 it will be seen that the resultant voltage–time curve is

$$V_{T1} + V_{T2} + V_{T3} + \text{etc.},$$

with V_{Tn} commencing $2l/v_0$ seconds after V_{Tn-1}. In the present example the delay is 2×10^{-6} second.

The voltage–time wave obtained is plotted in Fig. 6, showing the first cycle of a periodic wave which is undamped because the circuit is lossless.

Using Equs. (2) and (3) and the above data it is easy to show that the total capacitance of the transmission line ($C_0 l$) is 0·01 μF. If the transmission line in the above example be replaced by a lumped capacitance of 0·01 μF, the waveform of the voltage across the capacitor is also plotted in Fig. 6 for the purpose of comparison.

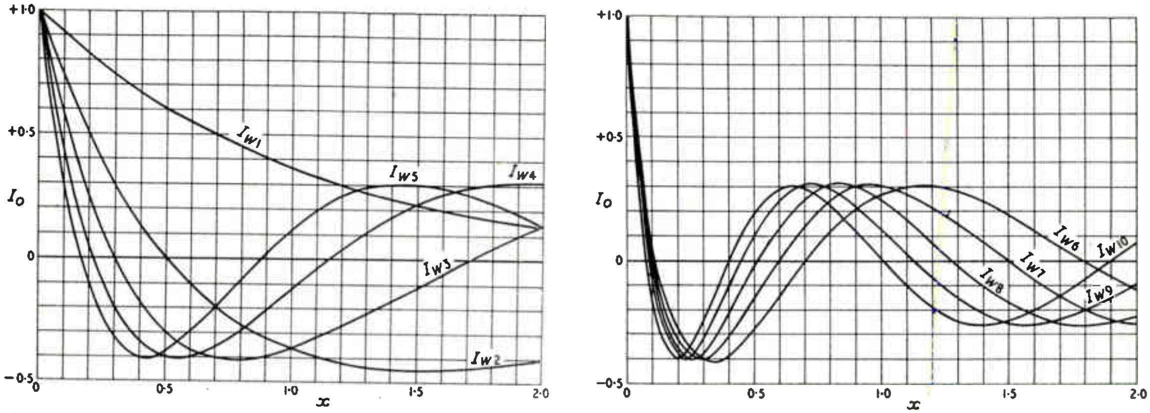
3.2. *Analysis of Circuit B*

3.2.1. *Simplifications in Procedure*

The circuit is shown in Fig. 7(a) and the initial energy is $\frac{1}{2} C V_0^2$ stored in the capacitor. The oscillation commences when the switch S is closed at time zero. The termination at the right-hand end of the transmission line is a short-circuit, permitting the following simplified equations:—

$$\left.\begin{aligned} I_{Rn} &= I_{Wn} \\ I_{Tn} &= 2I_{Wn} \\ I_{Sn} &= I_{Wn} + I_{Rn-1} \\ &= I_{Wn} + I_{Wn-1} \\ V_{Sn} &= Z_0 \,.\, I_{Wn} + (-Z_0) \,.\, I_{Rn-1} \\ &= Z_0(I_{Wn} - I_{Wn-1}) \end{aligned}\right\} \quad (18)$$

As before, all the circuit waveforms can be simply expressed in terms of I_{Wn}; thus, as in



Figs. 4 (left) *and* 5 (right). *Curves plotted from the figures of Table 2, showing the waveforms in a line connected to an inductance having stored energy, as in Fig. 3.*

TABLE 2

x	I_{W1}/I_0	I_{W2}/I_0	I_{W3}/I_0	I_{W4}/I_0	I_{W5}/I_0	I_{W6}/I_0	I_{W7}/I_0	I_{W8}/I_0	I_{W9}/I_0	I_{W10}/I_0
0	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000
0·1	0·9048	0·7238	0·5610	0·4150	0·2848	0·1692	0·0672	−0·0221	−0·0997	−0·1664
0·2	0·8187	0·4912	0·2292	0·0240	−0·1323	−0·2468	−0·3257	−0·3748	−0·3989	−0·4027
0·3	0·7048	0·2963	−0·0148	−0·2193	−0·3397	−0·3953	−0·4021	−0·3735	−0·3204	−0·2517
0·4	0·6703	0·1341	−0·1877	−0·3251	−0·4050	−0·3826	−0·3128	−0·2173	−0·1120	−0·0084
0·5	0·6065	0·0000	−0·3033	−0·4043	−0·3791	−0·2830	−0·1558	−0·0245	0·0934	0·1878
0·6	0·5488	−0·1098	−0·3732	−0·3995	−0·2994	−0·1475	0·0086	0·1410	0·2357	0·2883
0·7	0·4966	−0·1986	−0·4072	−0·3562	−0·1933	−0·0088	0·1469	0·2511	0·2983	0·2938
0·8	0·4493	−0·2696	−0·4134	−0·2888	−0·0798	0·1129	0·2434	0·2996	0·2888	0·2279
0·9	0·4066	−0·3253	−0·3985	−0·2082	0·0282	0·2072	0·2942	0·2931	0·2263	0·1219
1·0	0·3679	−0·3679	−0·3679	−0·1226	0·1226	0·2698	0·3025	0·2441	0·1320	0·0030
1·1	0·3329	−0·3995	−0·3262	−0·0392	0·1989	0·3010	0·2757	0·1674	0·0266	−0·1051
1·2	0·3012	−0·4217	−0·2771	0·0410	0·2549	0·3037	0·2229	0·0772	−0·0734	−0·1877
1·3	0·2725	−0·4360	−0·2235	0·1119	0·2907	0·2826	0·1533	−0·0144	−0·1570	−0·2399
1·4	0·2466	−0·4439	−0·1677	0·1729	0·3074	0·2428	0·0757	−0·0979	−0·2154	−0·2528
1·5	0·2231	−0·4462	−0·1116	0·2231	0·3068	0·1896	−0·0028	−0·1665	−0·2474	−0·2367
1·6	0·2019	−0·4442	−0·0565	0·2622	0·2915	0·1282	−0·0769	−0·2193	−0·2576	−0·2002
1·7	0·1827	−0·4385	−0·0037	0·2904	0·2641	0·0635	−0·1397	−0·2459	−0·2394	−0·1356
1·8	0·1653	−0·4298	0·0463	0·3081	0·2272	−0·0011	−0·1907	−0·2551	−0·1967	−0·0660
1·9	0·1496	−0·4189	0·0928	0·3164	0·1835	−0·0622	−0·2276	−0·2457	−0·1442	0·0093
2·0	0·1353	−0·4059	0·1353	0·3157	0·1353	−0·1173	−0·2496	−0·2203	−0·0846	0·0737

Section 3.1, it is only necessary to calculate I_{Wn} to obtain the complete solution of the circuit.

3.2.2. *Calculation of I_{Wn}*

As in Section 3.1.2 I_{S1} is calculated, giving I_{W1} immediately. The equivalent circuit used in the calculation is shown in Fig. 7(b). At time zero the switch S is closed and the capacitor, initially charged to V_0 volts, discharges into the characteristic impedance of the line. The behaviour of the circuit is governed by the following equation:—

$$\frac{CV_0 - \int_0^t I_{S1}\,dt}{C} - Z_0 \,.\, I_{S1} = 0 \quad \ldots \quad (19)$$

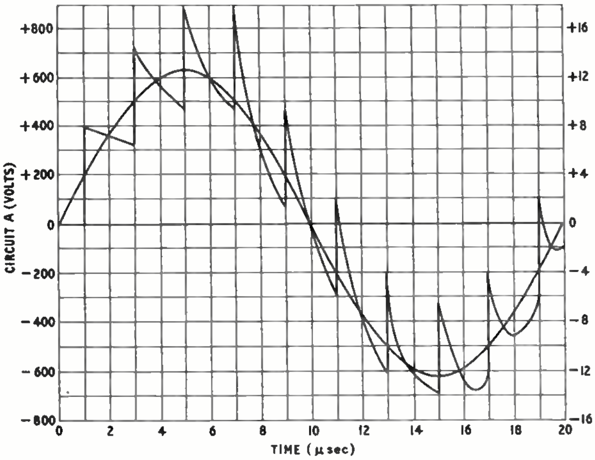


Fig. 6. *Current and voltage waveforms for particular conditions in the circuits of Figs. 3 and 7.*

As before, the sign convention adopted is that current circulating in a clockwise direction is positive, and a voltage increasing in the same direction is positive.

The complete solution for Equ. (19) is

$$I_{W1} = I_{S1} = I_0 e^{-t/CZ_0} \quad \ldots \quad \ldots \quad (20)$$

where $I_0 = \dfrac{V_0}{Z_0}$.

3.2.3. *Recurrence Formula for I_{Wn}*

The application of Thévenin's theorem enables the equivalent circuit of Fig. 7(c) to be derived for the calculation of I_{Sn}, the nth current wave in the capacitor. The principle of superposition used in the calculation requires that for all values of n other than 1, the capacitor is taken as being initially uncharged. The equation obtained from the circuit is

$$-\frac{1}{C}\int_0^t I_{Sn}\,dt - Z_0\, I_{Sn} - \{2(-Z_0) I_{Rn-1}\} = 0 \quad \ldots \quad \ldots \quad (21)$$

Since $I_{R1} = I_{W1}$, Equ. (21) can be used to evaluate I_{S2} and hence I_{W2}. It is found that

$$I_{W2} = I_0 e^{-t/CZ_0}\left\{1 - \frac{2t}{CZ_0}\right\} \quad \ldots \quad \ldots \quad (22)$$

In general $I_{Wn} = I_0 e^{-t/CZ_0}\{P_n\} \quad \ldots \quad \ldots \quad (23)$

where P_n is a polynomial in $\{t/CZ_0\}$.

A recurrence formula for P_n can be obtained from Equ. (21); the equation is transformed by writing the dependent variables in terms of I_{Wn} and I_{Wn-1}, while at the same time changing the independent variable from t to (t/CZ_0). The following equation is the result

$$P_n = \text{constant} + P_{n-1} - 2\int P_{n-1} \quad (24)$$

The values of P_1 and P_2 obtained from Equs. (20) and (22) show that the constant of integration is zero.

Therefore $P_n = P_{n-1} - 2\int P_{n-1} \ldots \quad (25)$

is the recurrence relation required.

3.2.4. *Summary of Results*

By comparison of Sections 3.2.3 and 3.1.3, it is clear that the equations for I_{Wn} in circuit B will take exactly the same form as for circuit A, provided only that $Z_0 t/L$ is replaced by t/CZ_0. It follows at once that Tables 1 and 2 and Figs. 4 and 5 apply equally to circuit B if x is taken to represent t/CZ_0. Thus, as might be expected, there is a close correspondence in the behaviour of the two circuits.

3.2.5. *Example*

As an example of this similarity, calculate the current–time curve at the short-circuit termination

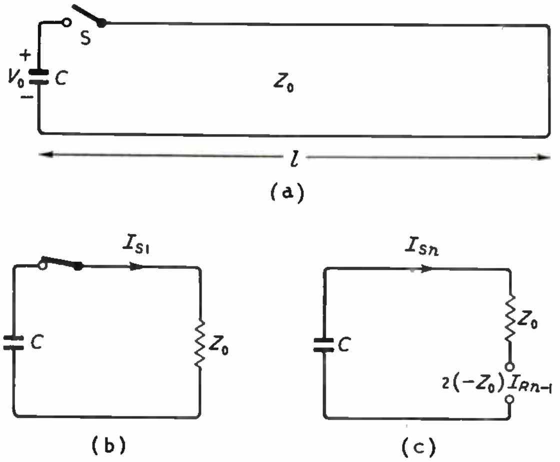


Fig. 7. *A line terminated by a charged capacitor is shown at (a), with an equivalent circuit at (b) and the Thévenin equivalent at (c).*

for the following case:—

$$\begin{aligned} V_0 &= 200 \text{ volts} \\ C &= 2 \times 10^{-7} \text{ farad} \\ Z_0 &= 50 \text{ ohms} \\ v_0 &= 150 \times 10^6 \text{ metres/second} \\ l &= 150 \text{ metres} \\ \text{therefore } I_0 &= 4 \text{ amps} \\ \text{and } x &= \frac{t}{cZ_0} = 10^5 t \\ \frac{2l}{v_0} &= 2 \times 10^{-6} \text{ second} \end{aligned}$$

The resulting current–time curve is given by Fig. 6 simply by changing the ordinate scale as shown.

The total inductance of the transmission line can be readily shown to be 5×10^{-5} henry. If the transmission line in the above example is replaced by this lumped inductance, the current–time curve in the inductance is given by the sinusoid in Fig. 6 in conjunction with the second ordinate scale.

4. Case II: Energy Stored Initially in the Transmission Line

4.1. *Introduction*

The first problem to arise is the method of representation of the line as a source of power when the energy is initially uniformly distributed along the line as electrostatic or magnetic energy. The experience gained in the preceding sections suggests that Thévenin's theorem could again be used.

When a termination is placed across the line, energy begins to flow from the line into the termination. However, the application of Thévenin's theorem leads to a first progressive wave which travels away from the termination. This apparent contradiction is resolved if the limitations of the principle of superposition are borne in mind. In fact the equations can be verified directly by showing that the total energy in the system remains constant.

4.2. *Analysis of Circuit A*

4.2.1. *Initial Procedure*

The circuit to be considered is shown as Fig. 8(a); initially the line is charged to a voltage V_0, and at time zero the switch S is closed.

The open-circuit termination at the right-hand end of the line allows Equ. (8) (Section 3.1.1) to apply to this problem as well. For the purpose of calculating I_{S1}, Thévenin's theorem is used to replace the line by a generator having an internal impedance of Z_0 ohms and an open-circuit voltage V_0 volts. For the calculation of I_{S2} and subsequent waves the principle of superposition requires that the line be regarded as initially uncharged, so that the technique used in the preceding sections will then apply.

4.2.2. *Calculation of I_{W1}*

As before, $I_{W1} = I_{S1}$, so that I_{S1} must first be calculated; the equivalent circuit of Fig. 8(b) is derived for this purpose. Using the same convention of signs as previously, the equation obtained is

$$-L\frac{dI_{S1}}{dt} - Z_0 \, . \, I_{S1} - V_0 = 0 \quad .. \quad (26)$$

The solution of this equation is

$$I_{W1} = I_{S1} = -I_0\{1 - e^{-Z_0t/L}\} \quad .. \quad (27)$$

where $I_0 = \dfrac{V_0}{Z_0}$.

4.2.3. *Recurrence Formula for I_{Wn}*

The equivalent circuit for calculating I_{Sn} is shown in Fig. 8(c). As in Section 3.1.3, the following equation is obtained:

$$-L\frac{dI_{Sn}}{dt} - Z_0 I_{Sn} - 2(-Z_0)I_{Rn-1} = 0 \quad (28)$$

Since $I_{R1} = -I_{W1}$, this equation can be used to solve for I_{S2} and I_{W2}. It is found that

$$I_{W2} = +I_0\left[1 - e^{-Z_0t/L}\left\{1 + \frac{2Z_0t}{L}\right\}\right] .. \quad (29)$$

The general equation for I_{Wn} is of the form

$$I_{Wn} = (-1)^n I_0 [1 - e^{-Z_0t/L}\{P_n\}] \quad .. \quad (30)$$

where P_n is a polynomial in $\{Z_0t/L\}$.

Equ. (28) can be used to obtain a recurrence formula for P_n, by expressing the dependent variables in terms of I_{Wn} and I_{Wn-1}, while changing the independent variable from t to $\{Z_0t/L\}$. The result obtained is

$$P_n = \text{constant} - P_{n-1} + 2\int P_{n-1}$$

By comparing P_1 and P_2 obtained from Equs. (27) and (29) the constant is evaluated as 2.

Hence the required recurrence relation is

$$P_n = 2 - P_{n-1} + 2\int P_{n-1} \; .. \quad .. \quad (31)$$

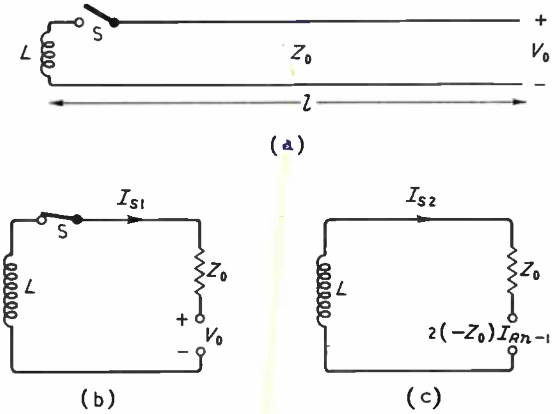
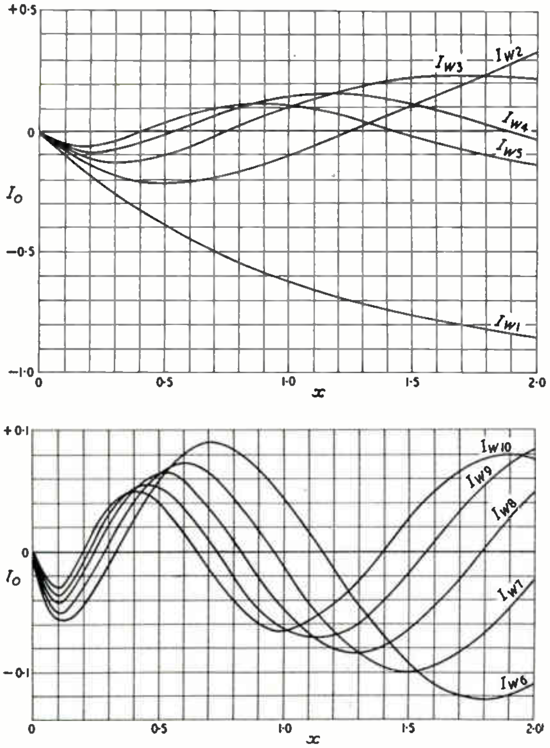


Fig. 8. *Line with stored energy and terminated by an inductance (a) and its equivalent circuits (b) and (c).*

4.2.4. *Summary of Results*

By the use of Equ. (31) successive expressions for I_{Wn} can be built up rapidly. The equations up to I_{W10} are tabulated in Table 3 where x is written for Z_0t/L. These equations have been evaluated in the range of x from 0 to 2 and the results are tabulated in Table 4; these figures have also been plotted as the curves of Figs. 9 and 10.



Figs. 9 (above) *and* 10 (below). *Curves plotted from the figures of Table 3, showing the waveforms in a line having stored energy and terminated by an inductance, as in Fig. 8.*

It is interesting to note that the end case $L = 0$ corresponds to the application of a short-circuit to the line. In this case I_{Wn} reduces to $(-1)^n I_0$.

4.2.5. *Example*

As an example of the application of the results obtained, suppose it is required to calculate the voltage waveform at the open-circuit termination of the line for the following case:—

$V_0 = 200$ volts.

Other data as in Section 3.1.5.

The voltage–time waveform obtained is plotted in Fig. 11, showing the first cycle of an undamped periodic curve approximating to a cosine wave.

Again following Section 3.1.5, if the line is replaced by a lumped capacitance of 0·01 μF initially charged to 200 volts, the voltage waveform across the capacitor is the cosine curve shown in Fig. 11.

4.3. *Analysis of Circuit B*

4.3.1. *Initial Procedure*

The circuit to be analysed is shown as Fig. 12(a); at time zero the external circuit driving a steady current I_0 through the transmission line is interrupted by opening the switch S.

The short-circuit termination at the right-hand end of the line permits the application of Equ. (18) (Section 3.2.1) to this problem.

For the purpose of applying Thévenin's theorem to the line as a source of energy it is necessary to determine the voltage developed at the left-hand end of the line under these conditions if the termination there is an open-circuit. It is clear that at time zero, the current I_0 at this termination must in this case fall instantly to zero; this necessitates a progressive current wave as a negative step function $-I_0$ with an associated voltage step of $-V_0$. The equivalent circuit for the line is thus a generator of open-circuit voltage $-V_0$ and internal impedance Z_0 ohms. For the

TABLE 3

$$I_{W1} = -I_0(1 - e^{-x})$$

$$I_{W2} = +I_0[1 - e^{-x}(1 + 2x)]$$

$$I_{W3} = -I_0[1 - e^{-x}(1 + 2x^2)]$$

$$I_{W4} = +I_0\left[1 - e^{-x}\left(1 + 2x - 2x^2 + \frac{4}{3}x^3\right)\right]$$

$$I_{W5} = -I_0\left[1 - e^{-x}\left(1 + 4x^2 - \frac{8}{3}x^3 + \frac{2}{3}x^4\right)\right]$$

$$I_{W6} = +I_0\left[1 - e^{-x}\left(1 + 2x - 4x^2 + \frac{16}{3}x^3 - \frac{6}{3}x^4 + \frac{4}{15}x^5\right)\right]$$

$$I_{W7} = -I_0\left[1 - e^{-x}\left(1 + 6x^2 - \frac{24}{3}x^3 + \frac{14}{3}x^4 - \frac{16}{15}x^5 + \frac{4}{45}x^6\right)\right]$$

$$I_{W8} = +I_0\left[1 - e^{-x}\left(1 + 2x - 6x^2 + \frac{36}{3}x^3 - \frac{26}{3}x^4 + \frac{44}{15}x^5 - \frac{20}{45}x^6 + \frac{8}{315}x^7\right)\right]$$

$$I_{W9} = -I_0\left[1 - e^{-x}\left(1 + 8x^2 - \frac{48}{3}x^3 + \frac{44}{3}x^4 - \frac{96}{15}x^5 + \frac{64}{45}x^6 - \frac{48}{315}x^7 + \frac{2}{315}x^8\right)\right]$$

$$I_{W10} = +I_0\left[1 - e^{-x}\left(1 + 2x - 8x^2 + \frac{64}{3}x^3 - \frac{68}{3}x^4 + \frac{184}{15}x^5 - \frac{160}{45}x^6 + \frac{176}{315}x^7 - \frac{14}{315}x^8 + \frac{4}{2835}x^9\right)\right]$$

calculation of I_{S2} and subsequent waves the procedure of Section 3.2.3 is followed.

4.3.2. *Calculation of I_{W1}*

The circuit used for calculating I_{S1} is given in Fig. 12(b); the equation obtained is

$$-\frac{1}{C}\int_0^t I_{S1}\,dt - Z_0 I_{S1} - (-V_0) = 0 \qquad (32)$$

The complete solution of this is

$$I_{S1} = I_0 e^{-t/CZ_0} \quad .. \quad .. \quad .. \quad (33)$$

But, by Kirchhoff's law,

$$I_{S1} = I_0 + I_{W1} \quad .. \quad .. \quad .. \quad (34)$$

Therefore $I_{W1} = -I_0\,[1 - e^{-t/CZ_0}]$ .. (35)

4.3.3. *Recurrence Formula for I_{Wn}*

Fig. 12(c) shows the circuit used for calculating I_{Sn}; as in Section 3.2.3, the following equation is obtained:

$$-\frac{1}{C}\int_0^t I_{Sn}\,.\,dt - Z_0\,.\,I_{Sn} - 2(-Z_0)\,.\,I_{Rn-1} = 0 \quad .. \quad .. \quad (36)$$

Since $I_{R1} = I_{W1}$, Equ. (36) can be used to calculate I_{S2} and hence I_{W2}. The result is

$$I_{W2} = +I_0\left[1 - e^{-t/CZ_0}\left\{1 + \frac{2t}{CZ_0}\right\}\right] \quad .. \quad (37)$$

and in general $I_{Wn} = (-1)^n I_0 [1 - e^{-t/CZ_0}\{P_n\}]$ .. .. (38)

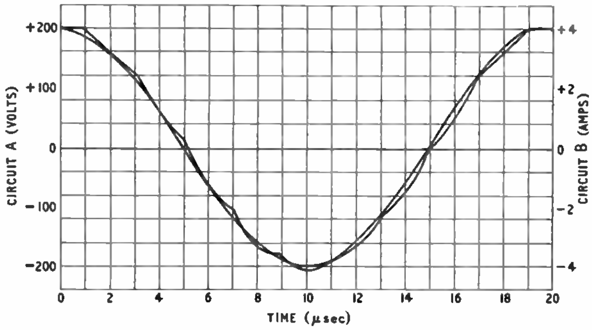


Fig. 11. *Current and voltage in a line with stored energy for particular conditions.*

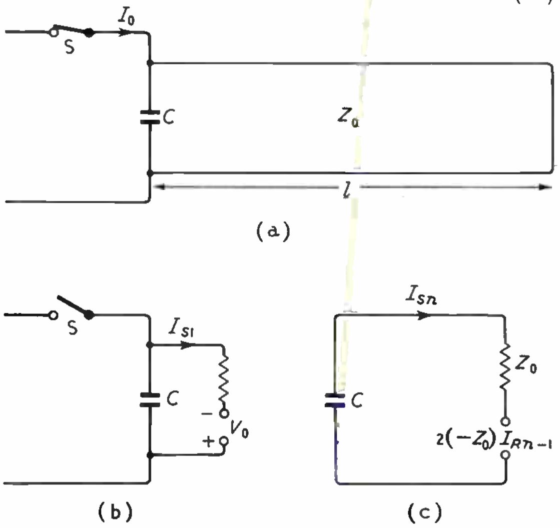


Fig. 12. *Line with stored energy connected to a capacitor (a) and equivalent circuits (b) and (c).*

To obtain the recurrence formula, Equ. (36) is transformed into

$$D\,\{I_{Wn} - I_{Wn-1}\} = -I_{Wn} - I_{Wn-1} \quad .. \quad (39)$$

Hence the recurrence relation is

$$P_n = 2 - P_{n-1} + 2\int P_{n-1} \quad .. \quad .. \quad (40)$$

4.3.4. *Summary of Results*

By comparison of these results with Section 4.2, it is clear that the equations of Table 3 also

TABLE 4

x	I_{W1}/I_0	I_{W2}/I_0	I_{W3}/I_0	I_{W4}/I_0	I_{W5}/I_0	I_{W6}/I_0	I_{W7}/I_0	I_{W8}/I_0	I_{W9}/I_0	I_{W10}/I_0
0	0	0	0	0	0	0	0	0	0	0
0·1	−0·0952	−0·0858	−0·0771	−0·0689	−0·0613	−0·0542	−0·0477	−0·0415	−0·0360	−0·0307
0·2	−0·1813	−0·1462	−0·1158	−0·0894	−0·0669	−0·0476	−0·0314	−0·0177	−0·0065	−0·0027
0·3	−0·2592	−0·1853	−0·1259	−0·0786	−0·0419	−0·0137	0·0069	0·0217	0·0314	0·0372
0·4	−0·3297	−0·2065	−0·1152	−0·0492	−0·0037	0·0261	0·0436	0·0519	0·0534	0·0502
0·5	−0·3935	−0·2130	−0·0903	−0·0108	0·0361	0·0599	0·0673	0·0640	0·0539	0·0405
0·6	−0·4512	−0·2074	−0·0561	0·0297	0·0704	0·0816	0·0746	0·0578	0·0368	0·0158
0·7	−0·5034	−0·1918	−0·0167	0·0677	0·0952	0·0893	0·0665	0·0376	0·0095	−0·0140
0·8	−0·5507	−0·1682	−0·0244	0·1002	0·1087	0·0840	0·0465	0·0097	−0·0204	−0·0405
0·9	−0·5934	−0·1385	0·0653	0·1250	0·1114	0·0676	0·0194	−0·0205	−0·0463	−0·0580
1·0	−0·6321	−0·1037	0·1037	0·1416	0·1037	0·0435	−0·0108	−0·0476	−0·0645	−0·0645
1·1	−0·6671	−0·0653	0·1385	0·1496	0·0875	0·0146	−0·0399	−0·0684	−0·0724	−0·0593
1·2	−0·6988	−0·0241	0·1687	0·1494	0·0646	−0·0158	−0·0651	−0·0806	−0·0700	−0·0443
1·3	−0·7275	0·0190	0·1936	0·1418	0·0370	−0·0451	−0·0841	−0·0837	−0·0589	−0·0240
1·4	−0·7534	0·0629	0·2133	0·1274	0·0070	−0·0716	−0·0955	−0·0780	−0·0395	0·0021
1·5	−0·7769	0·1076	0·2271	0·1076	−0·0239	−0·0932	−0·0992	−0·0645	−0·0163	0·0269
1·6	−0·7981	0·1530	0·2356	0·0831	−0·0538	−0·1094	−0·0956	−0·0468	0·0085	0·0489
1·7	−0·8173	0·1961	0·2387	0·0553	−0·0816	−0·1190	−0·0841	−0·0221	0·0337	0·0651
1·8	−0·8347	0·2396	0·2364	0·0254	−0·1063	−0·1220	−0·0676	0·0032	0·0553	0·0754
1·9	−0·8504	0·2819	0·2297	−0·0061	−0·1267	−0·1190	−0·0464	0·0283	0·0732	0·0803
2·0	−0·8647	0·3235	0·2177	−0·0373	−0·1431	−0·1095	−0·0228	0·0520	0·0837	0·0746

hold for circuit B, provided x is taken to represent t/CZ_0. It follows that the results given in Table 4 and in Figs. 9 and 10 also apply.

It can be noted in passing that for the end case $C = 0$, the formula for I_{Wn} reduces simply to

$$I_{Wn} = (-1)^n I_0 \quad .. \quad .. \quad .. \quad (41)$$

4.3.5. *Example*

To demonstrate the similarity of behaviour of the two circuits, suppose it is required to calculate the current–time curve for the short-circuit termination in the following case:—

$I_0 = 4$ amps.

Other data as in Section 3.2.5.

The waveform of Fig. 11 is the solution obtained, provided that the ordinate scale is changed as indicated. The cosine curve in Fig. 11 then shows the waveform obtained in a 50-μH inductance if this is used to replace the line in the above problem.

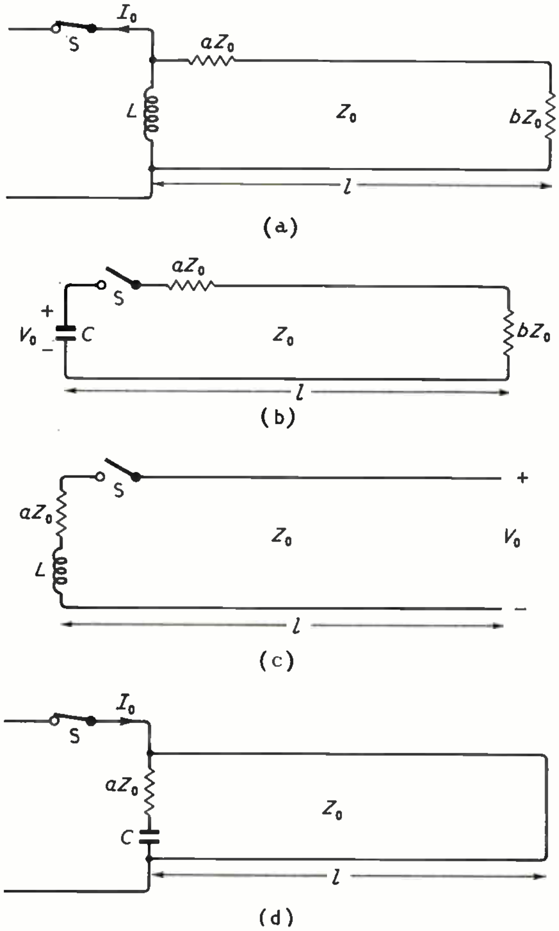


Fig. 13. *Conditions for circuit losses. At (a) and (b) resistance is included both in the line and the remote terminations. In (c) and (d) resistance is added in series with the reactive termination.*

4.4. *Comparison of Case I and Case II*

Since the only difference between Case I and Case II is the method of initial storage of energy it is to be expected that the circuit waveforms obtained will bear some close relationship to each other.

If the equations of Tables 1 and 3 are examined, it will be found that

$$\underset{\text{Case I}}{[-I_0 + I_{W1}]} = \underset{\text{Case II}}{[I_{W1}]} \quad .. \quad (42)$$

Also $$\underset{\text{Case I}}{[I_{Wn} - I_{Wn-1}]} = \underset{\text{Case II}}{[I_{Wn} + I_{Wn-1}]} \quad (43)$$

It follows that the two sets of equations are rigidly interrelated.

5. Effect of Additional Circuit Components

5.1. *Introduction*

In this section the effect of the introduction of certain modifications to the circuits previously analysed will be considered. The method of analysis used is the same as that employed in previous sections; for this reason the examples chosen will not be analysed in detail, but the results obtained will be discussed briefly.

5.2. *Effect of Power Dissipation*

5.2.1. *Effect of Losses in the Line*

Losses in transmission lines have been considered in Section 2.5. It should be stressed that line losses will produce a cumulative attenuation of progressive waves as the number of reflections increases, even though the waves be regarded as mathematical fictions.

5.2.2. *Line Terminating in a Resistance*

If the transmission line terminates in a resistance bZ_0 ohms, the conditions there can be solved as usual by the application of Thévenin's theorem. The result is

$$I_{Rn} = \left\{\frac{1-b}{1+b}\right\} I_{Wn} \quad .. \quad .. \quad (44)$$

and $$I_{Tn} = \left\{\frac{2}{1+b}\right\} I_{Wn} \quad .. \quad .. \quad (45)$$

The fraction $\frac{1-b}{1+b}$ is termed the reflection factor and it will be realized that even though it may be nearly unity, the cumulative effect is such that waveforms of high order are considerably reduced in magnitude. This cumulative effect can be seen in the formulae given in Section 5.2.3 and by the example in Section 5.2.4.

5.2.3. *Effect of Circuit Losses on Previous Calculations*

The formulae obtained in Sections 3 and 4 need to be modified if resistances are included in the line terminations. The circuits considered are redrawn in Fig. 13 to include a resistance aZ_0 in series with the left-hand termination in every case, and a resistance bZ_0 in series with the right-hand termination for the first two cases. Analysis of these circuits give the results outlined in Table 5.

It will be seen that the presence of the termination bZ_0 only influences the amplitudes of successive waves. The inclusion of aZ_0 influences wave shape as well as amplitude, since the factor a appears in the recurrence formulae. It will be noticed that in the last two cases the integration constant in the recurrence formulae is a function of n.

Free oscillations for Case II operation with purely resistive terminations are an end case of these results; i.e., by taking $L = 0$ for circuit A and $C = \infty$ for circuit B.

5.2.4. *Example*

As an illustration of the effect of circuit losses, consider the circuit of Fig. 13(a) having the following parameters:—

$a = 0$
$b = 10$

Other details as in Section 3.1.5.

By the application of Thévenin's theorem to the right-hand termination it follows that:

$$V_{Tn} = \frac{2b}{1+b} Z_0 \,.\, I_{Wn} \qquad \ldots \qquad \ldots \qquad (46)$$

The voltage–time waveform at this termination is shown in Fig. 14 in which the sinusoid of Fig. 6 is repeated for comparison. It will be seen that the waveform approximates to a damped sine wave.

If, in Fig. 13(b)

$a = 0$
$b = 1/10$

and other details are as in Section 3.2.5, then the waveform of Fig. 14 also represents the current-time curve in the right-hand termination.

The cumulative effect of the reflection factor

TABLE 5

	CASE I	
	Circuit A	Circuit B
Circuit diagram	Fig. 13 (a)	Fig. 13 (b)
General equation	$I_{W_n} = I_0\left\{\frac{b-1}{(a+1)(b+1)}\right\}^{n-1} . \, e^{-x}P_n$	$I_{W_n} = \frac{I_0}{(1+a)}\left\{\frac{1-b}{(1+a)(1-b)}\right\}^{n-1} . \, e^{-x}P_n$
P_1	1	1
Recurrence formula	$P_n = (1+a)P_{n-1} - 2\int P_{n-1}$	$P_n = (1-a)P_{n-1} - 2\int P_{n-1}$
X	$\frac{Z_0(1+a)t}{L}$	$\frac{t}{CZ_0(1+a)}$
	CASE II	
	Circuit A	Circuit B
Circuit diagram	Fig. 13 (c)	Fig. 13 (d)
General equation	$I_{W_n} = (-1)^n \frac{I_0}{(1+a)^n}\left[(1-a)^{n-1} - e^{-x}P_n\right]$	$I_{W_n} = (-1)^n \frac{I_0}{(1+a)^n}\left[(1+a)^n - e^{-x}P_n\right]$
P_1	1	1
Recurrence formula	$P_n = 2(1-a)^{n-2} - (1+a)P_{n-1} + 2\int P_{n-1}$	$P_n = 2(1+a)^{n-1} - (1-a)P_{n-1} + 2\int P_{n-1}$
X	$\frac{Z_0(1+a)t}{L}$	$\frac{t}{CZ_0(1+a)}$

in reducing the amplitudes of successive waves can be clearly seen.

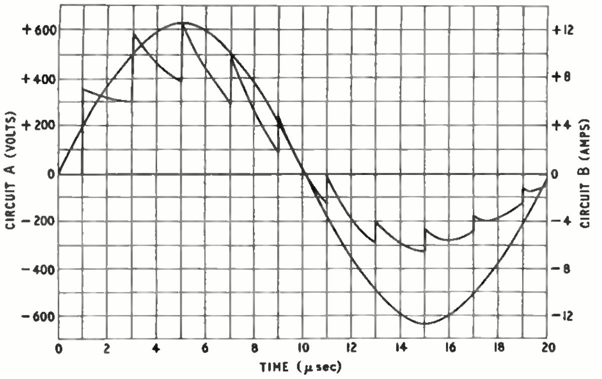


Fig. 14. *Current and voltages for the conditions of Fig.* 13(*a*).

5.3. *Presence of Both Inductance and Capacitance*

When both inductance and capacitance are present, either in the same or in opposite terminations, analysis of the circuit leads to complicated results. Instead of only one 'time constant' being involved as before, two now occur, and no simple recurrence relation can be found. With complex terminations (i.e., terminations involving one or more capacitor, inductance and resistance) second- or higher-order differential equations have to be solved to determine waveforms on reflection. The expressions obtained rapidly become unwieldy and the problem is perhaps best treated by purely numerical methods.

6. Conclusion

The method of analysis outlined is suitable for the calculation of waveforms in distributed circuits and is useful for determining the effect of measuring circuits and cables on waveforms which are to be recorded. The method can be applied to the calculation of free oscillations in cable systems, as in the paper, but except for certain simple cases the results of such an analysis are unwieldy.

NYQUIST'S STABILITY CRITERION

Proof using Laplace Transform Calculus

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SUMMARY.—In this paper the Nyquist Criterion of Stability is derived using the methods of the Laplace Transform Calculus.

The proof is divided into four parts:—(1) The necessary and sufficient condition for a stable response of a linear lumped-constant network to a step function input is obtained in terms of restrictions on the positions of the poles of the network transfer function in the S plane. (2) The above restrictions are interpreted in terms of the poles and zeros of the transfer functions of the forward and feedback sections of a single-loop feedback system. (3) The relation between the open-loop frequency response, of the feedback system and the restrictions necessary and sufficient for stability is derived. (4) Finally, the stability of response to a step-function input is shown to be a sufficient condition for the stability of response to any bounded input.

A brief discussion of the assumptions upon which the proof is founded is given.

In the conclusions it is shown that non-zero initial conditions do not modify the criterion and a method of applying the criterion to multiloop feedback systems is given.

Introduction

THE Nyquist criterion of stability is fundamental to the theory of linear feedback systems. Attempts to determine a criterion of stability from steady-state arguments produce results which are not always in agreement with experiment, owing to the fact that such an analysis neglects to investigate the stability of an oscillation. Although the analysis contained in Nyquist's proof of the theorem[1] is a complete discussion of the problem of stability, the mathematical presentation tends to obscure the main argument. Other attempts[2,3,4,5,6] to derive the criterion have either sacrificed generality in favour of simplicity or adopted a steady-state approach.

The proof which is presented in this paper employs a branch of mathematics, the Laplace Transform Calculus, which was little known when Nyquist published his paper. The use of this calculus enables the criterion to be derived in a more direct manner than previously. The elegance of the method rests upon the fact that the criterion of stability of response of a system may be deduced for a comparatively simple input, namely, a unit step function, the criterion being then given complete generality by the proof that the stability of response to unit step function is a sufficient condition for the stability of response to any bounded input.

MS accepted by the Editor, May 1956

1. Condition of Stability in Terms of Poles of Network Transfer Function

Consider a linear lumped-constant network whose transfer function will be denoted by $F(s)$

$$X(s) = \int_0^\infty \text{exp.}\,(-st)x(t)dt \text{ and is written } \mathcal{L}\{x(t)\}$$

$$Y(s) = \int_0^\infty \text{exp.}\,(-st)y(t)dt \text{ and is written } \mathcal{L}\{y(t)\}$$

$F(s)$ is defined by Equ. (1).

$$X(s)F(s) = Y(s) \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

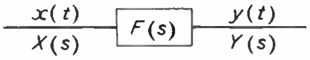

Fig. 1. *Linear lumped-constant network.*

Simple network theory shows[7] that any linear, lumped-constant network, containing active and passive elements, has a transfer function which is a rational function of s.

Accordingly we will write

$$F(s) = \frac{\prod_{\phi=1}^{n}(s - z_\phi)^\beta}{\prod_{\lambda=1}^{m}(s - p_\lambda)^\alpha} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where $\alpha = r_\lambda$ the order of the pole of $F(s)$ at $s = p_\lambda$ and $\beta = r_\phi$ the order of the zero of $F(s)$ at $s = z_\phi$. It follows that the degree of the numerator of $F(s)$ is $\sum_{\phi=1}^{n} r_\phi$ and that of the denominator of $F(s)$ is $\sum_{\lambda=1}^{m} r_\lambda$.

Fig. 2. *Unit-step function.*

Let us consider the response $\{\mathcal{L}^{-1}[Y(s)]\}$ of the network to an input $X(s) = 1/s$; that is, to a unit step applied at $t = 0$ (Fig. 2).

From Equs. (1) and (2)

$$Y(s) = \frac{1}{s}\,\frac{K\prod_{\phi=1}^{n}(s - z_\phi)^\beta}{\prod_{\lambda=1}^{m}(s - p_\lambda)^\alpha} \quad \ldots \quad \ldots \quad (3)$$

In order to evaluate $\mathcal{L}^{-1}\{Y(s)\}$ we will expand $Y(s)$ in partial fractions.

Now the partial fraction expansion of $\dfrac{1}{(s - p_\lambda)^\alpha}$ is given by

$$\frac{1}{(s - p_\lambda)^\alpha} = \sum_{k=1}^{\alpha} \frac{a_k}{(s - p_\lambda)^k}$$

Hence the complete partial fraction expansion of $Y(s)$ may be written as

$$Y(s) = \frac{a_0}{s} + \sum_{\lambda=1}^{m}\sum_{k=1}^{\alpha} \frac{a_{\upsilon\lambda}}{(s - p_\lambda)^\upsilon} \quad \ldots \quad (4)$$

Where $\nu = k$ if $p_\lambda \neq 0$
$\nu = k + 1$ if $p_\lambda = 0$

On inverting $Y(s)$ we obtain

$$y(t) = \mathcal{L}^{-1}\{Y(s)\} = a_0 + \sum_{\lambda=1}^{m}\sum_{k=1}^{\alpha} \frac{a_{\upsilon\lambda.}\, t^{\upsilon-1}\,\text{exp.}\,(p_\lambda t)}{(\nu - 1)!} \quad \ldots \quad \ldots \quad (5)$$

The response $y(t)$ to the step input is defined to be stable if

$$\sum_{\lambda=1}^{m}\sum_{k=1}^{\alpha} \frac{a_{\upsilon\lambda.}\, t^{\upsilon-1}\,\text{exp.}\,(p_\lambda t)}{(\nu - 1)!} \to 0 \text{ as } t \to \infty$$

This means that any transient generated within the network, by the application of the step-function input, tends to zero as $t \to \infty$.

Thus for a stable response, $\{y(t)\}$, the necessary and sufficient condition is that every term in the series

$$\sum_{\lambda=1}^{m}\sum_{k=1}^{\alpha} \frac{a_{\upsilon\lambda.}\, t^{\upsilon-1}\,\text{exp.}\,(p_\lambda t)}{(\nu - 1)!} \text{ tends to zero as } t \to \infty.$$

Now any term of the form t^μ exp. $(\rho t) \to 0$ as $t \to \infty$ if and only if Re.$(\rho) < 0$ for $\mu \geqslant 0$.

Thus the necessary and sufficient condition for a stable response, $\{y(t)\}$, to a step-function input is

$\text{Re.}\,(p_\lambda) < 0$
$\lambda = 1, 2, 3, \ldots .m.$

It is shown, in the Appendix that if $y(t)$ is stable for a step-function input it is also stable for any bounded input.

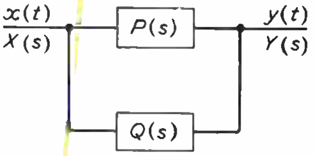

Fig. 3. *Single-loop feedback network.*

2. A Feedback Network

Consider now the feedback network shown in Fig. 3.

Let $P(s)$ and $Q(s)$ be rational functions of s then

$$\{X(s) - Q(s)\,Y(s)\}\,P(s) = Y(s)$$

hence

$$\frac{Y(s)}{X(s)} = \frac{P(s)}{1 + P(s)Q(s)} \quad \ldots \quad \ldots \quad (6)$$

By the previous discussion $y(t)$ is stable for $X(s) = 1/s$ if and only if $\dfrac{P(s)}{1 + P(s)Q(s)}$ has no poles with non-negative real parts.

Poles of $\dfrac{P(s)}{1 + P(s)Q(s)}$ occur when

(1) $1 + P(s)Q(s) = 0$.

This condition may be satisfied with

(a) $P(s)$ and $Q(s)$ both finite,

(b) $P(s)$ a pole of order ψ and $Q(s)$ a zero of order ψ,

(c) $P(s)$ a zero of order γ and $Q(s)$ a pole of order γ, if the resulting order of the zero of $\{1 + P(s)Q(s)\}$ is greater than γ.

(2) $P(s)$ has a pole, if

(a) $\{1 + P(s)Q(s)\}$ finite at the s for which $P(s)$ has a pole,

(b) $P(s)Q(s)$ has a pole of smaller order than the pole of $P(s)$. This can occur if, and only if, $Q(s)$ has at least a simple zero at the s for which $P(s)$ has a pole.

If $P(s)$ and $Q(s)$ have no zeros for finite s in the positive half s-plane, then the necessary and sufficient condition for a pole of $\dfrac{P(s)}{1 + P(s)Q(s)}$ is that $\{1 + P(s)Q(s)\} = 0$ with $P(s)$ and $Q(s)$ both finite.

Let us denote $P(s)Q(s)$ by $G(s)$.

3. Geometrical Interpretation

In order to determine the nature of the zeros of $\{1 + G(s)\}$, consider the following theorem[8].

If $f(z)$ is a function of the complex variable $z = x + jy$ and is meromorphic inside a closed contour C, and is not zero or infinity at any point on the contour, then

$$\frac{1}{2\pi j}\int_C \frac{f'(z)dz}{f(z)} = N - P \qquad \ldots \quad \ldots \qquad (7)$$

where

N = Number of zeros of $f(z)$ within C

P = Number of poles of $f(z)$ within C

A $\begin{Bmatrix}\text{zero}\\ \text{pole}\end{Bmatrix}$ of order r being counted as $r\begin{Bmatrix}\text{zeros}\\ \text{poles}\end{Bmatrix}$.

The contour C is traced in an anti-clockwise direction.

If we let $f(z) = W$, Equ. (7) becomes

$$\frac{1}{2\pi j}\int_\Gamma \frac{dW}{W} = N - P \qquad \ldots \quad \ldots \qquad (8)$$

Where the contour C in the z-plane is mapped into the contour Γ in the W-plane by the transformation $W = f(z)$.

W may be written $W = R \exp.(j\theta)$

Substituting this in Equ. (8) we obtain

$$\frac{1}{2\pi}\int_\Gamma d\theta = N - P \qquad \ldots \quad \ldots \qquad (9)$$

$f(z)$ being a continuous function of $(x + jy)$

$$\int_\Gamma d\theta = 2\pi(N - P)$$

= the change in argument of $f(z)$ as the contour C is traced once in the counter-clockwise direction.

This means that the vector $f(z)$ makes $(N - P)$ counter-clockwise revolutions about the origin, as the contour C is traced once in the counter-clockwise direction.

Consider the semi-circular contour ζ in the s-plane as shown in Fig. 4.

The radius R is chosen so that ζ encloses all the poles and zeros of $\{1 + G(s)\}$ in the positive half of the s-plane. Since $\{1 + G(s)\}$ is a rational function of s, $\{1 + G(s)\}$ has a finite number of poles and zeros and a contour can be chosen to enclose all poles and zeros in the positive half s-plane.

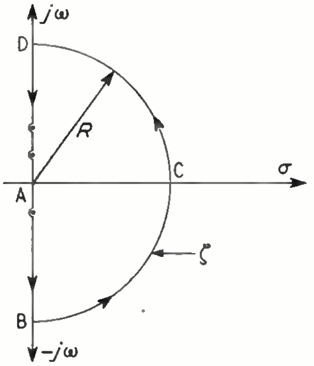

Fig. 4. *Contour enclosing all poles and zeros of* $[1 + G(s)]$ *in the positive half s-plane.*

If $\{1 + G(s)\}$ has poles and zeros on the imaginary axis the contour, ζ, must be indented into the negative half s-plane in order to enclose such poles and zeros. (Fig. 4.)

By the theorem stated above, it follows that the vector $\{1 + G(s)\}$ makes $(N - P)$ counter-clockwise revolutions about the origin as s makes one counter-clockwise revolution around ζ.

Where N = Number of zeros of $\{1 + G(s)\}$ in the positive half s-plane.

P = Number of poles of $\{1 + G(s)\}$ in the positive half s-plane.

Rotation of $\{1 + G(s)\}$ about the origin is equivalent to the rotation of $G(s)$ about the point $(-1, 0)$ in the same sense.

4. Examination for Stability

The stability of a feedback network may be examined as follows:—

(1) The open-loop transfer function of the network is plotted for ω in the range $\omega = 0$ to ∞; i.e., the locus of the vector $P(j\omega)Q(j\omega)$ is obtained for $\omega = 0$ to ∞.

(2) By taking the mirror image of this locus in the real axis, the locus for ω in the range $\omega = 0$ to $-\infty$ is obtained.

(3) In order to determine the locus of $P(s)Q(s)$ on the portion BCD of the contour ζ, Fig. 4, the form of $P(s)Q(s)$ as $s \to \infty$ is examined. Since $P(s)$ and $Q(s)$ are rational functions of s, $P(s)Q(s)$ may be expressed as the ratio of two polynomials in s. If the degree of the numerator of $P(s)Q(s)$ is n and the degree of its denominator is d then as $s \to \infty$

$$P(s)Q(s) \rightarrow \begin{cases} 0 \text{ if } d > n \\ \infty \text{ if } n > d \\ K \text{ if } n = d \; K \text{ being a constant.} \end{cases}$$

If $n > d$ the locus of $P(s)Q(s)$, when s is on the portion BCD of the contour, ζ degenerates to a point.

If $n < d$, the locus of $P(s)Q(s)$, when s is on the portion BCD of the contour, ζ is given by KR^{n-d} exp. $\{(n - d)j\theta\}$ since $s = R.\exp.(j\theta)$; $-\pi/2 \leqslant \theta \leqslant \pi/2$ on the portion BCD of the contour ζ.

Thus the locus of $P(s)Q(s)$, makes $\frac{n-d}{2}$ counter-clockwise revolutions about the origin as the portion BCD of the contour ζ is traversed.

The necessary and sufficient condition for the stability of $y(t)$ is that the vector, $\{P(s)Q(s)\}$, make P revolutions around $(-1, 0)$ in the positive sense as the contour ζ is traversed once in the negative sense.

5. Discussion

In this section, the assumptions which have been made in the analysis will be considered in more detail.

(1) In order to examine a system for stability using the method described in the paper, it is necessary that both $P(s)$ and $Q(s)$ have no zeros in the finite part of the positive half s-plane. This means that there is no finite frequency at which either $P(j\omega)$ or $Q(j\omega)$ produce infinite attenuation. In any practical system this condition is always satisfied.

(2) The statement that a contour ζ can be chosen to enclose all the poles and zeros of $\{1 + G(s)\}$ in the positive half s-plane requires that $\{1 + G(s)\}$ shall have no poles or zeros at $|s| = \infty$.

(a) Poles of $\{1 + G(s)\}$ at $|s| = \infty$

If $\{1 + G(s)\}$ has a pole at $s = s_0$ then $G(s)$ has a pole at $s = s_0$.

$G(s)$ is defined by the equation $G(s)\,X(s) = Y(s)$ where $X(s) = \mathcal{L}\{\text{Input to Network}\} = \mathcal{L}\{x(t)\}$ and $Y(s) = \mathcal{L}\{\text{Output of Network}\} = \{\mathcal{L}\,y(t)\}$.

In order that $Y(s)$ exist,

i.e. that $\int_0^\infty \exp.(-st)y(t)dt$ converges, it is necessary and sufficient that

$$\frac{G(s)}{s} \rightarrow 0 \text{ as } |s| \rightarrow \infty$$

$$\therefore G(s) \rightarrow \text{Constant, or Zero as } |s| \rightarrow \infty$$

since $G(s)$ is a rational function of s.

Thus $G(s)$ and therefore $\{1 + G(s)\}$ has not a pole at infinity. Similarly $P(s)$ and $Q(s)$ have not poles at infinity.

(b) Zeros of $\{1 + G(s)\}$ at $|s| = \infty$

If $G(s) \rightarrow 0$ as $s \rightarrow \infty$ then $\{1 + G(s)\} \rightarrow 1$.

If $G(s) \rightarrow -1$ as $s \rightarrow \infty$ then $\{1 + G(s)\} \rightarrow 0$; that is, $\{1 + G(s)\}$ has a zero at infinity.

If $\{1 + G(s)\}$ has a zero at infinity then $\left\{\frac{P(s)}{1 + G(s)}\right\}$ (i.e., the transfer function of the feedback network) has a pole at infinity.

Since $\left\{\frac{P(s)}{1 + G(s)}\right\}$ is a rational function of s it follows from (a) that $\left\{\frac{P(s)}{1 + G(s)}\right\}$ cannot have a pole at infinity.

Hence $\{1 + G(s)\}$ cannot have a zero at infinity.

Thus a contour, ζ, may be drawn to enclose all the poles and zeros of $\{1 + G(s)\}$ in the positive half s-plane.

The transfer function of any practical network falls to zero as frequency tends to infinity. Thus $\{1 + G(s)\} \rightarrow 1$ as $|s| \rightarrow \infty$ and therefore $\frac{G(s)}{s} \rightarrow 0$ as $s \rightarrow \infty$. Thus, in any practical network, $Y(s)$ exists.

6. Conclusions

(1) *Non-Zero Initial Conditions*

The analysis in this paper has assumed initial conditions of the network to be zero. That the existence of non-zero initial conditions does not modify the criterion of stability may be seen from the following argument:—

It is shown (in Appendix) that, with zero initial conditions, a network which has a stable response to a step-function input has a stable response for any bounded input. Consider such a network. At $t = 0$ let a bounded input be applied to the network, initial conditions being zero; the form of this input being such that after a time t_0 the conditions in the network constitute a desired set of initial conditions. At the instant t_0 let the bounded input be reduced to zero and a second bounded input applied. The input to the system from $t = 0$ to $t \rightarrow \infty$ is a bounded input. Thus the response is stable, by definition. Hence the response between $t = t_0$ and ∞ is stable.

(2) *Multiloop Feedback Networks*

In deriving the criterion, it has been assumed that the networks $P(s)$ and $Q(s)$ were not themselves feedback networks. However, the criterion can still be applied when either or both of the networks are feedback networks.

For example:—

Suppose $P(s)$ is an unstable feedback network, and $Q(s)$ is a non-feedback network. Let us examine the stability of the feedback network shown in Fig. 5. Let $P(s)$ be represented by the feedback network shown in Fig. 6.

$$P(s) = \frac{l(s)}{1 + l(s)m(s)}$$

The transfer function of the feedback network shown in Fig. 5 is:—

$$\frac{P(s)}{1 + P(s)Q(s)} = \frac{l(s)}{1 + l(s)\{Q(s) + m(s)\}}$$

Thus, in order to examine this network for stability, the locus of $l(s)\{Q(s) + m(s)\}$ is obtained in the normal way.

More complicated feedback systems may be broken down and examined for stability in a similar manner.

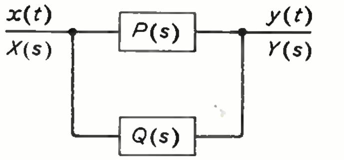

Fig. 5. *Unstable feedback network P(s) stabilized by auxiliary loop.*

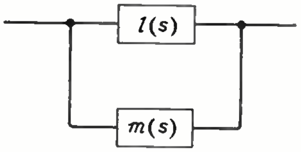

Fig. 6. *Feedback network P(s).*

Acknowledgments

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APPENDIX

System Stability for any Bounded Input

Theorem

If $F(t)$ and $G(t)$ have absolutely convergent Laplace transforms $f(s)$ and $g(s)$ respectively, then $f(s)g(s)$ is the Laplace transform of the function:—

$$\int_0^t F(\tau)G(t-\tau)d\tau \text{ or } \int_0^t F(t-\tau)G(\tau)d\tau.$$

It has been shown that the response $y(t)$ of a system to a step-function input is stable if the transfer function $F(s)$ of the system has no poles with non-negative real parts. We require to prove that this condition is sufficient for the stability of response to any bounded input.

Proof

Let $F(s)$ be the transfer function of the system

Then $Y(s) = F(s)X(s)$

where $Y(s)$ and $X(s)$ are defined at the beginning of the paper.

The response to a unit step function input; $X(s) = 1/s$ is $h(s)$ given by

$$h(s) = 1/s \,.\, F(s).$$

$$\therefore F(s) = sh(s) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where $\mathcal{L}^{-1}\{h(s)\} = y(t)$

$y(t)$ being stable by definition and given by

$$y(t) = a_0 + \sum_{\lambda=1}^{m} \sum_{k=1}^{\alpha} \frac{a_{\upsilon\lambda}\, t^{\upsilon-1} \exp.\,(p_\lambda t)}{(\nu - 1)!}$$

where $\nu = k$ if $p_\lambda \neq 0$

$\nu = (k+1)$ if $p_\lambda = 0$

with Re. $(p_\lambda) < 0$

$\lambda = 1, 2, 3, \ldots. m.$

Now $Y(s) = F(s)X(s)$

$= sh(s)X(s)$ from 1

$\mathcal{L}^{-1}\{sh(s)X(s)\} = g(t)$

where $\mathcal{L}\{g(t)\} = Y(s)$.

$g(t)$ being therefore the response of the system to an arbitrary input $\mathcal{L}^{-1}\{X(s)\}$

$$\therefore g(t) = \frac{d}{dt}\left\{\mathcal{L}^{-1}[h(s)X(s)]\right\}$$

$$= \frac{d}{dt}\left\{\int_0^t y(t-\tau)x(\tau)d\tau\right\}$$

(by the theorem stated above)

$$= \int_0^t y'(t-\tau)x(\tau)d\tau + x(t)y(\tau)\}$$

where $y'(t-\tau) = \dfrac{d}{dt}\{y(t-\tau)\}$

Now

$y(t)$ and $x(t)$ are bounded functions of t (by definition).

Hence $g(t)$ is bounded if $\int_0^t y'(t-\tau)x(\tau)d\tau$ is bounded.

$$y(t) = a_0 + \sum_{\lambda=1}^{m} \sum_{k=1}^{\alpha} \frac{a_{\upsilon\lambda} t^{\upsilon-1} \exp.\,(p_\lambda t)}{(\nu - 1)!}$$

$$\therefore y'(t) = \sum_{\lambda=1}^{m} \sum_{k=1}^{\alpha} \frac{a_{\upsilon\lambda} t^{\upsilon-2} \exp.\,(p_\lambda t)\{p_\lambda t + (\nu - 1)\}}{(\nu - 1)!}$$

In order to show that $\int_0^t x(\tau)y'(t-\tau)d\tau$ is bounded we require to show that

$\int_0^t Ax(\tau)(t-\tau)^k \exp.\,\{p_\lambda(t-\tau)\}d\tau$ is bounded as $t \to \infty$

Consider the integrand:—

$$|x(\tau)(t-\tau)^k \exp.\,\{p_\lambda(t-\tau)\}| = |x(\tau)|\,|(t-\tau)^k \exp.\,\{\sigma_\lambda(t-\tau)\}|\,|\exp.\,\{j\omega_\lambda(t-\tau)\}|$$

but $|x(t-\tau)| \leqslant N$.

Since the input is bounded (by definition).

Thus $|x(\tau)|\,|(t-\tau)^k \exp.\,\{\sigma_\lambda(t-\tau)\}| \leqslant N|(t-\tau)^k \exp.\,\{\sigma_\lambda(t-\tau)\}|$.

Now $\left|\int U(\tau)d\tau\right| \leqslant \int \left|U(\tau)\right| d\tau.$

Thus $\left|\int_0^t Ax(t)(t-\tau)^k \exp.\,\{p_\lambda(t-\tau)\}d\tau\right| \leqslant \int_0^t NA|(t-\tau)^k \exp.\,\{\sigma_\lambda(t-\tau)\}|\,d\tau = N\left|A\right|\int_0^t (t-\tau)^k \exp.\,\{\sigma_\lambda(t-\tau)\}\,d\tau.$

Since the integrand is essentially positive.

But $\int_0^t (t-\tau)^k \exp.\,\{\sigma_\lambda\,(t-\tau)\}d\tau$ tends to a constant as $t \to \infty$ for all $\sigma_\lambda < 0$.

Since all σ_λ terms are negative (by definition) the theorem is established.

N-TERMINAL NETWORKS

Some Theorems with Applications to the Directive Properties of Aerial Arrays

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(Communication from the Staff of the Research Laboratories of The General Electric Company Limited, Wembley, England)

Introduction

PART I of the paper gives some basic theorems (required for Part II) which are generalizations of the corresponding theorems for 2-terminal networks. For this reason it is quite possible that they are not new, though the author is at a loss to give (Theorem 1 excepted) any reference for them.

Part II of the paper deals with certain applications of these theorems to aerial arrays which have been adjusted for maximum absorption of power from an incident wave. It is shown by reference to the Travelling Wave Theorem[2] for maximum directivity of such arrays, that one half of the energy extracted by such an array from the incident wave is re-radiated in the forward direction with the maximum directivity of which the array is capable.

If an aerial array has been adjusted so as to transfer the maximum amount of power from a wave into a single load, it will have maximum directivity for transmission in the reverse direction if we replace this load by a generator. By designing a feeder network whose action is especially simple to follow it can be seen that, in this case, the voltages supplied to the elements of the array are those required by the Travelling Wave Theorem. Thus the condition for maximum directivity of an aerial array can be proved by network considerations only.

1. Network Theorems

Theorem I

Every active n-terminal network of linear elements can be replaced—so far as the action on another linear network is concerned—by the inactive network with a voltage source in series with each terminal such that on open circuit the original network and the simulating network are indistinguishable.*

As has been pointed out on another occasion by the author[1] this theorem is really a special case of Helmholtz's Theorem of the Electromotive Surface and follows from the superposition theorem. Let us insert (Fig. 1) into each terminal lead of the original network a pair of voltage sources which mutually cancel (say, for the ith lead $-E_i$ and $+E_i$). Now, if we open-circuit the network at A′, B′, C′ . . . N′ we see certain open-circuit voltages (measured against some suitable reference point) of amount $E^{(o)}_1$ $E^{(o)}_2$, . . . $E^{(o)}_n$. If we choose $E_1 = +E^{(o)}_1$, . . . $E_n = +E^{(o)}_n$ it follows that $E^{(o)}_1 - E_1 = 0$ . . . $E^{(o)}_2 - E_2 = 0$, . . . and so on; i.e., if we remake the connections at A′ . . . N′ and now open-circuit at A . . . N we see a network with zero open-circuit voltages. But, as the voltage sources which we inserted are supposed to have zero internal impedance, all the impedances seen from the various terminals have remained unchanged. This means that, seen from these terminals, the network which we have obtained is indistinguishable from the inactive counterpart of the original network. Hence we are permitted to substitute this inactive network to the left of terminals A . . . N.

If we now remake the connections at A . . . N we arrive at the arrangement described in the theorem.

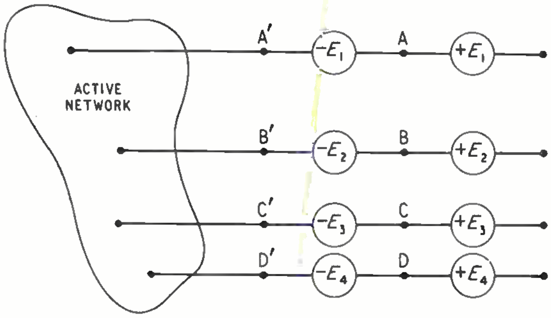

Fig. 1. *Helmholtz's make and break theorem for n-terminal network.*

Theorem II

Every active n-terminal network consisting of linear elements can be replaced—so far as the action on another linear network is concerned—by the inactive network, provided we place across the terminals a sufficient number of current generators such that on short circuit the original network and the simulating network are indistinguishable.

The proof of this theorem is similar to that of Theorem I. The system will be unaffected if we place across any pair of terminals a pair of current generators of equal magnitude and opposite sign

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* The active network is supposed to owe its activity to ideal voltage or current sources. The inactive network is obtained from the active network by replacing every voltage source contained therein by a short circuit and every current source by an open circuit.

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(in parallel to each other). We shall now apply a whole system of such current generator-pairs in the following way:

First, we inactivate the network from the point of view of the load by applying short-circuiting straps across a sufficient number of terminals. By doing this we reduce the voltages across any pair of relevant terminals to zero but, of course, we also destroy completely the impedance relations seen by the load across these terminals. However, if we now substitute for each of these short-circuiting straps a current generator carrying exactly the same current as was flowing in the short circuit, then we have still the same current distribution that led to the disappearance of the terminal voltages; but we have also—on account of the infinite impedance of these current generators—restored the original impedance relations. Let us call the set of current generators thus introduced the positive set. We parallel now each current generator by another one carrying exactly the same amount of current in the other direction. These current generators form the negative set. The application of the positive set made the active network as seen from the load indistinguishable from the inactive network; the application of the negative set restores the original activity and, indeed, if we now short-circuit the active network it is seen immediately that these current generators will supply currents of the correct amount and direction.

The two procedures—insertion of series voltage generators or parallel-current generators can be used in a suitable mixed fashion to convert the active network into an inactive network. The subsequent application of the corresponding set of cancelling generators will then lead to the appropriate equivalent circuit. The following should be noted:

(a) Corresponding to the choice of voltage-reference point different voltages will be required for these voltage sources.

(b) Different sets of straps can be applied for short circuiting, leading to different sets of current generators (e.g., in the case of a 3-terminal network we can apply short circuits either between terminals 1–2 and 2–3, or between 2–3 and 3–1)*.

(c) If the equivalent circuit is required only from the point of view of a specific load—or a specific group of loads—it may not be necessary to apply a full set of cancelling generators; hence it may be possible to fulfil specific requirements with equivalent circuits of a simpler kind. A trivial example is the case where certain terminals of the active network are never used by the groups of loads considered. Less trivial is the case where the loads use all terminals but where the nature of the loads forbids currents between certain groups of terminals. In such a case the voltages between that group of terminals (or the short-circuit currents flowing between them) may be ignored. An example is the case of a 4-terminal network with 2-terminal loads that are only capable of connection to terminals 1–2 or 3–4. Any potentials between terminals 1–4 or 2–3 can then be ignored.

Conjugate Networks

By a conjugate network we understand a network which is obtained from another network (the 'original' network) by replacing each element of impedance $Z' = R' + jX'$ by an element of impedance $Z'' = Z'^* = R' - jX'$.

It is evident that any impedance or admittance measured between any terminals of the original network is by this process changed to its conjugate value.

Theorem III

Of all inactive loads that can be attached to an active n-terminal network the network forming its conjugate counterpart will extract maximum power.

Using Theorem I the terminal voltages of the active network can be written as

$$E^{(l)}{}_k = E^{(o)}{}_k - \Sigma_n I_n Z_{nk} \quad \ldots \quad \ldots \quad (1)$$

where Z_{nk} is the impedance matrix relating the currents I_n from the n terminals of the inactive network to the voltages E_k (measured against the agreed reference point) produced thereby at these terminals.

Multiplying this equation by I_k^* and summing over all terminals we obtain the power output as the real part of

$$W = \Sigma_k E^{(o)}{}_k I_k^* - \Sigma_k \Sigma_n I_n I_k^* Z_{nk} \quad \ldots \quad (2)$$

The currents I_n in this equation are quite generally determined by the requirement

$$\Sigma_n I_n Z^{(l)}{}_{nk} = E^{(l)}{}_k \quad \ldots \quad \ldots \quad (3)$$

where $Z^{(l)}{}_{nk}$ is the impedance matrix of the load between the terminals n and k. In the present case

$$Z^{(l)}{}_{nk} = Z_{nk}^* \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

If the currents vary, as the result of load changes, say I_k by δI_k, W varies by δW, and if the theorem is correct, the real part of this variation should be zero. Now

$$\delta W = \Sigma_k E^{(o)}{}_n \delta I_k^* - \Sigma_k \Sigma_n Z_{nk} (I_n \delta I_k^* + \delta I_n I_k^*) \quad \ldots \quad \ldots \quad (5)$$

But, as $Z_{nk} = Z_{kn}$ it is seen that n and k are here interchangeable dummy indices and the second term in this equation can be written as $\delta I_k I_n^*$. This makes it the conjugate of the first term and the bracket must therefore be real. Any real contribution to the double sum must therefore

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*These different sets of generators are, of course, derivable from each other by linear combination.

come from the real part R_{nk} of Z_{nk}. Hence we can write for the real part δW_r of δW

$$\delta W_r = \mathrm{Re}\Sigma_k E^{(o)}_k \delta I_k^* - \mathrm{Re}\Sigma_n\Sigma_k 2R_{nk} I_n \delta I_k^* \quad \ldots \quad (6)$$

But from equations (1), (3) and (4) we can write

$$E^{(o)}_k = \Sigma_n I_n (Z_{nk} + Z_{nk}^*) = 2\Sigma_n I_n R_{nk} \quad \ldots \quad (7)$$

Hence equation (6) can be written

$$\delta W_r = \mathrm{Re}\Sigma_k E^{(o)}_k \delta I_k^* - \mathrm{Re}\Sigma_k E^{(o)}_k \delta I_k^* \quad \ldots \quad (8)$$

which is indeed identically zero for all values $E^{(o)}_k$.

As Equ. (7) is an essential stepping stone to Equ. (8) it is seen that the converse theorem, properly formulated must also be true. If an active linear network (impedance matrix Z_{nk}) delivers maximum power into a load, the currents in this condition being denoted by I_n, then the impedance matrix $Z^{(l)}_{nk}$ of this load must be such that when 'tested' with these currents it cannot be distinguished from Z_{nk}^*, i.e.,

$$\Sigma_n I_n Z^{(l)}_{nk} = \Sigma_n I_n Z_{nk}^* \; (n = 1, 2 \; . \; . \; . \; N) \quad (9)$$

If Equ. (9) is to hold for all possible sets of currents I_n (i.e., all possible sets of voltages $E^{(o)}_n$) then

$$Z^{(l)}_{nk} = Z_{nk}^*.$$

For a single set of currents I_n arising from a single set of voltages $E^{(o)}_n$ Equ. (9) leaves considerable freedom for $Z^{(l)}_{nk}$. A case of special interest is that where we impose the additional condition that the matrix $Z^{(l)}_{nk}$ only contains diagonal elements; this leads to the so-called 'driving point impedances' discussed in the following Section.

Driving Point Impedance and Equivalent Two-Terminal Loading

Quite often the terminals of the multi-terminal network can be grouped in pairs (for convenience, say, n pairs) so that the members of each pair carry equal but opposite currents. If such a network is connected to other networks through a corresponding number of transmission lines we may ask, what are the impedances which the multi-terminal network offers to these transmission lines?

These impedances are commonly called the driving-point impedances and their inverse the driving-point admittances. Their values are given by

$$Z^{(d)}_k = \frac{E_k}{I_k} = \frac{\Sigma I_i Z_{ik}}{I_k} \quad \ldots \quad \ldots \quad (10)$$

$$Y^{(d)}_k = \frac{I_k}{E_k} = \frac{\Sigma E_i Y_{ik}}{E_k} \quad \ldots \quad \ldots \quad (11)$$

where the values I_i and E_i are the currents and voltages appearing at terminal pair i.

It will be noted that $Z^{(d)}_k$ and $Y^{(d)}_k$ are not constants of the multi-terminal network but depend on the values of I_i or E_i. Thus, for instance, even a purely resistive network with an admittance matrix $[G_{ik}]$ will lead to complex values of $Y^{(d)}_k$ if the values of E_i are not all in phase with E_k.

In order to provide optimum loading for a multi-terminal network according to Theorem III we have to use as load another multi-terminal network which is the conjugate of the first network. It is possible to replace this network by 2-terminal networks (one for each pair of terminals) provided these 2-terminal networks carry the same currents as the network they are going to replace. This will be the case if the input admittance of each 2-terminal network is equal to the corresponding driving point admittance of the conjugate network. For a set of open-circuit voltages $E^{(o)}_i$ and a purely resistive matrix G_{ik} this leads to the equivalent 2-terminal admittances

$$Y^{(d)}_k = \frac{\Sigma E^{(o)}_i G_{ik}}{E^{(o)}_k} \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

as with this particular load, all the terminal voltages E_i, E_k will be exactly one half of the original open-circuit voltages $E^{(o)}_i$. The left-hand side of the equation will change to its conjugate value if the values $E^{(o)}_i$, $E^{(o)}_k$ are replaced by their conjugate counterparts.

PART II

Application to Absorption, Re-Radiation and Directive Properties of Aerial Arrays

A plane electromagnetic wave transports through each unit area of its wave front a certain amount of power; if an aerial is provided to receive it we can give an indication of the amount of power extracted from the wave by quoting the cross-sectional area of the wave-front through which this power has passed. This area is called the absorption area of the aerial and its magnitude depends evidently on the loading of the aerial. If the aerial is optimally loaded in the sense used in Part I, it will have its maximum absorption area.

From the point of view of the theorems of Part I, an aerial array constitutes an n-pair terminal network in which the terminal currents and voltages are related by an impedance matrix

$$[Z_{ik}] = [R_{ik} + jX_{ik}]$$

The optimum load for this aerial array consists therefore of a network with an impedance matrix

$$[Z'_{ik}] = [Z^*_{ik}] = [R_{ik} - jX_{ik}] \quad \ldots \quad (13)$$

It will be noticed that such a load will cause the aerial to have maximum absorption area for any direction of the incident radiation, though the size of this area will, in general, vary with this direction. If $[G_{ik}]$ is the reciprocal matrix to

$[R_{ik}]$ and if the open-circuit voltages of the various aerials are denoted by $E^{(o)}{}_i$, the power flow into the load and thus the absorption area is determined by

$$W = \tfrac{1}{4}\Sigma\Sigma E^{(o)}{}_i E^{(o)*}{}_k G_{ik} \qquad \ldots \quad \ldots \quad (14)$$

The set of voltages $E^{(o)}{}_i$ varies, of course, with the direction of the incident radiation.

From the point of view of the load the impedance matrix Z_{ik} represents the internal impedance of the power supply. However, with a lossless aerial, the resistive part of this matrix does not correspond to an actual dissipation of electrical energy into heat; it corresponds in this case to energy that is re-radiated from the aerial.

It should be noted that this energy is re-radiated according to a polar diagram that is, in general, different from the polar diagram of the array when used in transmission for the very simple reason that the current distribution in both cases need not necessarily be the same*.

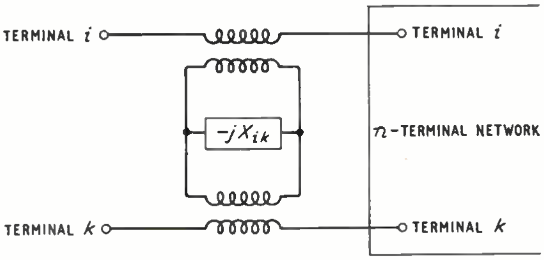

Fig. 2. *Network for cancellation of mutual reactance* $+jX_{ik}$.

Now, the Travelling Wave Theorem for maximum directivity of aerial arrays states[2] that in order to radiate with maximum directivity we have to arrange on the array a current distribution as follows:—The 'resistance voltages' at the individual elements of the array (that is those components of the terminal voltages which are related to the currents in the array by disregarding the reactive parts of the impedance matrix) must vary over the elements of the array as if they were the field-strength values at each element position of a plane electromagnetic wave travelling across the array in the direction in which the array is intended to transmit. In symbols: if $E^{(o)}{}_i$ denotes the open-circuit voltage defined by the travelling wave then the currents I_i are given by the equations

$$\Sigma_k I_k R_{ik} = E^{(o)}{}_i \qquad \ldots \quad \ldots \quad \ldots \quad (15)$$

We have quoted here the Travelling Wave Theorem, as formulated in reference 2, for arrays consisting of identical elements in identical orientation and we recognize immediately that we would have obtained the same current distribution if we had a real wave travelling across the array (producing at each element an open-circuit voltage equal to twice its ascribed resistance voltage) and if the array had been loaded with its conjugate counterpart:—

$$\Sigma_k I_k (Z_{ik} + Z_{ik}{}^*) = 2\Sigma I_i R_{ik} = 2E^{(o)}{}_i \qquad \ldots \quad (16)$$

Hence it can be stated immediately, that in the case of such an array, re-radiation will take place with maximum directivity in the direction in which the original wave train was travelling.

We shall use the last part of the paper to give an independent proof of the Travelling Wave Theorem. It follows from reciprocity that the power gain of an aerial is the same for transmission and reception. Hence, if the feeders of an aerial array are adjusted so as to deliver maximum power from a distant transmitter into a single load, this same aerial will have maximum power gain for transmission in the opposite direction when we replace this load by a generator. By constructing a feeder network that is particularly simple to follow in its action we shall find—by inspection—that the current distribution in the transmitting case is indeed the distribution specified by the Travelling Wave Theorem. In reference 2, the case of non-identical elements has also been dealt with by a slightly modified form of the Travelling Wave Theorem. However, it is shown here in Appendix II that the procedure which we have just described covers this more general case. It is of some interest that the condition for maximum directivity of an aerial array can thus be derived by the mere application of network considerations.

As the first step in the construction of the feeder network we arrange that all the reactance terms of the impedance matrix

$$Z_{ik} = R_{ik} + jX_{ik}$$

of the array are cancelled by appropriate additions to the leads going to the terminals of the array. A reactance term like jX_{ii} can be cancelled by inserting into the lead to the ith terminal a reactance $-jX_{ii}$. To cancel a mutual reactance term like jX_{ik} we proceed as shown in Fig. 2. Ideal transformers are inserted into the leads going to terminals i and k and a reactance $-jX_{ik}$ is inserted in shunt.

After these modifications have been carried out, the array offers from its new terminals an impedance matrix $[R_{ik}]$. It will also be noted that the open-circuit voltages $E^{(o)}{}_i$ that appear on these new terminals are the same as those that appeared across the old terminals of the array.

To adjust the array for maximum absorption we shall have to load the new terminals with an n-terminal network of impedance matrix $[R_{ik}]$.

---

* The current distribution in both cases can differ, as the mode of excitation differs. This has been known for individual aerials for some time [3, 4, 5, 6], and will be discussed further in Appendix I. The validity of the reciprocity theorem is in no way affected. This theorem is only concerned with currents and voltages at the final aerial terminals and not with the ratios of currents, measured at some intermediate positions.

By doing so the voltages at the various new terminals will change to 1/2 their original open-circuit values. As the next step, however, we replace this load by a set of equivalent 2-terminal networks (see Equ. 10, Part I) each consisting of a resistance R'_k and (in general) a reactance X'_k in parallel. The resistance part of such an aerial load can be separated from the reactance part by a lossless transmission line of a characteristic impedance equal to that resistance. This leaves the amplitudes of current and voltage at the resistance unchanged but delays their phase by an angle that corresponds to the electrical length of the transmission line. By using lines of suitable length we can thus arrange that the voltages across all load resistances are in phase. We can then replace all these resistances by ideal transformers of suitable turns ratios, the secondaries of which are all joined in parallel and supply a single load resistor R_L. The procedure is illustrated in Fig. 3. Here we have assumed a wave coming from the right, making the phase angles of the open-circuit voltages of the various aerials equal to $\alpha_1, \alpha_2 \ . \ . \ . \ \alpha_n$ (in increasing order). By adding transmission lines of length $\beta_i = \text{const.} - \alpha_i$ all outputs have been brought into coincident phase and it will be noted that the voltage across each load resistance; i.e., across each primary of the ideal transformers is equal to 1/2 of the original open-circuit voltage of each aerial.

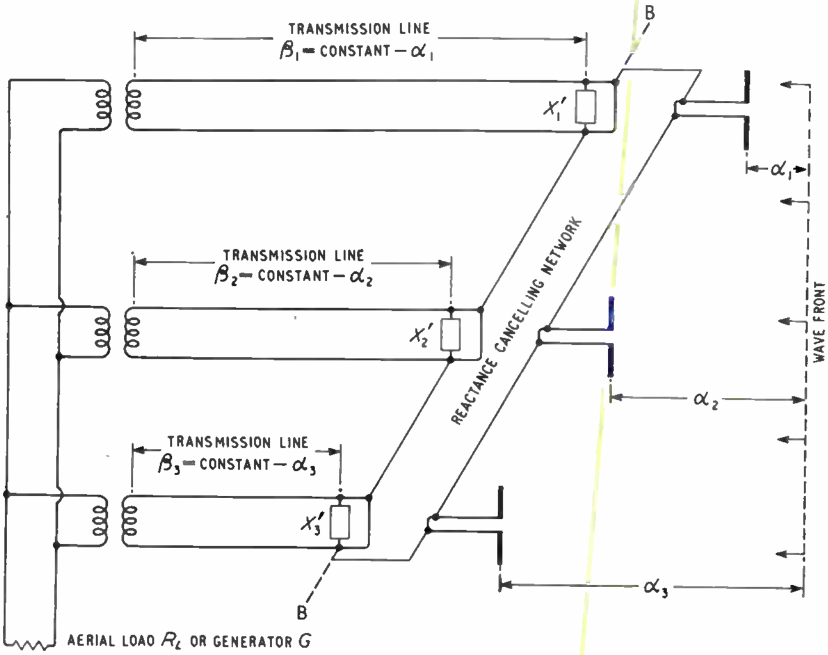

Fig. 3. *Derivation of the travelling-wave theorem for maximum directivity.*

We now replace the final load R_L by a generator G to which, for simplicity, we give twice the voltage that previously appeared across R_L. This means that at the left-hand end of each transmission line a voltage appears equal in magnitude and phase to the original open-circuit voltage of each aerial. We assert that these voltages $(E^{(o)}{}_i)$ will appear in equal amplitude but suitably delayed at the right-hand end of the various transmission lines, corresponding to a wave that is now progressing from the left to the right; thus, the excitation applied to the elements of the array will be exactly as required by the Travelling Wave Theorem for maximum transmission in the direction from which the original wave came, for we have then for the array

$$\Sigma_k I_k R_{ik} = (E^{(o)}{}_i) \qquad \ldots \quad \ldots \quad \ldots \quad (17)$$

This result will be obvious if we can show that the transmission lines are all properly terminated at their right-hand ends.

Now, the loading of these transmission lines consists of the reactance parts X'_i of the original equivalent load, together with the combined aerial array and reactance-cancellation network to the right-hand side of the boundary lines B – B of Fig. 3; the latter combination has an input impedance matrix $[R_{ik}]$. Using Equ. (10) of Part I we will replace this combination (not including the reactances X'_i) by an equivalent set of 2-terminal networks, each consisting of a resistance R_i'' and a reactance X_i'' in parallel. If our assertion is correct (i.e., if the transmission lines behave as if they were properly terminated) then the voltages $(E^{(o)}{}_i)$ that appear at the right-hand end of these lines will be the complex conjugates of the original open-circuit voltage $E^{(o)}{}_i$ that were used, in combination with Equ. (12) to derive the values of R_i' and X_i'. Hence the concluding remark of Part I applies and we have

$$R_i'' = R_i' \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (18)$$

$$X_i'' = -X_i' \qquad \ldots \quad \ldots \quad \ldots \quad (19)$$

This means that the reactances at the load end cancel and the resistances are of the magnitude required for the correct termination of the transmission lines.

APPENDIX I

The Current Distribution in Aerial Arrays for Reception and Transmission

That the current distribution in the receiving case will, in general, differ from the current distribution in the transmitting case can be seen as follows:

We cut the connection between the aerials and the feeder network and apply Theorem I. In the receiving case there will then be an equivalent network consisting of the passive aerials and in series with each aerial terminal a voltage generator (voltages $E^{(or)}{}_1$, $E^{(or)}{}_2$ . . . $E^{(or)}{}_n$). If we remake the connection, the excitation supplied by these generators will be responsible for the feeder currents and hence for the currents in the aerials.

To change from reception to transmission we place a generator in series with the final load resistance of the feeder network. Cutting the feeder network from the aerials we can, according to Theorem I, replace it by a passive network which, in this case, is identical with the feeder network as it was used before in the receiving case; in series with each feeder pair is a voltage generator (voltages $E^{(ot)}{}_1$, $E^{(ot)}{}_2$ . . . $E^{(ot)}{}_n$). If we remake the connection we have the same network configuration as in the receiving case, only now with voltages $E^{(ot)}{}_i$ instead of $E^{(or)}{}_i$ in the generators. Now, the current distribution in the first case is determined by the impedance matrix that arises from the addition of the impedance matrix $Z^{(a)}{}_{nk}$ of the aerial system and the impedance matrix $Z^{(f)}{}_{nk}$ of the feeder system, together with the ratios of the voltages $E^{(or)}{}_1 : E^{(or)}{}_2 : E^{(or)}{}_2$ . . . $E^{(or)}{}_n$. The current distribution in the second case is determined by the same impedance matrix and by the ratios of the voltages $E^{(ot)}{}_1 : E^{(ot)}{}_2 :$ . . . $E^{(ot)}{}_n$. The first set of these voltage ratios is a property of the aerials only, the second set is a property of the feeder network only. In general, we cannot expect these two sets and the results to be identical.

An alternative and also very instructive way of looking at the same problem is as follows:

Assume the individual elements of the array to be connected to a common feeder network with a 2-terminal output to which we have joined an impedance—the load of the array. Let us place in series with this load a voltage source (E_1) of such strength that it just balances the open-circuit voltage of the network. The current through the load will then be zero but the currents in the individual elements of the array will not be zero. We will call the resultant current distribution the 'idling distribution'*. We now add another voltage source (E_2) in series with the first one which just cancels it and thus brings the array back to its normal loaded state. But source (E_2) by itself causes in the array a current distribution of the shape of the 'transmitting distribution'. Hence the receiving current distribution is obtained by the superposition of the idling current distribution and the transmitting current distribution. Only when these two current distributions have the same shape (i.e., are proportional to each other) will the receiving distribution be of the shape of the transmitting distribution. In general, this cannot be expected and there will then be a corresponding difference between the polar diagrams for re-radiation and transmission.

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* This idling distribution is evidently not a property of the array by itself but of the combination 'array + feeder network' and direction of incident wave.

APPENDIX II

The Travelling Wave Theorem for Arrays with Non-Identical Elements

In reference 2 the problem of non-identical aerials was solved as follows:

$$\text{Let } H = \Sigma h_m I_m e^{j\theta m} \qquad \text{(A1)}$$

the distant field-strength produced by the aerial currents I_m where h_m denotes a suitable (real) factor of proportionality. Introduce modified currents and modified resistances as follows:

$$I^{+}{}_m = I_m h_m \qquad \text{(A2)}$$

$$r^{+}{}_{lm} = r_{lm}/h_l h_m \qquad \text{(A3)}$$

Assume a constant amplitude $e^{-j\theta}$ of resistance voltage as in the case of identical aerials and solve as before; i.e.,

$$I^{+}{}_m = \Sigma e^{-j\theta_l}\, g^{+}{}_{lm} \qquad \text{(A4)}$$

where $[g^{+}{}_{lm}]$ is the reciprocal matrix to $[r^{+}{}_{lm}]$.

To show the equivalence of this procedure to that described in the present text we rewrite (A3) in matrix notation:

$$[r^{+}{}_{lm}] = [h^{-1}] \,.\, [r_{lm}] \,.\, [h^{-1}] \qquad \text{(A5)}$$

where $[h^{-1}]$ denotes a diagonal matrix with elements $h^{-1}{}_l$ . . . $h^{-1}{}_l$. From this follows by inversion

$$[g^{+}{}_{lm}] = [h]\, [g_{lm}]\, [h] \qquad \text{(A6)}$$

or

$$g^{+}{}_m = g_{lm} h_l h_m \qquad \text{(A7)}$$

Hence (A4) can be written

$$I^{+}{}_m = I_m h_m = \Sigma e^{-j\theta_l} g_{lm} h_l h_m \qquad \text{(A8)}$$

or

$$I_m = \Sigma h_l e^{-j\theta_l}\, g_{lm} \qquad \text{(A9)}$$

This is, however, also the result of the present procedure as on account of reciprocity the open-circuit voltages of the individual aerials are no longer equal but given by

$$E^{(o)}{}_l = h_l e^{-j\theta_l} \qquad \text{(A10)}$$

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[1] A. Bloch, Letter to *Wireless Engineer*, 1943, Vol. 20, pp. 367–8.

[2] A. Bloch, R. G. Medhurst, S. D. Pool, *Proc. Instn elect. Engrs, Part* III, 1953, Vol. 100, pp. 303–13.

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[4] F. M. Colebrook, *J. Instn elect. Engrs*, 1932, Vol. 71, p. 235.

[5] R. Kiry and C. W. Harrison, *Proc. Inst. Radio Engrs*, 1944, Vol. 32, p. 18.

[6] T. Morita, *Proc. Inst. Radio Engrs*, 1950, Vol. 38, p. 898.

CORRESPONDENCE

Letters to the Editor on technical subjects are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

Standard-Frequency Transmissions—Droitwich 200 kc/s

SIR,—We are rather disturbed to notice that the usual monthly reports on the accuracy of the Droitwich transmitter on 200 kc/s published in *Wireless Engineer* have not been quoted for the months of September and October.

In view of the fact that a large number of instrument manufacturers rely on Droitwich as their main source of frequency calibration, we would be very much obliged to know the reason why the monthly reports appear to have been discontinued.

We might just add that we find Droitwich by far the most useful of all the standard-frequency transmissions in this country, largely because of the high field strength and also because of the very convenient frequency.

M. I. FORSYTH-GRANT

Racal Engineering Ltd.,
Bracknell, Berks.
19th October 1956.

SIR,—When we started publishing results for MSF we decided after consultation with the B.B.C. to include values for Droitwich which we knew to be widely used, although it is not so closely controlled as MSF. There has, however, been no evidence submitted to us that these values serve any useful purpose and it has been suggested that for those applications for which Droitwich is adequate no corrections are necessary. According to our measurements the frequency is usually within ± 5 parts in 10^8, and the value we published, with an accuracy of ± 1 part in 10^8, applied to only a particular time of the day, and was moreover six weeks in retrospect. However, the matter can be reconsidered if a publication in this form is useful and we shall welcome any specific comments on the matter.

You will probably be aware of the difficulty of securing frequency allocations for standard transmissions. We may mention that the closer control of the Droitwich station was considered some years ago but that it was then feared that the frequency would be moved off the round figure which is such a useful feature for standard transmission purposes. This possibility must be borne in mind, as no frequency below 2·5 Mc/s is specifically allocated to such services. Our 60-kc/s MSF transmission remains on an experimental basis.

L. ESSEN

Electricity Division,
National Physical Laboratory,
Teddington, Middlesex.
25th October 1956.

NEW BOOKS

" Wireless World " Diary 1957

80 pages of reference material, and diary pages of one week to an opening. Size 4½ in. × 3⅛ in. Published by T. J. & J. Smith in conjunction with *Wireless World*, Dorset House, Stamford Street, London, S.E.1. Price, Leather 6s., Rexine 4s. 3d.

Introduction to Printed Circuits

By ROBERT L. SWIGGETT. Pp. 112. John F. Rider Publisher Inc., 480 Canal Street, New York 13. Price $2.70.

A brief history of printed circuits is followed by descriptions of present-day printed-circuit practice on the part of several U.S. manufacturers.

Picture Book of TV Troubles. Vol. 7—Sound Circuits and Low-Voltage Power Supplies

By JOHN F. RIDER LABORATORIES STAFF. Pp. 64. John F. Rider Publisher Inc., 480 Canal Street, New York 13, U.S.A. Price $1.50.

Some typical U.S. television receiver h.t. supply and sound i.f. amplifier and detector circuits are considered from the viewpoint of the effect of component failures on circuit voltages and waveforms.

Analysis of Bistable Multivibrator Operation

By P. A. NEETESON. Pp. 82. Philips Technical Library. Cleaver Hume Press Ltd., 31 Wright's Lane, Kensington, London, W.8. Price 15s.

The Eccles-Jordan flip-flop circuit is analysed under static and dynamic conditions. Chapters are included on trigger sensitivity, triggering speed, waveforms during the complete trigger cycle, design considerations and variations on the fundamental circuit.

Progress in Semiconductors, Vol. 1

Edited by A. F. Gibson, P. Aigrain and R. E. Burgess. Pp. 220. Heywood & Co. Ltd., Tower House, Southampton Street, London, W.C.2. Price 50s.

This volume contains seven articles, all on the physical aspects of transistors rather than on circuit applications. The individual subjects are: Recent advances in silicon; The germanium filament in semiconductor research; Theory of the Seebeck effect in semiconductors; The electrical properties of phosphors; The design of transistors to operate at high frequencies; Photo-magneto-electric effect in semiconductors and Field effect in semiconductors.

NOBEL PRIZE

Dr. William Shockley shares the 1956 Nobel prize for physics with Dr. John Bardeen and Dr. Walter Hauser Brattain. He is well known for his work on solid-state physics at the Bell Telephone Laboratories which led to the development of the transistor. He recently joined Bechman Instruments Inc., where he is in charge of the semiconductor laboratory.

OBITUARY

James Robinson, M.B.E., D.Sc., Ph.D., M.I.E.E., F.Inst.P., died on 21st October at the age of 72. During the 1914–18 war he served in the R.N.V.R. and R.N.A.S. and he developed the crossed-loop direction-finding system which is known by his name. This was embodied in one of the early R.A.F. homing systems.

He was equally well known for the Stenode Radiostat which aroused a great controversy about the physical reality of sidebands in the early '30s. The stenode embodied a quartz-crystal resonator as a highly-selective circuit in conjunction with an a.f. amplifier having an inverse frequency characteristic over the range of modulation frequencies.

MEETINGS

I.E.E.

10th December. " Unsolved Problems arising from Automation", discussion to be opened by G. L. E. Metz.

12th December. " The B.B.C. Sound Broadcasting Service on Very-High Frequencies", by E. W. Hayes and H. Page, M.Sc.

14th December. " The Teaching of the Fundamentals of Transistor Circuits to Students of Electrical Engineering", discussion to be opened by P. Godfrey, B.Sc.(Eng.), at 6 o'clock.

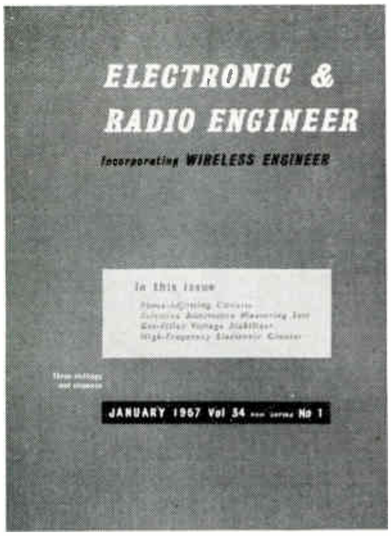
18th December. " Breakdown in Dielectrics", discussion to be opened by C. G. Garton and J. H. Mason, B.Sc.

These meetings will be held at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, and will commence at 5.30, except where otherwise stated.

Brit.I.R.E.

12th December. " Principles of the Light Amplifier and Allied Devices", by T. B. Tomlinson, Ph.D., to be held at the London School of Hygiene & Tropical Medicine, Keppel Street, Gower Street, London, W.C.1, at 6.30.

THE NEW "WIRELESS ENGINEER"



With the new title, *Electronic & Radio Engineer*, and a larger page area, the January 1957 issue of this journal will, we feel sure, be welcomed by our readers.

Electronic & Radio Engineer will still contain all the normal features of *Wireless Engineer*. The original scientific papers and Abstracts and References will be there in full measure.

The journal will, however, include an expanded editorial content; and this new material will deal extensively with today's engineering applications of yesterday's research findings in the wider field of electronics generally.

We feel sure that you will find *Electronic & Radio Engineer* of even greater importance in its new form. The price of the journal remains unaltered.

Television Society

7th December. " 90° Scanning," by R. H. C. Morgan, B.Sc. and K. E. Martin. To be held at 7 o'clock at the Cinematograph Exhibitors' Association, 164 Shaftesbury Avenue, London, W.C.2.

British Kinematograph Society

13th December. " A Magnetic Tape Recording System for Colour Television Signals", by H. R. L. Lamont, Ph.D., M.A., to be held at 7.15 at the Royal Society of Arts, John Adam Street, Adelphi, London, W.C.2.

Royal Society of Arts

10th December. " Engineering Electronics (excluding radar and Service equipment)," by L. E. C. Hughes, B.Sc.(Eng.), Ph.D., A.C.G.I., to be held at 6 o'clock at the Royal Society of Arts, John Adam Street, Adelphi, London, W.C.2.

Society of Instrument Technology

" Phase-plane Methods in Control System Design", by G. D. S. MacLellan, M.A., Ph.D., to be held at 7 o'clock at Manson House, Portland Place, London, W.1.

RADIO AND ELECTRONIC COMPONENT SHOW

The 14th annual exhibition organized by the Radio and Electronic Component Manufacturers' Federation is to be held at Grosvenor House and Park Lane House, Park Lane, London, W.1, from Monday to Thursday, 8th–11th April 1957.

STANDARD-FREQUENCY TRANSMISSIONS

(Communication from the National Physical Laboratory)

Values for October 1956

Date 1956 October	MSF 60 kc/s Frequency deviation from nominal*: parts in 10^9
1	0
2	+1
3	+2
4	+1
5	+1
6	N.M.
7	N.M.
8	+1
9	+1
10	+1
11	+1
12	+2
13	+2
14	+2
15	+2
16	+1
17	+2
18	+1
19	+2
20	N.M.
21	N.M.
22	+2
23	+2
24	+2
25	+2
26	+2
27	+3
28	+3
29	+3
30	+2
31	+2

N.M. = Not Measured.

*Nominal frequency is defined to be that frequency corresponding to a value of 9 192 631 830 c/s for the N.P.L. caesium resonator.

ABSTRACTS and REFERENCES

Compiled by the Radio Research Organization of the Department of Scientific and Industrial Research and published by arrangement with that Department.

The abstracts are classified in accordance with the Universal Decimal Classification. They are arranged within broad subject sections in the order of the U.D.C. numbers, except that notices of book reviews are placed at the ends of the sections. U.D.C. numbers marked with a dagger (†) must be regarded as provisional. The abbreviations of journal titles conform generally with the style of the World List of Scientific Periodicals. An Author and Subject Index to the abstracts is published annually; it includes a selected list of journals abstracted, the abbreviations of their titles and their publishers' addresses.

ACOUSTICS AND AUDIO FREQUENCIES

534.232 3599

Variable Resonant Transducer.—D. H. Robey. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 700–704.) Variation of the resonance frequency of a composite system, such as a crystal plate associated with a backing plate, is effected by applying a force which varies the friction between the two plates.

534.232 : 534.64 3600

Transducer Calibration by Impedance Measurements.—G. A. Sabin. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 705–710.)

534.24 3601

Reflection of a Plane Acoustic Wave from a Surface of Nonuniform Impedance.—H. S. Heaps. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 666–671.) Theory is presented for surfaces with (*a*) random and (*b*) nonrandom nonuniformity. In case (*a*), the reflection obeys Lambert's cosine law if the surface is at approximately zero pressure; perfectly diffuse scattering is obtained if the surface is approximately rigid. In case (*b*), the scattered radiation is contained in a beam whose axis lies in the direction of specular reflection.

534.24 3602

Reflection of Plane Sound Waves from an Irregular Surface.—J. G. Parker. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 672–680.) Analysis is presented in which the reflected field is regarded as formed by superposed plane waves with unequal amplitudes. The method is used to investigate scattering from a surface with sinusoidal corrugations in one dimension. The results are compared with those given by Rayleigh's theory and with measurements made by LaCasce & Tamarkin (1938 of July).

534.413 : 534.115 3603

Gaseous and Liquid Jets Sensitive [to sound].—M. Dubois. (*Ann. Télécommun.*, May 1956, Vol. 11, No. 5, pp. 111–116.) Results of measurements on air and water jets are presented graphically to show the frequency ranges over which jets with given diameter and flow velocity are sensitive.

534.414 : 534.833 3604

The Degree of Sound Absorption by Cavity Resonators and its Dependence on the Arrangement.—E. Kohlsdorf. (*Hochfrequenztech. u. Elektroakust.*, April 1956, Vol. 64, No. 5, pp. 162–164.) Results of calculations are compared with measurements by the Kundt's tube and reverberation-room methods. Point, line and area distributions of the resonators are considered.

534.612.2 3605

Acoustic Wattmeter.—T. J. Schultz. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 693–699.) Equipment is described comprising a small probe containing a pair of microphones with their pre-amplifiers, connected by cable to the unit containing amplifiers, equalizers, phase-shifters and measuring circuits. Direct readings of acoustic intensity are obtained over a 50-dB range at frequencies up to 10 kc/s. Theory and measurement results are given.

534.7 3606

Effect of attenuating One Channel of a Dichotic Circuit upon the Word Reception of Dual Messages.—G. C. Tolhurst & R. W. Peters. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 602–605.) Experiments indicate that the improvement in the reception of the unattenuated message is more pronounced with a noisy than with a quiet background.

534.7 : 534.86 3607

Articulation Reduction by Combined Distortions of Speech Waves.—D. W. Martin, R. L. Murphy & A. Meyer. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 597–601.) The effects on intelligibility of the following four types of distortion were studied individually and in combination, with different levels of background noise: attenuation of high-frequency components; multiple echo; random amplitude modulation; irregular frequency-response characteristic.

534.7 : 621.39 **3608**

Speech Communication Research Symposium.—(*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 531–591.) The full or summarized text is given of a number of papers presented at the symposium held at San Diego in November 1955. The material was grouped under the headings: Temporal Factors in Speech Reception; Speech Communication in Noise; Speech Analysis and Synthesis Systems.

534.7 : 621.396.822 **3609**

Detection of Signals in Noise: a Comparison between the Human Detector and an Electronic Detector.—C. W. Sherwin, F. Kodman, Jr, J. J. Kovaly, W. C. Prothe & J. Melrose. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 617–622.) Recorded signals mixed with noise were presented to (*a*) four observers and (*b*) a detector system comprising filter with 60-c/s pass band, square-law detector, and integrator. Incomplete correlation between the responses of the observers and the detector can be explained by assuming that the observers' threshold fluctuates about a mean value, or that noise is generated internally within the observers. The false-alarm rate is about an order of magnitude lower for the observers than for the detector system.

534.75 **3610**

Masked Threshold and its Relation to the Duration of the Masked Stimulus.—E. J. Thwing. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 606–610.)

534.75 **3611**

Masking of Tones by Bands of Noise.—R. C. Bilger & I. J. Hirsh. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 623–630.)

534.771 **3612**

Study of Audiometer Standardization.—R. Lehmann. (*Onde élect.*, May 1956, Vol. 36, No. 350, pp. 466–477.) The determination of the mean threshold of hearing, and measurement techniques for air and bone conduction, are discussed, with a description of progress in various countries in the construction of artificial ears. 39 references.

534.78 : 621.39 **3613**

Bandwidth and Channel Capacity Necessary to transmit the Formant Information of Speech.—J. L. Flanagan. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 592–596.)

534.78 : 621.39 **3614**

The Intelligibility of Amplitude-Limited Speech.—H. Schneider. (*Frequenz*, April & May 1956, Vol. 10, Nos. 4 & 5, pp. 97–106 & 152–161.) Various known limiter systems are compared; the problem of improving signal/noise ratio by amplitude limiting and level regulating, without impairing intelligibility, is discussed. Experimental results indicate that the dynamic range of single tones is at least as significant as the formant structure of the spectrum. A new theoretical explanation is given for the success of the limiting system in which the signal spectrum is pre-distorted and later restored. Systems involving frequency transposition of the speech band are superior as regards freedom from distortion. Separate limiting in sub-bands gives better results again. Intelligibility losses with the less satisfactory systems may amount to 50%, but are only about 10% with the two last-mentioned systems.

534.83/.84 **3615**

Architectural Acoustics.—J. Matras. (*Onde élect.*, May 1956, Vol. 36, No. 350, pp. 384–415.) A survey covering sources of noise and modes of propagation of sound in buildings, measurement of noise levels, and factors affecting the acoustics of large and small interiors.

534.83 **3616**

Acoustic Insulation of Heavy Structures.—J. Pujolle. (*Onde élect.*, May 1956, Vol. 36, No. 350, pp. 435–440.) Research on wall materials and methods of construction is carried out in a laboratory consisting of two rooms separated by the test wall. Measurements are reported on some composite structures made of brick and/or cement; the structure selected as satisfactory for insulating studios comprised a three-leaved cement wall with glass wool in the intervening spaces, providing a mean insulation of 94 dB. The importance of avoiding indirect transmission of sound is emphasized.

534.833 : 534.414 **3617**

Coupled Vibrations in [acoustic] Cavity Resonators with Grids.—E. Kohlsdorf. (*Hochfrequenztech. u. Elektroakust.*, April 1956, Vol. 64, No. 5, pp. 160–162.) Calculations are made for resonators faced with perforated panels, taking account of resonance of the panel on its own as well as resonance of the whole cavity system. The results are in good agreement with measurements on several systems.

534.833.4 : 621.395.623.54 **3618**

Noise Bands *versus* Pure Tones as Stimuli in measuring the Acoustic Attenuation of Ear Protective Devices.—J. C. Webster, P. O. Thompson & H. R. Beitscher. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 631–638.)

534.84 : 621.374.32 **3619**

New Acoustic Characterization of Rooms and the Development of a Multipurpose Electronic Counter.—R. Lamoral & R. Trembasky. (*Onde élect.*, May 1956, Vol. 36, No. 350, pp. 441–449.) The importance of the diffusion characteristics for the acoustic quality of a room is emphasized. An index of diffusion is defined in general terms and apparatus for determining it is described, including details of a specially developed four-decade counter. The index is measured over a range of frequencies up to 4 kc/s as the number of peaks whose value exceeds a given mean level. The apparatus may be used for measuring reverberation time and other acoustic properties.

534.843 **3620**

Sound Level in the Corners and near the Walls of Closed Rooms in the Presence of Noise.—W. Wöhle. (*Hochfrequenztech. u. Elektroakust.*, April 1956, Vol. 64, No. 5, pp. 158–160.) A simple method of calculation is presented; the results are confirmed by measurements on a room of volume 63 m^3, using noise bands of 200–400 and 37·5–75 c/s. The greatest difference in sound level between the corners and the middle of the room was about 9 dB.

534.845 **3621**

Visual Display of Sound and Ultrasonic Waves.—F. Canac. (*Onde élect.*, May 1956, Vol. 36, No. 350, pp. 422–427.) See 2291 of 1954.

534.845 **3622**

The Acoustic Properties of Materials.—T. Vogel. (*Onde élect.*, May 1956, Vol. 36, No. 350, pp. 428–434.) The analogy between acoustic and electrical phenomena is used to derive an expression for the coefficient of absorption; a method of determining this coefficient is described, based on measurements of incident and reflected sound fields in a specially constructed chamber (see also 2197 of 1953). Comparison with the original work of Sabine relating acoustic quality with reverberation time shows that Sabine's formula is applicable to conditions involving higher absorption coefficients than are encountered in practice.

534.846 **3623**

Acoustics of the Auditorium at the State Opera House, Berlin, Unter den Linden.—W. Reichardt. (*Hochfrequenztech. u. Elektroakust.*, April 1956, Vol. 64, No. 5, pp. 134–144.) Details are given of tests made in connection with the rebuilding of this opera house; diffusivity, clarity and reverberation time were investigated. Measurements made on models were confirmed by the final results. The reverberation time was made as long as possible, and is longer than that of the building in its previous form.

534.86 : 546.82 **3624**

Application of Metal Titanium to the Acoustic Instruments, in Japan.—T. Hayasaka, K. Masuzawa, S. Nagai & M. Suzuki. (*Rep. elect. Commun. Lab., Japan*, April 1956, Vol. 4, No. 4, pp. 39–54.)

534.86 : 621.396.712.3 **3625**

Modern Broadcasting Studios: Marseilles.—J. Pujolle. (*Onde élect.*, May 1956, Vol. 36, No. 350, pp. 419–421.) A brief description is given of the acoustic treatment of these studios, which include one with a volume of 3 000 m^3, having a reverberation time of about 1·5 s, and four smaller studios having reverberation times from 0·5 to 0·8 s.

534.861 : 621.396.813 **3626**

The Receiving Side of a Radio Broadcast Transmission and its Influence on the Audio-Frequency Bandwidth.—Ebert. (See 3881.)

621.395.616 **3627**

Full-Range Electrostatic Loudspeakers.—H. J. Leak & A. B. Sarkar. (*Wireless World*, Oct. 1956, Vol. 62, No. 10, pp. 486–488. Correction, *ibid.*, Nov. 1956, Vol. 62, No. 11, p. 528.) Discussion of a design using two parallel plastic diaphragms, with resistive coatings on the faces turned away from each other, and a parallel conducting electrode fixed midway between them. With this arrangement there is no need for a high resistance in the lead to the charged middle electrode. Other advantages are that the diaphragms need not be unreasonably large, and that they form a dust-proof protection for the middle electrode.

621.395.623.8 **3628**

Experimental Investigation of Sound Coverage of an Open Space by a Distributed System of Loudspeakers.—B. D. Tartakovski. (*C. R. Acad. Sci. U.R.S.S.*, 1st June 1956, Vol. 108, No. 4, pp. 636–639. In Russian.) The results indicate that the required coverage can be achieved using 20-W loudspeakers with nondirectional characteristics in the horizontal plane, mounted at a height of 5 m and spaced at about 20 m.

AERIALS AND TRANSMISSION LINES

621.372.029.6 : 621.318.134 **3629**

Waveguide Components with Nonreciprocal Properties.—Brown & Clarricoats. (See 3666.)

621.372.2 + 621.396.677.3 : 512.3 **3630**

Application of Chebyshev [Tchebycheff] Polynomials in the Calculation of Step Transitions.—Ya. M. Turover & N. I. Strutinski. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 143–161.) Applications to the theory of transmission lines and aerial arrays are discussed.

621.372.2 : 621.315.212 **3631**

On the Theory of a Coaxial Transmission Line consisting of Elliptic Conductors.—J. Y. Wong. (*Canad. J. Phys.*, April 1956, Vol. 34, No. 4, pp. 354–361.) Analysis using elliptic-cylinder wave functions is presented for a line in which the inner and outer conductors have confocal cross-sections. The theory is applicable to the shielded-strip line and the rectangular coaxial line as special cases.

621.372.21 : 621.3.015.3 **3632**

The Capacitor Discharge on the Infinitely Long Line with Uniform Distribution of Resistance and Capacitance.—F. Böttcher. (*Frequenz*, April 1956, Vol. 10, No. 4, pp. 120–125.) Analysis is presented based on a finite source resistance, corresponding to a finite value of current at the instant when the line is connected to the capacitor. Expressions are derived for the voltage and current at any subsequent instant at any point along the line.

621.372.8 **3633**

Curved Waveguides with Constant Cross-Section.—B. Z. Katsenelenbaum. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 171–185.) Propagation in a waveguide comprising a straight and a curved section is considered theoretically. If the radius of curvature is sufficiently large, the solution for the field can be obtained approximately by considering a series of straight sections in place of the actual curved guide. The coefficients for the modes satisfy a system of ordinary differential equations of the first order.

621.372.8 **3634**

Conditions at the Boundary of Imperfectly Conducting Waveguides.—M. L. De Socio. (*R. C. Accad. naz. Lincei*, April 1956, Vol. 20, No. 4, pp. 469–476.) Analysis is presented; expressions derived are compared with those obtained by Baudoux (3151 of 1955).

621.372.8 **3635**

Transmission Loss due to Resonance of Loosely Coupled Modes in a Multi-mode System.—A. P. King & E. A. Marcatili. (*Bell Syst. tech. J.*, July 1956, Vol. 35, No. 4, pp. 899–906.) " In a multi-mode transmission system the presence of spurious modes which resonate in a closed environment can produce an appreciable loss to the principal mode. The theory for the evaluation and control of this effect under certain conditions has been derived and checked experimentally in the particularly interesting case of a TE$_{01}$ transmission system, where mode conversion to TE$_{02}$, TE$_{03}$ . . . is produced by tapered junctions between two sizes of waveguide."

621.372.8 : 538.221 : 538.63 **3636**

Polarimetric Study of a Ferrite in the 2 000-Mc/s Frequency Band.—P. Loudette & A. Charru. (*C. R. Acad. Sci., Paris*, 16th July 1956, Vol. 243, No. 3, pp. 251–254.) Measurements were made on a system comprising three ferrite rods arranged along the axis of a circular waveguide. The rotation of the plane of polarization on application of a longitudinal magnetic field *H*, and the square of the ellipticity, are plotted (*a*) as functions of H with λ as parameter, and (*b*) as functions of λ with H as parameter. Corresponding points of inflection are noted.

621.396.67 : 537.226 **3637**

Some Investigations on Dielectric Aerials: Part 1.—R. Chatterjee & S. K. Chatterjee. (*J. Indian Inst. Sci.*, Section B, April 1956, Vol. 38, No. 2, pp. 93–103.) The radiation field intensity at a distant point due to a circular-section dielectric rod aerial excited in the HE_{11} mode is derived theoretically. General expressions are given for the radiation patterns in two planes of particular interest, and are evaluated for a polystyrene rod of length 3 λ and diameter 0·46 λ.

621.396.67 : 621.396.822 **3638**

Induced Thermal Noise in Aerials.—M. L. Levin. (*Zh. tekh. Fiz.*, Nov. 1955, Vol. 25, No. 13, pp. 2313–2318.) Induced fluctuation currents in a thin aerial due to external heated bodies are discussed. Considerable mathematical difficulties arise in the calculation of these currents, owing to the fact that the fluctuation field is not δ-correlated along the aerial. These difficulties are largely avoided by use of the electrodynamic theory of reciprocity. The general formulae so obtained are applied to the following two cases: (*a*) aerial in an equilibrium radiation field; (*b*) thermal noise induced by remote bodies.

621.396.67.029.62 : 621.397.7 **3639**

The Crystal Palace Television Transmitting Station.—McLean, Thomas & Rowden. (See 3895.)

621.396.674.3 **3640**

Some Comments on Wide-Band and Folded Aerials.—E. O. Willoughby. (*J. Brit. Instn Radio Engrs*, Aug. 1956, Vol. 16, No. 8, pp. 455–462.) Reprint. See 2622 of September.

621.396.677 : 621.397.26 **3641**

Deviating Aerial Installations for Television Coverage.—H. Hesselbach. (*Frequenz*, April 1956, Vol. 10, No. 4, pp. 116–120.) Aerial systems for ensuring reception in obscured or marginal areas are discussed; they are termed active or passive according as they are or are not associated with amplifiers; the passive class includes both simple reflectors and systems with separate receiving and transmitting aerials.

621.396.677.012.12 **3642**

End-Fire Arrays of Magnetic Line Sources mounted on a Conducting Half-Plane.—R. A. Hurd. (*Canad. J. Phys.*, April 1956, Vol. 34, No. 4, pp. 370–377.) Expressions are derived for the radiation patterns of arrays of sources such as slots in a perfectly conducting half-plane. The problem is made two-dimensional by assuming the sources to run parallel to the edge of the plane. The variation of beam tilt, beam width and side-lobe level with the array parameters is studied. The theory gives a reasonable representation of the behaviour of corrugated surface radiators embedded in a finite ground plane, provided the distance from the array to the edge is about equal to the array length.

621.396.677.029.6.012.12 **3643**

Microwave Aerial Testing at Reduced Ranges.—D. K. Cheng. (*Wireless Engr*, Oct. 1956, Vol. 33, No. 10, pp. 234–237.) Three methods are presented for determining the appropriate amount of defocus of the primary source for simulating Fraunhofer patterns within the Fresnel zone. The results are plotted and compared.

621.396.677.3 : 523.7 **3644**

The Multiple-Aerial Interferometer at the Nançay Station.—É. J. Blum, A. Boischot & M. Ginat. (*C. R. Acad. Sci., Paris*, 2nd July 1956, Vol. 243, No. 1, pp. 19–22.) A system for locating centres of solar r.f. radiation comprises eight parabolic mirrors of 5 m diameter on an east-west base of length 700 m; it operates on 169 Mc/s and has a resolving power of 7·5′. Some records of the passage of r.f. sources are reproduced. A system of 32 aerials on a 1 500-m base is projected, which is to include the present system.

621.396.677.3.012.12 **3645**

Aerial Pattern Synthesis.—H. E. Salzer. (*Wireless Engr*, Oct. 1956, Vol. 33, No. 10, pp. 240–244.) When the Dolph-Tchebycheff distributions are used to determine the feeding coefficients required to produce sharp beams with broadside arrays, the numerical work increases with the number of sources. An alternative method is described which uses a special case of a general formula due to Poisson to synthesize extremely sharp patterns. A simple explicit expression is derived for the amplitude of the feeding coefficients which is just as easy to calculate for a large number of terms as for a small number.

621.396.677.83 **3646**

Theory of Periscopic Aerial Systems.—L. B. Tartakovski & A. M. Pokras. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 186–196.) A system comprising a parabolic radiator and a plane elliptical deflector is investigated theoretically by a method similar to that used previously by Jakes (1243 of 1953). The solution for the field gain η_E of the system is obtained in terms of infinite series of Bessel functions; the expression is considerably simplified in the cases of (*a*) a point source, and (*b*) uniform distribution of amplitudes over the aperture and coincidence of the radiator aperture with the circular projection of the deflector. η_E is plotted as a function of a dimensionless parameter m for three different amplitude distributions over the aperture and five different ratios of the diameter of the radiator aperture to that of the deflector projection; the effect of the amplitude distribution is shown to be small. The results obtained are in good agreement with those calculated by Jakes and the experimental results of Drexler (2565 of 1954).

621.396.677.83 **3647**

Aerial System with [raised] **Reflector.**—V. D. Kuznetsov. (*Radiotekhnika, Moscow*, March 1956, Vol. 11, No. 3, pp. 4–15.) The radiation characteristics of various arrangements of the type used at microwave relay stations, comprising a reflector-type aerial and a raised deflecting reflector, are considered theoretically.

621.396.677.833 **3648**

The Electromagnetic Field of a Dipole Radiator located inside a Paraboloidal Reflector.—I. P. Skal'skaya. (*Zh. tekh. Fiz.*, Nov. 1955, Vol. 25, No. 13, pp. 2371–2380.) The case of a dipole arranged perpendicular to the axis of the paraboloid is considered. The solution given by Pinney (2687 of 1947) in the form of series of Laguerre polynomials is not justified mathematically. A new solution applicable to the whole region inside the paraboloid is obtained which gives the desired field components in the form of complex integrals. This solution is used to determine the field in the limiting case when the wavelength is much smaller than the focal length of the paraboloid.

621.396.677.833 : 523.16 **3649**

The George R. Agassiz Radio Telescope of Harvard Observatory.—Bok. (See 3715.)

621.396.677.833.1 **3650**

Electromagnetic Field of a Linear Radiator located inside an Ideally Conducting Parabolic Screen [reflector].—G. A. Grinberg, N. N. Lebedev, I. P. Skal'skaya & Ya S. Uflyand. (*Zh. eksp. teor. Fiz.*, March 1956, Vol. 30, No. 3, pp. 528–543.) The field problem considered earlier (2867 of 1954) is re-examined and a more rigorous solution is derived. This is shown to agree with the geometrical-optics solution at frequencies tending to infinity.

621.396.677.833.2 **3651**

The Far Field of a Paraboloid of Revolution with Hertzian Dipole Normal to the Plane of the Aperture.—F. Müller. (*Hochfrequenztech. u. Elektroakust.*, April 1956, Vol. 64, No. 5, pp. 155–158.) Calculations show that the power density and field direction are rotationally symmetrical about the axis of the paraboloid; the transverse electric field has zero intensity on the axis.

621.396.677.85 : 621.372.43 **3652**

Reflection and Transmission at a Slotted Dielectric Interface.—R. E. Collin. (*Canad. J. Phys.*, April 1956, Vol. 34, No. 4, pp. 398–411.) Theory presented by Collin & Brown (2293 of August) is extended to the problem of matching a microwave lens to free space for waves incident obliquely. Calculations show that the reflection coefficient can be reduced from 23% to 5% for angles of incidence up to 30°, for waves of 3–3·28 cm λ, the dielectric constant of the slotted medium being 2·56.

AUTOMATIC COMPUTERS

681.142 **3653**

Trends in Computer Input/Output Devices.—J. M. Carroll. (*Electronics*, Sept. 1956, Vol. 29, No. 9, pp. 142–149.)

681.142 **3654**

Design of Computer Circuits for Reliability.—W. Renwick. (*Electronic Engng*, Sept. 1956, Vol. 28, No. 343, pp. 380–384.) Factors influencing the choice of components, and precautions taken during the initial circuit design and mechanical construction of the EDSAC II machine are described.

681.142 **3655**

A Circuit for Analogue Formation of xy/Z.—M. J. Somerville. (*Electronic Engng*, Sept. 1956, Vol. 28, No. 343, pp. 388–389.) " A quarter squares multiplier, using a triangle carrier waveform in the squaring circuits is extended to give division simultaneously with multiplication. This is achieved by controlling the slope of the triangle carrier waveform so as to be proportional to the divisor Z."

681.142 : 621.317.729.1 **3656**

An Automatic Electron Trajectory Tracer.—Pizer, Yates & Sander. (See 3833.)

681.142(083.7) **3657**

I.R.E. Standards on Electronic Computers: Definitions of Terms, 1956.—(*Proc. Inst. Radio Engrs*, Sept. 1956, Vol. 44, No. 9, pp. 1166–1173.) Standard 56. I.R.E. 8.S1.

CIRCUITS AND CIRCUIT ELEMENTS

621.3.002.2 **3658**

High-Temperature Components.—G. W. A. Dummer. (*Wireless World*, Oct. 1956, Vol. 62, No. 10, pp. 510–512.) New materials and methods of production to meet Service demands are briefly described.

621.3.049.75 **3659**

Printed Circuits.—(See 3902.)

621.318.4.045 **3660**

Winding Method for Coils with Parallel Windings.—P. von Belatini. (*Bull. tech. Univ. Istanbul*, 1956, Vol. 9, pp. 10–21. In German.) Theory is presented indicating the purposes for which parallel-wound coils are suited, and practical examples are described.

621.318.57 : 621.314.7 **3661**

***P-N-P-N* Transistor Switches.**—Moll, Tanenbaum, Goldey & Holonyak. (See 3899.)

621.318.57 : 621.385 **3662**

Ten-Channel Time-Division Multiplexer.—H. Moss & S. Kuchinsky. (*Tele-Tech & Electronic Ind.*, May 1956, Vol. 15, No. 5, pp. 80–82 . . 154.) A ' magnetron ' beam-switching tube [3434 of 1955 (Fan)] forms the basis of a 10-contact, single-channel circuit giving switching times of about 0·2 μs. The tube is used in conjunction with a gating system; a gate circuit is described which permits the examination of signals in the microvolt range.

621.319.4 : 621.373.4 **3663**

Nonlinear D.C.-Tuned Capacitors.—T. W. Butler, Jr, H. Diamond & L. W. Carr. (*Tele-Tech & Electronic Ind.*, May 1956, Vol. 15, No. 5, pp. 68–69 . . 135.) The design and production of very small tuning capacitors using Ba-Sr titanate ferroelectric dielectrics is described. Examples are given of applications to oscillators for the frequency range 25–400 Mc/s, with c.w. power outputs of 50 mW–3 W.

621.372.011.1 **3664**

Formulae relating some Equivalent Networks.—R. J. Duffin & E. Keitzer. (*J. Math. Phys.*, April 1956, Vol. 35, No. 1, pp. 72–82.) Explicit formulae are obtained for the elements of a network without transformers which has the same driving-point impedance as an arbitrary two-loop passive network.

621.372.011.2 **3665**

An Existence Theorem for Driving-Point Impedance Functions.—N. DeClaris. (*J. Math. Phys.*, April 1956, Vol. 35, No. 1, pp. 83–88.)

621.372.029.6 : 621.318.134 **3666**

Waveguide Components with Nonreciprocal Properties.—J. Brown & P. J. B. Clarricoats. (*Electronic Engng*, Aug. & Sept. 1956, Vol. 28, Nos. 342 & 343, pp. 328–332 & 376–379.) The mechanism of the nonreciprocal effects occurring when an e.m. wave is propagated through a magnetized material, particularly a ferrite, is discussed; the gyrator, the isolator and the circulator are described.

621.372.029.64 : 538.569.4 **3667**

Further Aspects of the Theory of the Maser.—Shimoda, Wang & Townes. (See 3710.)

621.372.412 **3668**

Variation of the Quality Factor of Piezoelectric Crystals as a Function of Pressure.—H. Mayer. (*C. R. Acad. Sci., Paris*, 16th July 1956, Vol. 243, No. 3, pp. 246–249.) Measurements were made on a 100-kc/s quartz crystal and on a Rochelle-salt crystal, using apparatus described in *J. Phys. Radium*, June 1956, Vol. 17, Supplement to No. 6, *Phys. appl.*, pp. 104A–107A. Results are presented as $Q/\log p$ curves for values of $\log p$ up to 4, where p is in mm Hg. Decrease of pressure below about 10^{-2} mm Hg does not affect Q value.

621.372.413 **3669**

Design of a Toroidal Cavity Resonator by the Method of Curvilinear Coordinates.—V. L. Patrushev. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 162–170.) The application of the formulae derived is illustrated by a calculation of the resonance frequency of a cavity of given dimensions. The calculated value of $\lambda = 23{\cdot}0$ cm agrees well with the experimental value of 23·2 cm.

621.372.5 **3670**

Restrictions on the Shape Factors of the Step Response of Positive Real System Functions.—A. H. Zemanian. (*Proc. Inst. Radio Engrs*, Sept. 1956, Vol. 44, No. 9, pp. 1160–1165.) Extension of previous analysis of the transient response of networks (1577 of 1955).

621.372.5 : 537.227 **3671**

Theory of Nonlinear Coupling in a Novel Ferroelectric Device.—W. H. Higa. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 775–777.) A device which can be used as a modulator or as a frequency divider or multiplier comprises a block of ferroelectric material with electrodes arranged on two pairs of facing sides. On connecting an inductance across one pair of electrodes, a resonant circuit is provided in which the capacitance varies periodically, oscillations being sustained when the frequency of this parametric excitation is twice the resonance frequency of the circuit. Analysis is presented using the Mathieu equation.

621.372.54 **3672**

The Analysis of Three-Terminal Null Networks.—T. H. O'Dell. (*Electronic Engng*, Sept. 1956, Vol. 28, No. 343, pp. 398–400.) A simple method of analysis is presented; the twin-T and bridged-T networks are treated as examples.

621.372.54 **3673**

By-Pass Filters.—R. O. Rowlands. (*Wireless Engr*, Oct. 1956, Vol. 33, No. 10, pp. 238–240.) "By-pass filters are described having three pairs of terminals and in which all frequencies are passed, without distortion, between two of the pairs but only a limited band of frequencies is transmitted between either of these pairs and the third pair of terminals."

621.372.543.3 **3674**

An Improved Crystal Band-Elimination Filter.—R. C. Leigh. (*A.T.E. J.*, April 1956, Vol. 12, No. 2, pp. 101–106.) An all-pass network consisting of two filters in parallel is described, suitable for applications in which it is required to transmit a wide frequency range while suppressing one or more narrow frequency bands within the range. Internal impedance transformations eliminate the need for high-ratio transformers.

621.372.56.029.6 : 621.372.8 : 621.318.134 **3675**

The Field Displacement Isolator.—S. Weisbaum & H. Seidel. (*Bell Syst. tech. J.*, July 1956, Vol. 35, No. 4, pp. 877–898.) A nonreciprocal device with forward loss about 0·2 dB and reverse loss about 30 dB over a wide band at about 6 kMc/s is based on use of a single ferrite slab spaced from the wall of a rectangular waveguide and having a resistive strip on one face. Optimum field conditions in the waveguide are discussed.

621.372.57 : 621.374.34 **3676**

Operation of an Amplitude Limiter.—M. E. Zhabotinski & Yu. L. Sverdlov. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 205–212.) Theoretical analysis and experimental evidence suggest that the stray capacitance shunting the nonlinear element causes a parasitic phase modulation of the output signal and limits the efficiency. A neutralized circuit is shown and design formulae are given.

621.372.632 : 621.314.63 **3677**

Two-Terminal *P-N* Junction Devices for Frequency Conversion and Computation.—Uhlir. (See 3897.)

621.373.421.1 **3678**

Mutual Synchronization of Three Coupled Oscillators with Weak Couplings.—V. N. Parygin. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 197–204.) The system investigated theoretically and experimentally comprises three triode valve oscillators coupled by small capacitors between the grids of the first and second and second and third valves. Approximate expressions are derived for the frequency and amplitude of the oscillations in each oscillator. The regions where mutual synchronization takes place are shown in a Δ_2/Δ_1 graph, where Δ_1 and Δ_2 are respectively the frequency differences between the first and second and the third and second oscillators.

621.373.421.13 : 621.396.96 **3679**

Stable Local Oscillator for S-Band Radar.—W. J. Dauksher. (*Electronics*, Sept. 1956, Vol. 29, No. 9, pp. 179–181.) A continuous frequency range of 1·3% is obtained using six crystal oscillators tunable over overlapping ranges of 0·25%. The desired output frequency is obtained by means of harmonic amplifiers.

621.374.3 **3680**

A Possible Construction of Amplitude Analysers.—A. M. Bonch-Bruevich. (*Zh. tekh. Fiz.*, Nov. 1955, Vol. 25, No. 13, pp. 2397–2398.) A circuit is described by means of which pulses with amplitudes exceeding or lying within certain limits can be counted.

621.374.3 : 621.396.822 **3681**

Influence of Large Fluctuations on an Electronic Relay.—V. I. Tikhonov. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 213–224.) The probability of untimely triggering by fluctuation voltages is considered theoretically. The cases discussed include the effect of fluctuations on a relay with or without inertia both in the presence and in the absence of regular pulses; the effect on a coincidence-type circuit is also discussed.

621.375.13 **3682**

Effect of Component Tolerances in Low-Frequency Selective Amplifiers: some Experimental Results.—N. S. Nagaraja & V. Rajaraman. (*J. Indian Inst. Sci.*, Section B, April 1956, Vol. 38, No. 2, pp. 81–92.) Results obtained previously by analysis [1339 of May (Nagaraja)] have been verified experimentally, using the operational amplifiers of the PREDA analogue computer [24 of January (Biswas et al.)].

621.375.232.3 : 621.3.018.75 **3683**

Trailing Edge of Pulse in Cathode Follower with Capacitive Load.—M. L. Volin. (*Radiotekhnika, Moscow*, March 1956, Vol. 11, No. 3, pp. 63–69.) The decay time of a rectangular pulse at the output of a cathode follower can be shortened by connecting a triode in parallel with the cathode resistor and capacitor and controlling the triode grid voltage via a *RC* coupling from the anode of the cathode-follower tetrode valve. The circuit constants are such that the triode impedance decreases momentarily at the end of each pulse.

621.375.4 : 621.314.7 3684

The Design of Tetrode Transistor Amplifiers.—J. G. Linvill & L. G. Schimpf. (*Bell Syst. tech. J.*, July 1956, Vol. 35, No. 4, pp. 813–840.) Methods are discussed for determining suitable loads when the two-port parameters of the transistor are known. Charts are presented for determining power gain and input impedance as functions of load. Circuits described as examples include a common-base 20-Mc/s video amplifier, a common-emitter 10-Mc/s video amplifier, and i.f. amplifiers centred at 30 Mc/s and 70 Mc/s respectively. Predicted and measured gains are compared.

621.375.4 : 621.314.7 3685

Servo Amplifiers use Power Transistors.—B. M. Benton. (*Electronics*, Sept. 1956, Vol. 29, No. 9, pp. 153–155.) High efficiency in a class-B-type amplifier using Ge power transistors is obtained by providing the collector power by full-wave rectification of the a.c. power supply.

621.375.4 : 621.314.7 : 546.28 3686

Micro-power Operation of Silicon Transistors.—Keonjian. (See 3898.)

GENERAL PHYSICS

535.33-1 : 535.417 : 538.569.4 3687

Interferometric Spectroscopy in the Far Infrared.—H. A. Gebbie & G. A. Vanasse. (*Nature, Lond.*, 25th Aug. 1956, Vol. 178, No. 4530, p. 432.) The response of a thermal detector to the resultant of two interfering infrared beams was measured using a reflection interferometer with the path difference varied up to 7 mm. The spectral information is displayed in a Fourier transform obtained by analysis of the resultant-intensity/path-difference curve. An instrument with 30-cm aperture has been made for studying atmospheric transmission at submillimetre wavelengths.

537.2 3688

An Extension of the Circle and Sphere Theorems.—G. Power. (*Brit. J. appl. Phys.*, June 1956, Vol. 7, No. 6, pp. 218–221.) Theory relating to cylinders and spheres immersed in two- and three-dimensional electric fields (e.g. 3555 of 1955) is extended to include certain other boundaries along which either the electric potential or the current function takes a constant value.

537.311.1 3689

On the Bohm-Pines Theory of a Quantum-Mechanical Electron Plasma.—C. G. Kuper. (*Proc. phys. Soc.*, 1st June 1956, Vol. 69, No. 438A, pp. 492–495.) Analysis indicates that as a result of neglecting certain conditions discussed by Adams (3219 of 1955), the Bohm-Pines theory (1375 of 1954 and back references) may give incorrect results.

537.311.31 + 537.533 3690

Concerning the Papers by S. E. Khaikin, S. V. Lebedev, and L. N. Borodovskaya [on effects of high current densities] **published in *Zh. eksp. teor. Fiz.* in 1954–1955.**—I. F. Kvartskhava. (*Zh. eksp. teor. Fiz.*, March 1956, Vol. 30, No. 3, pp. 621–623.) Criticism of papers abstracted e.g. in 2992 of 1955 and back references.

537.311.31 3691

Integrals of Interest in Metallic Conductivity.—D. K. C. MacDonald & L. T. Towle. (*Canad. J. Phys.*, April 1956, Vol. 34, No. 4, pp. 418–419.)

537.5 : 538.56 3692

Oscillations and Fluctuations in Gas Discharges.—K. G. Emeleus. (*Nuovo Cim.*, 1956, Vol. 3, Supplement, No. 3, pp. 490–495. In English.) A tentative classification is made of different forms of disturbance encountered in gaseous conductors constituted by low-pressure tubes. A distinction is drawn between (*a*) cases where the gaseous conductor acts as a circuit unit possessing resistance, capacitance and inductance, any of which may be positive or negative, and (*b*) cases where internal disturbances occur in the gaseous conductor which are practically independent of the external circuit. The origin and nature of electron and ion oscillations is discussed.

537.52 : 538.56.029.6 3693

Electrical Breakdown in Argon at Ultra-high Frequencies.—A. D. MacDonald & J. H. Matthews.—(*Canad. J. Phys.*, April 1956, Vol. 34, No. 4, pp. 395–397.) Report of measurements made using resonant cavities at a frequency of 2·8 kMc/s, with pressures ranging from 4×10^{-2} to 200 mm Hg.

537.533 3694

Thermionic Emission, Field Emission, and the Transition Region.—E. L. Murphy & R. H. Good, Jr. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, pp. 1464–1473.) The combined thermionic and field emission from a metal is studied as a whole; a general expression is derived in the form of a definite integral, relating the emission current to the field, the temperature and the work function. Modified forms of the Richardson-Schottky and Fowler-Nordheim formulae are shown to be respectively valid over limited regions of low field and high temperature on the one hand and low temperatures and high field on the other. An expression is also derived for the emission current in the transition region.

537.533.8 : 537.226 3695

Secondary Electron Emission from Single Crystals of Alkali Halide Compounds.—A. R. Shul'man & B. P. Dement'ev. (*Zh. tekh. Fiz.*, Nov. 1955, Vol. 25, No. 13, pp. 2256–2263.) Experiments were carried out which show that the dielectrics investigated differ from metals in respect of the dependence of the coefficient of secondary emission on the energy of the primary electrons and also in respect of the secondary-electron energies, which in this case are approximately uniform.

538.114 3696

Thermodynamic Behavior of an Ideal Ferromagnet.—F. J. Dyson. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1230–1244.) The free energy of an ideal ferromagnetic lattice is evaluated as a series expansion in powers of the temperature. A mathematical formulation for calculating the effect of spin-wave interactions is developed in a separate paper (*ibid.*, pp. 1217–1230).

538.244.2 3697

The Magnetization of a Cylinder by means of a Coil, taking Account of Magnetic Viscosity.—A. N. Tikhonov & A. A. Samarski. (*Zh. tekh. Fiz.*, Nov. 1955, Vol. 25, No. 13, pp. 2319–2328.) The problem of the magnetization of a conducting cylinder in a magnetic field, when the value of the field is abruptly changed, was solved in a general form by Vvedenski (*J. Soc. phys.-chim. russe*, 1923, Vol. 55, p. 1). A solution is now given for the case when magnetic after-effects are present. The results are used for determining the coefficients of magnetic permeability and viscosity, and the retarding action of the coil is taken into account by a corresponding change in the boundary condition on the cylinder surface.

538.3 **3698**

The Determination of the Electromagnetic Field inside a Homogeneous and Isotropic Conductor.—A. Tonolo. (*R. C. Accad. naz. Lincei*, April & May 1956, Vol. 20, Nos. 4 & 5, pp. 403–408 & 556–560.) A new method of integrating Maxwell's equations is presented.

538.3 **3699**

Field of a Uniformly Charged Disk and Magnetic Field of a Thin [single-layer] **Circular-Cylinder Coil with Contiguous Turns traversed by a Direct Current.**—R. Cazenave. (*Rev. gén. Élect.*, May 1956, Vol. 65, No. 5, pp. 301–310.) The field of the uniformly charged disk is used to study that of the coil, by virtue of the magnetic equivalence between the coil and a magnet of the same shape with opposite magnetic poles on the two end faces. Formulae for mutual and self inductance are hence derived.

538.561 : 537.122 **3700**

Electrodynamics of Moving Media and the Theory of the Čerenkov Effect.—B. D. Nag & A. M. Sayied. (*Proc. roy. Soc. A*, 12th June 1956, Vol. 235, No. 1203, pp. 544–551.) "The generalized Frank & Tamm's formula for the total energy radiated as Čerenkov radiation by a swiftly moving charged particle in a medium of dielectric constant ϵ and permeability μ has been derived employing the invariance of the phenomenological electrodynamic equations of Maxwell. The scheme is self-consistent, and the idea of the indetectability of the ether wind is contained in it. It is found that the Čerenkov radiation is μ times larger than that predicted by the Frank & Tamm's formula for $\mu = 1$. Experiments are suggested to detect strong Čerenkov radiation in highly permeable mediums."

538.561 : 621.373.029.65/.66 **3701**

Pulsed Coherent Generation of Millimetre Waves by Nonrelativistic Electron Bunches.—G. A. Askar'yan. (*Zh. eksp. teor. Fiz.*, March 1956, Vol. 30, No. 3, pp. 584–586.) The production of microwaves by bunched electron beams incident on metallic or dielectric anticathodes or by interaction with strong localized fields is briefly discussed and energy relations are stated.

538.566 **3702**

The Effect of the Surface Curvature of a Convex Metal Body on the Radiation from a Source on its Surface.—M. L. Levin. (*Zh. tekh. Fiz.*, Nov. 1955, Vol. 25, No. 13, pp. 2395–2396.) The radiation is usually calculated from 'reflection' formulae derived by replacing the convex surface by a plane. The magnitude of the error thus introduced is estimated.

538.566 : 535.42] + 534.26 **3703**

The Diffraction of a Cylindrical Pulse by a Half-Plane.—R. D. Turner. (*Quart. appl. Math.*, April 1956, Vol. 14, No. 1, pp. 63–73.) A method of analysis is used which enables the Green's function to be derived. Two transformations and two inversions are involved.

538.566 : 535.42 **3704**

Diffraction Pattern in the Plane of a Half-Screen.—L. R. Lewis. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 837–838.) Measurements are briefly reported for the case of plane-polarized radiation incident normally on a half-plane and polarized parallel to the diffracting edge. The results are discussed in relation to a formula derived by Andrews (3141 of 1950) and the observations of Harden (88 of 1953).

538.566 : 535.42 **3705**

Integro-differential Equations and Babinet's Principle for Plane Screens with Directional Conductivity.—G. Toraldo di Francia. (*R. C. Accad. naz. Lincei*, April 1956, Vol. 20, No. 4, pp. 476–480.) Analysis is presented for diffraction by screens formed e.g. of parallel conducting wires. Four cases are distinguished: (*a*) a finite parallel-wire screen alone; (*b*) a finite parallel-wire screen surrounded by an infinite nondirectionally conducting screen; (*c*) a finite aperture surrounded by an infinite parallel-wire screen; (*d*) a finite nondirectionally conducting screen surrounded by an infinite parallel-wire screen. Cases (*a*) and (*b*) are complementary in the sense of Babinet's principle; so also are cases (*c*) and (*d*). There is no special relation between cases (*a*) and (*c*) or (*b*) and (*d*).

538.566 : 537.56 **3706**

Electromagnetic Radiation from Electron Plasma.—S. Hayakawa & N. Hokkyo. (*Progr. theor. Phys.*, March 1956, Vol. 15, No. 3, pp. 193–202.) Theory developed by Bohm & Pines (1375 of 1954 and back references) is extended to treat the coupling between longitudinal and transverse plasma oscillations, arising from the quantum fluctuation of electrons interacting with the e.m. field. The theory may provide the explanation of the outbursts of solar r.f. emission.

538.566 : 539.13 **3707**

Molecular Ringing.—S. Bloom. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 785–788.) "Semiclassical radiation theory is used to describe the response of an assemblage of two-state molecules driven by an electromagnetic field. When the field is suddenly removed, the assemblage does not immediately become quiescent; it continues to radiate in diminishing amount. This coherent molecular-ringing radiation persists until the molecular populations return to the values they had at the beginning of the driving pulse. Depending upon the strength and duration of the driving pulse, the ringing radiation may exhibit a delayed peak."

538.566 : 621.372.8 **3708**

Radiation of Electromagnetic Waves during the Uniform Motion of Electric Charges near an Inhomogeneity.—V. B. Braginski. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 225–232.) The radiation occurring in a nonuniform waveguide in which a given convection current is flowing and the transient radiation due to the passage of finite bunches of charge through ideally conducting grids are considered theoretically using the methods of perturbation theory.

538.569.4 : 621.372.029.64 **3709**

Theory of Molecular [-beam] **Oscillator and Molecular** [-beam] **Power Amplifier.**—N. G. Basov & A. M. Prokhorov. (*Zh. eksp. teor. Fiz.*, March 1956, Vol. 30, No. 3, pp. 560–563.) See 2931 of 1955.

538.569.4 : 621.372.029.64 **3710**

Further Aspects of the Theory of the Maser.—K. Shimoda, T. C. Wang & C. H. Townes. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1308–1321.) Problems relating to saturation effects and cavity-resonator design for the device discussed previously [e.g. 403 of February (Gordon et al.)] are examined; various types of noise and oscillator frequency shift are considered. The theoretical minimum detectable beam intensity when the maser is used as a spectrometer for the 3–3 ammonia line is about 10^9 molecules/sec under typical experimental conditions.

621.318.3 **3711**

A General-Purpose Electromagnet.—W. Sucksmith & S. P. Anderson. (*J. sci. Instrum.*, June 1956, Vol. 33, No. 6, pp. 234–236.) Details are given of a magnet for laboratory purposes, with a soft iron yoke having low residual magnetism and poles of diameter 10 cm, together with a table showing the variation of the field in the centre of the gap with excitation and gap length.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.16 **3712**

Distribution of Radio Stars.—J. G. Bolton. (*Observatory*, April 1956, Vol. 76, No. 891, pp. 62–64.) A tentative explanation is given of discrepancies between the distribution derived by Ryle from interferometer measurements at 81 Mc/s and that derived by Pawsey from Mills Cross measurements, also at 81 Mc/s, as discussed at the recent Jodrell Bank symposium.

523.16 **3713**

The Radio Source near the Galactic Centre.—B. Y. Mills. (*Observatory*, April 1956, Vol. 76, No. 891, pp. 65–67.) Recent observations on 3·5 m λ with the 'cross' aerial are discussed in relation to earlier observations on 9·4 cm and 21 cm λ. The position of the dominant source is shown on a contour map of equivalent brightness temperatures. Alternative models accounting for the observations and involving absorbing H II regions are mentioned; whichever model is assumed, the nucleus of Type-II stars in the Galaxy is not itself detectable as a r.f. source.

523.16 **3714**

Polarization Measurements on Three Intense Radio Sources.—R. H. Brown, H. P. Palmer & A. R. Thompson. (*Mon. Not. R. astr. Soc.*, 1955, Vol. 115, No. 5, pp. 487–492.) Measurements have been made on radiation of wavelength 1·9 m from sources in Cygnus, Cassiopeia and Taurus. The results indicate that there is no plane polarized component > 1% and no circularly polarized component > 4% in the flux from the first two of these sources; the corresponding figures for the source in Taurus are 2½% and 4% respectively.

523.16 : 621.396.677.833 **3715**

The George R. Agassiz Radio Telescope of Harvard Observatory.—B. J. Bok. (*Nature Lond.*, 4th Aug. 1956, Vol. 178, No. 4527, pp. 232–234.) The aerial of this 60-ft instrument is a paraboloid of expanded aluminium-wire mesh with a horn collector at the focus. At a wavelength of 21 cm the angular resolution is about 0·7°, thus the accuracy of setting and following is more than sufficient for research on discrete radio sources. The receiver is a double-conversion superheterodyne comparison radiometer with a 20-channel comb filter at the second conversion frequency. The instrument is to be used both for research and training.

523.5 **3716**

Some Factors affecting the Radio Determination of Meteoric Velocities.—D. W. R. McKinley. (*Naturwissenschaften*, May 1956, Vol. 43, No. 10, pp. 221–222. In English.) Questions raised by Hoffmeister (409 of February) are discussed further. Deceleration of meteors along the path prior to the point of measurement may be an important factor; techniques for measuring the deceleration over an appreciable path length by the radio amplitude/time method require to be developed. Existing techniques may be failing to detect faint meteors with hyperbolic orbits.

523.5 : 621.396.96 **3717**

Radar Echoes from Meteor Trails under Conditions of Severe Diffusion.—G. S. Hawkins. (*Proc. Inst. Radio Engrs*, Sept. 1956, Vol. 44, No. 9, p. 1192.) An expression is derived indicating that the power of the echo is proportional to λ^6 and to R^{-4}, where R is the range. For a given meteor velocity there is a critical height above which the effects of diffusion become serious. A graph shows the critical-height/velocity curves for values of λ between 0·5 and 16 m.

523.7 : 621.396.677.3 **3718**

The Multiple-Aerial Interferometer at the Nançay Station.—Blum, Boischot & Ginat. (See 3644.)

523.72 : 523.78 **3719**

Radio-Frequency Observations of the Solar Eclipse of June 30, 1954.—G. Eriksen, O. Hauge & E. Tandberg-Hanssen. (*Astrophys. norveg.*, Aug. 1955, Vol. 5, No. 4, pp. 131–152.) "Radio-frequency power received from the sun at wavelengths of 60 cm and 1·5 m was measured during the solar eclipse of June 30, 1954. The sun was essentially free from active areas, and the eclipse curves obtained have been used to derive models of the radio sun at the two wavelengths. These models give predicted eclipse curves in good agreement with the observed ones. Comparison has been made with models derived by other investigators on the same wavelengths."

523.746 **3720**

The Constancy of the Scale of the Relative Sunspot Numbers.—W. Gleissberg. (*Naturwissenschaften*, May 1956, Vol. 43, No. 9, p. 196.) Comparison of sunspot numbers with the Greenwich data for sunspot areas over several cycles indicates that the proportionality factor between total sunspot area and relative sunspot number increases with the latter, but there is no significant variation of the scale of the relative sunspot number.

550.38 : 523.165 **3721**

Effective Geomagnetic Equator for Cosmic Radiation.—J. A. Simpson, K. B. Fenton, J. Katzman & D. C. Rose. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, pp. 1648–1653.) The distribution of the geomagnetic field extending far from the surface of the earth is investigated by using cosmic-ray particles as probes. Measurements using the neutron intensity from the nucleonic component indicate wide discrepancies between the observations and geomagnetic coordinates derived from surface magnetic-field measurements. Some anomalous observations of cosmic rays can be explained as due to the interaction of the rotating and inclined magnetic dipole field with a highly ionized interplanetary medium. See also 2371 of August (Simpson et al.).

550.385.523.78 **3722**

Theory of Solar-Eclipse Effects on the Earth's Magnetic Field.—H. Volland. (*J. atmos. terr. Phys.*, Aug./Sept. 1956, Vol. 9, Nos. 2/3, pp. 131–143. In German.) "The deformation of the S_q current during a solar eclipse is represented by a current function S_e, which is superposed on the S_q system and moves with the eclipse. The magnetic field components of S_e are computed, and the influence of the part induced in the earth's crust is discussed."

551.5 **3723**

Upper-Air Density and Temperature by the Falling-Sphere Method.—F. L. Bartman, L. W. Chaney, L. M. Jones & V. C. Liu. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 706–712.) Technique and results are described of a method for investigating the atmosphere at heights up to 100 km. A 4-ft nylon sphere with a transponder and aerial is ejected from a rocket near the peak of its trajectory.

551.510.5 : 621.396.11 **3724**

Turbulent-Mixing Theory applied to Radio Scattering.—Silverman. (See 3853.)

551.510.534 **3725**

An Experimental Investigation of the $9{\cdot}6$-μ Band of Ozone in the Solar Spectrum.—C. D. Walshaw & R. M. Goody. (*Quart. J. R. met. Soc.*, April 1956, Vol. 82, No. 352, pp. 177–186.) Mean heights of atmospheric ozone have been investigated over a period of two years, using Strong's method (1297 of 1941). A seasonal variation is observed, with a minimum height in summer and a range of 3·4 km.

551.510.534 **3726**

Determination of the Vertical Distribution of Ozone from Emission Spectra.—R. M. Goody & W. T. Roach. (*Quart. J.R. met. Soc.*, April 1956, Vol. 82, No. 352, pp. 217–221.)

551.510.535 **3727**

Electron Density in a Nonisothermal Ionosphere.—F. Mariani. (*Ann. Geofis.*, Jan. 1956, Vol. 9, No. 1, pp. 43–62.) Continuation of work noted previously (749 of March). The difference in the calculated values of electron density when the earth's curvature is taken into account may be appreciable, especially for the winter; the corresponding difference in critical frequency may amount to 20%–25% for the period just after sunrise. Comparison of calculated and observed values of f_0F_1 suggests that a representative model of an F region can be based on the assumption that the temperature varies linearly with height up to the F_1/F_2 interface and then remains constant. The parabolic law of variation of electron density is acceptable only for heights corresponding to reflection frequencies not less than 0·7–0·8 times the critical frequency. A general expression is derived relating temperature, electron density, density of matter, recombination coefficient and absorption coefficient.

551.510.535 **3728**

Resonance Scattering by Atmospheric Sodium: Part 1—Theory of the Intensity Plateau in the Twilight Airglow.—J. W. Chamberlain. (*J. atmos. terr. Phys.*, Aug./Sept. 1956, Vol. 9, Nos. 2/3, pp. 73–89.) Numerical results based on theory of radiative transfer are compared with observations by various workers, for a layer scattering solar D-line radiation, observed in the zenith or at zenith distance 75°. Winter observations indicate an absolute brightness slightly greater than given by the theory. Abundance of Na appears to vary between 10^9 (summer) and 10^{10} (winter) atoms/cm^2 (column).

551.510.535 **3729**

The Effect of Ambipolar Diffusion in the Night-Time F Layer.—J. W. Dungey. (*J. atmos. terr. Phys.*, Aug./Sept. 1956, Vol. 9, Nos. 2/3, pp. 90–102.) The effect is examined in the light of recent low estimates of the density of neutral particles in the F layer [e.g. *Rocket Exploration of the Upper Atmosphere*, 1954, p. 347 (Bates)] and assuming that the rate of loss of electrons is proportional to the electron density, N. With certain other simplifying assumptions, N may be expressed as a sum of functions which decay exponentially with time; an approximately parabolic (Chapman) model based on the most slowly decaying of these is discussed. Correlation is found between both $f_0\,F_1$ and the magnetic C figure and the sunspot-cycle variation of the F-region temperature.

551.510.535 **3730**

Observation at Akita of Ionospheric Drift.—Y. Ogata. (*J. Radio Res. Labs, Japan*, April 1956, Vol. 3, No. 12, pp. 135–140.) Simultaneous observations of the variations with time of the virtual heights of the E, E_s and F layers were made at three observatories in Japan, during the period July–August 1955, mainly at night. Drift velocities of the layers are deduced; the results are presented in the form of histograms.

551.510.535 : [523.3 + 523.7 **3731**

Lunar Variations of the F_2 Layer at Ibadan.—R. A. Brown. (*J. atmos. terr. Phys.*, Aug./Sept. 1956, Vol. 9, Nos. 2/3, pp. 144–154.) Analysis of h_m, y_m, f_0 and h' determinations for the F_2 layer, made at Ibadan from December 1951 to April 1954, shows semidiurnal lunar variations of considerable amplitude; these variations in turn exhibit marked variations of amplitude and phase with season and with time of solar day. Values of the recombination coefficient in the layer, deduced from the luni-solar variations, decrease exponentially with increasing height.

551.510.535 : 523.78 **3732**

Behaviour of the Ionosphere at Rome during the Partial Solar Eclipse of 30th June 1954.—P. Dominici. (*Ann. Geofis.*, Jan. 1956, Vol. 9, No. 1, pp. 107–131.) Observed eclipse effects are compared with effects calculated on the assumption that the electrons are produced by photo-ionization and removed by ionic recombination or attachment to neutral atoms and molecules, and that the ionizing radiation is distributed uniformly over the visible disk of the sun. It is deduced that the electron loss rate is consistent with an ionic recombination process in the E and F_1 layers and with an attachment process in the F_2 layer. The attachment and recombination coefficients decrease with increasing height; their variations during the eclipse are related to the vertical movements of the ionosphere. Seasonal variations between effects observed in a number of eclipses are explained in terms of different degrees of superposition of the F_1 and F_2 layers. The existence of secondary minima of electron density is interpreted as indicating that a distinction must be drawn between the 'ionizing' sun and the visible sun. Eclipse effects in the E_s layer are also discussed. 62 references.

551.510.535 : 523.78 **3733**

Recombination and Attachment in the F_1 and F_2 Layers during the Solar Eclipse of 25 December 1954.—M. E. Szendrei & M. W. McElhinny. (*J. atmos. terr. Phys.*, Aug./Sept. 1956, Vol. 9, Nos. 2/3, pp. 118–130.) Examination of the variations of electron density at Grahamstown in relation to actual, rather than virtual, heights in the F region during the annular eclipse of 25th December 1954 suggests that there combination process is predominant in the F_1 region; in the F_2 region, recombination and attachment coefficients decrease regularly with height. Possible explanations of the separation of the F_1 and F_2 layers are advanced.

551.510.535 : 537.533.1 : 621.396.11 **3734**

Theory of Nonlinear Effects in the Ionosphere.—Zhevakin & Fain. (See 3856.)

551.510.535 : 621.3.087.4 **3735**

Ionospheric Sounding Equipment.—J. O. Cardus. (*Rev. Geofis., Madrid*, Oct./Dec. 1955, Vol. 14, No. 56, pp. 285–312.) The characteristics of the ionosphere are briefly reviewed and some soundings obtained at the Tortosa station, inaugurated in 1955, are reproduced. The sounding equipment installed is identical with that used by the Bureau Ionosphérique Français.

551.510.535 : 621.396.11 3736

Ionospheric Prediction Methods and the Probable Sources of Error.—Baral. (See 3854.)

551.510.535 : 621.396.11 3737

Equatorial Ionospheric Absorption.—Skinner & Wright. (See 3855.)

551.510.535 : 621.396.812.3 3738

Study of the Selective Fading appearing on the *fct*-Traces.—Uyeda & Nakata. (See 3863.)

551.594.5 3739

Height Distribution of Auroral Emissions.—L. Harang. (*J. atmos. terr. Phys.*, Aug./Sept. 1956, Vol. 9, Nos. 2/3, pp. 157–159.)

551.594.5 : 551.508 : 621.397.424 3740

Measurement of Auroral Radiation 3 200 Å with a Photon Counter (Geiger Tube).—E. V. Ashburn. (*J. atmos. terr. Phys.*, Aug./Sept. 1956, Vol. 9, Nos. 2/3, pp. 156–157.) A copper-cathode G-M counter is satisfactory for measuring this radiation.

551.594.6 : 621.396.821 3741

The Level of Interference due to Atmospherics in the Very-Long-Wave Range, and its Diurnal and Seasonal Variations.—Lauter. (See 3868.)

LOCATION AND AIDS TO NAVIGATION

621.396.96 3742

Radar Echoes from Birds and Insects.—L. L. Bonham & L. V. Blake. (*Sci. Mon.*, April 1956, Vol. 82, No. 4, pp. 204–209.) General discussion and report of observations confirming Crawford's view (2300 of 1949) that certain otherwise unexplained echoes are in fact due to birds and insects. The quantitative aspects of the phenomena are briefly touched on.

621.396.96 : 621.396.62 : 621.396.822 3743

Technical Possibilities for Noise Reduction in the Reception of Weak Radar Signals.—H. Borg. (*Ann. Télécommun.*, May 1956, Vol. 11, No. 5, pp. 90–110.) Known systems for detecting a weak signal in the presence of noise are critically reviewed. The optimum-filter method is most generally useful. Correlation methods are not directly applicable to the detection of moving targets, but are best for detecting very weak periodic signals. 40 references.

621.396.96 : 621.397.2 3744

The Transmission of Radar Displays with Compressed Bandwidth.—H. Meinke & H. Groll. (*Nachrichtentech. Z.*, May 1956, Vol. 9, No. 5, pp. 214–221.) Methods using c.r. tubes with line-storage techniques are discussed; the bandwidth can be reduced to 12 kc/s. The requirements in respect of scanning precision are stringent, but much less so than with area storage. Special pulses are used for distortion testing. Photographs show original and transmitted displays obtained at Munich using Decca radar equipment on a tower. The possibility of storing the display on magnetic tape is also discussed.

621.396.96.001.362 3745

A Synthetic Radar Trainer.—F. W. Cook. (*A.T.E. J.*, April 1956, Vol. 12, No. 2, pp. 89–100.)

621.396.962.2 : 621.376.3 3746

A Precise New System of F.M. Radar.—M. A. W. Ismail. (*Proc. Inst. Radio Engrs*, Sept. 1956, Vol. 44, No. 9, pp. 1140–1145.) A system for measurement of both range and speed of the target uses a sinusoidal rather than a symmetrical triangular frequency-modulating waveform. Relatively small frequency deviations are required, and there is no fixed error, hence short ranges can be measured accurately. Brief details are given of an altimeter based on the principles discussed.

621.396.962.3 3747

Maximum Angular Accuracy of a Pulsed Search Radar.—P. Swerling. (*Proc. Inst. Radio Engrs*, Sept. 1956, Vol. 44, No. 9, pp. 1146–1155.) "Using a result in the theory of statistical estimation, a lower bound is derived for the standard deviation of regular unbiased estimates of target angular position, for a large class of methods of angular position determination; the lower bound depends on scan rate, pulse repetition rate, beamwidth, beam shape, and signal-to-noise ratio. A similar analysis is made of the limits on angular accuracy imposed by a combination of receiver noise and one particular type of target cross section fluctuation. . . The relation between the estimation of angular position and the problem of target detection is discussed. A graphical presentation of the main results is given."

MATERIALS AND SUBSIDIARY TECHNIQUES

533.5 3748

Ionic Pump with Cold Electrodes, and its Characteristics.—E. M. Reikhrudel', G. V. Smirnitskaya & A. I. Borisenko. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 253–259.) The characteristics of an ionic pump using both an electric and a magnetic field were investigated. Pressures down to 5×10^{-8} mm Hg have been obtained in particular cases, the normal working range being 10^{-2}–10^{-7} mm Hg with air, Ne and He.

535.215 : 537.311.33 3749

Optical and Electrical Measurements on Caesium-Antimony Layers of Different Composition.—G. Wallis. (*Ann. Phys., Lpz.*, 30th April 1956, Vol. 17, Nos. 6–8, pp. 401–416.) Measurements are reported of the optical absorption and temperature dependence of conductivity for Cs-Sb layers produced by a method giving rise to a stratified structure. The absorption measurements were extended beyond the region of photosensitivity into the infrared. Values are derived and discussed for the activation energy. The nature of the particular compound formed and the influence of the crystal structure on the results are considered. The absorption of films of pure Sb and Cs at wavelengths of 400–1 800 mμ was also measured.

535.215 + 535.37] : 546.482.21 3750

Photoconductivity and Luminescence of Polycrystalline CdS(Cu).—N. A. Tolstoi, B. T. Kolomiets, O. I. Golikova & M. Ya. Tsenter. (*Zh. eksp. teor. Fiz.*, March 1956, Vol. 30, No. 3, pp. 575–576.) Brief report on results of measurements on nine CdS specimens containing up to 10^{-3} g/g Cu and one specimen containing 10^{-3} g/g Cu and 10^{-5} g/g Fe. The results are discussed in relation to the degenerate bimolecular recombination mechanism and the two-step excitation mechanism.

535.215 : 546.817.221 : 539.234 3751

Photosensitization of PbS Films.—R. H. Harada & H. T. Minden. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1258–1262.) Experiments are reported in which evaporated PbS films were treated with O_2 and the resulting changes in the photoconductive response were observed. The variations of conductance in the absence and in the presence of illumination are found to be correlated. The photoconduction response time increases monotonically as the film changes from *n* to *p* type. The results are interpreted in terms of two oxygen surface states.

535.37 3752

Excitation and Destruction of Phosphors by H^+ Ions.—H. P. Gilfrich. (*Z. Phys.*, 17th April 1956, Vol. 145, No. 2, pp. 241–248.) Measurements have been made of the reduction of luminescence intensity in various inorganic and organic phosphors bombarded by 10-kV H^+ ions. The reduction can be expressed by the formula $I/I_0 = 1/(1 + CN)$, where N is the number of ions and C is the 'destruction constant'. The value of C drops to about a tenth for each step of the series constituted by organic phosphors, sulphides, oxides and alkali halides; the nature of the activator is significant, but the activator concentration is not.

535.37 3753

Infrared Luminescence of Zinc and Cadmium Sulphide Phosphors.—P. F. Browne. (*J. Electronics*, July 1956, Vol. 2, No. 1, pp. 1–16.) Garlick & Dumbleton (3234 of 1954) have observed ZnS luminescence at wavelengths near $1{\cdot}6\,\mu$; the present author has observed corresponding bands for CdS near $1{\cdot}8\,\mu$. A detailed investigation is reported of the origin of these infrared bands and of their kinetic relations with the emission bands at shorter wavelengths and with other phenomena such as luminescence quenching and photoconductivity. A new infrared stimulation band of the visible luminescence of ZnS has been found at about $2{\cdot}55\,\mu$; this may correspond to the single thermal glow peak of these phosphors.

535.376 : 546.472.21 3754

On the Electroluminescence in ZnS Phosphor.—M. Kimata & T. Nomura. (*J. phys. Soc. Japan*, April 1956, Vol. 11, No. 4, pp. 466–467.) The interpretation of the light output characteristic for applied a.c. fields of 1 800 V/mm is discussed; the effect of d.c. bias is considered.

535.376 : 546.472.21 3755

The Effect of Electron Traps on Electroluminescence.—P. D. Johnson, W. W. Piper & F. E. Williams. (*J. electrochem. Soc.*, April 1956, Vol. 103, No. 4, pp. 221–224.) Measurements of the temperature dependence of electro- and thermo-luminescence of ZnS phosphors show that at low temperatures traps may, by field ionization, supply electrons in the region of high field strength; at higher temperatures the traps are thermally emptied, enhancing the field in the barrier region.

535.376 : 621.327.43 3756

The Voltage Drop through Phosphor Screens and its Bearing on Performance of Cathodoluminescent Lamps.—L. R. Koller. (*J. electrochem. Soc.*, April 1956, Vol. 103, No. 4, pp. 214–218.) By using a high-conductivity phosphor, such as ZnO, the major part of the voltage across a c.r. tube is made available for light excitation, thus making possible the construction of mains-voltage lamps.

537.226/.227 : [546.431.824-31 + 546.42.824-31 3757

The Production and the Dielectric and Optical Properties of Single Crystals of Solid Solutions of Barium and Strontium Titanates.—A. L. Khodakov, M. L. Sholokhovich, E. G. Fesenko & O. P. Kramarov. (*C. R. Acad. Sci. U.R.S.S.*, 11th June 1956, Vol. 108, No. 5, pp. 825–828. In Russian.) Single crystals were prepared from solutions of K_2F_2 of mixtures of Ba and Sr titanates by evaporation of the K_2F_2 at the temperature of crystallization of the solid solutions and subsequent cooling. The temperature characteristics of ϵ are shown graphically for crystals containing 10% and 50% $SrTiO_3$, respectively, before and after thermal treatment; the latter curves show maxima near the temperatures corresponding to the Curie points of polycrystalline specimens. The tan δ/temperature curve for the crystal containing 10% $SrTiO_3$, after thermal treatment, is also shown. The magnitude of tan δ determined at room temperature at a frequency of 10^6 c/s depends on the composition of the crystal and lies between 50×10^{-4} and 500×10^{-4}. Other results are tabulated and oscillograms of the polarization hysteresis effect at temperatures between 27° and 139°C in a specimen containing 5% $SrTiO_3$ are shown.

537.226/.227 : 546.431.824-31 3758

Influence of Structure on Hysteresis Effects in $BaTiO_3$ Ceramics.—W. Heywang & R. Schöfer. (*Z. angew. Phys.*, May 1956, Vol. 8, No. 5, pp. 209–213.) Difference between the hysteresis loops for coarse-grained and fine-grained material are discussed. Loop constrictions observed with coarse-grained material disappear on prolonged subjection to an alternating field. The relaxation time associated with this effect decreases as the applied alternating field increases and as the grain size increases, and also as the ferroelectric Curie point is approached.

537.226/.227 : 546.431.824-31 3759

Polarization Reversal in the Barium Titanate Hysteresis Loop.—R. Landauer, D. R. Young & M. E. Drougard. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 752–758.) The a.f. hysteresis loop of tetragonal $BaTiO_3$ is examined in relation to Merz's finding (445 of 1955) that the rate at which the polarization reverses in an applied field of intensity E is proportional to $e^{-\alpha E}$, where α depends on temperature. The switching rate adjusts to variations in the applied field with a time lag whose order of magnitude does not exceed 10^{-8} sec. The results imply that domains cross the crystal with a speed of the order of that of sound. Increases in dielectric constant measured during switching remain unexplained.

537.226 : 539.215 3760

Effective Dielectric Constant of Heterogeneous Media.—R. S. Smith. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 824–831.) A formula is derived for calculating the effective dielectric constant of powders as a function of particle shape, intrinsic dielectric constant, density of the powder, and the packing properties of elliptical particles. On inserting experimentally obtained values for various materials, including silica and polystyrene, results are obtained in agreement with those of other workers for the dielectric constants of the bulk material.

537.311.3 : 538.632 : 539.217 3761

Hall Effect and Conductivity in Porous Media.—H. J. Juretschke, R. Landauer & J. A. Swanson. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 838–839.) Formulae are derived based on the assumption that all the pores are completely surrounded by the conducting material but none of the conducting material is completely surrounded by space.

537.311.31 : 539.23 3762

The Resistivity of Very Thin Metal Films.—G. Darmois. (*C. R. Acad. Sci., Paris*, 16th July 1956, Vol. 243, No. 3, pp. 241–243.) Theory accounting for observed variations of resistivity with thickness and temperature is outlined; as the thickness is increased the conduction changes from a two-dimensional to a three-dimensional process.

537.311.31 : 546.57 : 539.234 3763

Variation of Conductivity of Thin Evaporated Films of Silver with Electrostatic Charging.—A. Deubner & K. Rambke. (*Ann. Phys., Lpz.*, 30th April

1956, Vol. 17, Nos. 6–8, pp. 317–328.) Experiments were made with the object of explaining discrepancies between observations reported previously by various workers. The results indicate that the discrepancies are probably due to the magnitude of the effect decreasing as the films age. Some related effects associated with prolonged passage of current are also discussed.

537.311.33 **3764**

The Electrical Behaviour of Bicrystal Interface Layers.—H. F. Mataré. (*Z. Phys.*, 17th April 1956, Vol. 145, No. 2, pp. 206–234.) Extension of previous investigations (e.g. 3086 of October). Methods are discussed for preparing bicrystals with desired orientation. A bicrystal with appropriately polarized interface layer exhibits transistor properties similar to those of the *n-p-n* impurity-containing transistor, with the possibility of improved h.f. performance.

537.311.33 **3765**

Formation of *p-n* Junctions in Semiconductors by the Variation of Crystal Growth Parameters.—H. E. Bridgers. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 746–751.) The dependence of the distribution of impurities between liquid and solid phases on the growth rate of crystals grown from a melt and on the amount of stirring is discussed.

537.311.33 **3766**

Theory of Transport Effects in Semiconductors: the Nernst Coefficient, and its Relation to Thermoelectric Power.—P. J. Price. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1245–1251.) Theory presented previously (1079 of April) is extended to give an expression consistent with that derived by Putley (2028 of 1955) for the complete Nernst coefficient. The information obtainable from experimental values of this coefficient and of the thermoelectric power is discussed in the light of the theory. An estimate is made of the anomaly in the Nernst coefficient due to the phonon drag effect.

537.311.33 : 061.3 **3767**

Conference on the Theory of Semiconductors.—G. E. Pikus & Yu. A. Firsov. (*Zh. tekh. Fiz.*, Nov. 1955, Vol. 25, No. 13, pp. 2381–2394.) Report of a conference held by the U.S.S.R. Academy of Sciences in Leningrad in February 1955. Extensive summaries of the papers read and the discussions are given. The papers are grouped under the following headings: theory of polarons; multi-electron theory of semiconductors; magnetic properties of semiconductors; theory of excitons; theory of mobility and of thermo- and galvano-magnetic effects; theory of liquid and amorphous semiconductors; theory of non-radiative transitions; theory of rectification; catalytic action of semiconductors. The research program decided upon by the conference is given in full.

537.311.33 : 061.3 **3768**

The Physics of Semiconductor Surfaces.—C. G. B. Garrett. (*Nature, Lond.*, 25th Aug. 1956, Vol. 178, No. 4530, p. 396.) Brief account of a conference held in Philadelphia in June 1956. The papers are to be published in book form by the University of Pennsylvania Press.

537.311.33 : 535.215 : 621.311.6 **3769**

Theoretical Considerations governing the Choice of the Optimum Semiconductor for Photovoltaic Solar-Energy Conversion.—J. J. Loferski. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 777–784.) In consequence of the modification of the spectral distribution of solar energy due to atmospheric absorption, the optimum value of the semiconductor energy gap for conversion of solar energy ranges between 1·2 and 1·6 eV for different times and locations. Possible departures of the *p-n*-junction rectifier characteristic from that indicated by simple theory may reduce the advantages of these energy-gap values over others in the range 1·1 – 2·0 eV. Calculations yield efficiency values for InP, GaAs and CdTe greater than the values predicted for Si, CdS, Se and AlSb.

537.311.33 : 535.37 **3770**

Theory of Impurity-Centre Electrons: Part 1—Optical Transitions.—G. Helmis. (*Ann. Phys., Lpz.*, 30th April 1956, Vol. 17, Nos. 6–8, pp. 356–370.) A method of calculating the probability of optical transitions at impurity centres is presented.

537.311.33 : [537.32 + 536.21 **3771**

On the Thermal Conductivity and Thermoelectric Power of Semiconductors.—D. ter Haar & A. Neaves. (*Advances Phys.*, April 1956, Vol. 5, No. 18, pp. 241–269). A comprehensive discussion of scattering mechanisms in semiconductors, neglecting the influence of deviations from spherical energy surfaces and of many-electron phenomena, and assuming only one type of carrier to be present. Six temperature ranges are hence distinguished; expressions are derived for the thermal conductivity and thermoelectric power in each range. The theoretical results are in qualitative agreement with such experimental results as are available.

537.311.33 : 537.32 **3772**

Theory of the Transverse Magneto-thermoelectric Effect in Semiconductors.—M. Rodot. (*C. R. Acad. Sci., Paris*, 9th July 1956, Vol. 243, No. 2, pp. 129–132.) The laws governing the variation of the Seeback effect in the presence of a transverse magnetic field are established, starting from Boltzmann's transport equation and assuming dispersion of charge carriers by ionization impurities.

537.311.33 : 537.32 **3773**

Thermoelectric Properties of the Compound $CrSb_2$.—N. Kh. Abrikosov & V. F. Bankina. (*C. R. Acad. Sci. U.R.S.S.*, 1st June 1956, Vol. 108, No. 4, pp. 627–628. In Russian.) The temperature coefficient of thermo-electric force of this semiconducting compound varies between $-81\,\mu$V/°C at 18°C and $-22\,\mu$V/°C at 437°C, the conductivity at these temperatures being $6{\cdot}4\,\Omega^{-1}$.cm^{-1} and $43{\cdot}6\,\Omega^{-1}$.cm^{-1}. respectively. Results of measurements between these temperatures are tabulated and the effect of a small variation of the composition of the compound on the conductivity and thermoelectric force at 550°C is shown graphically.

537.311.33 : 546.26-1. **3774**

Electronic Band Structure of Diamonds.—J. J. Brophy. (*Physica*, March 1956, Vol. 22, No. 3, pp. 156–158.) A band structure similar to that found in other group-IV elements is proposed; the differences between the various types of diamond are explained as effects of impurities.

537.311.33 : [546.28 + 546.289 **3775**

Some Defects in Crystals grown from the Melt: Part 1—Defects caused by Thermal Stresses.—E. Billig. (*Proc. roy. Soc. A.*, 10th April 1956, Vol. 235, No. 1200, pp. 37–55.) A study of monocrystals of Ge and Si pulled from the melt under extreme conditions of temperature gradient and thermal stress is reported. Reasonable correlation has been obtained between the density of the etch-pits marking the dislocations and characteristics of the ingot such as lifetime of minority carriers, transistor action and the highest inverse voltage that can be sustained at the rectifying point contact. For solid-state devices requiring material of highest perfection, the portion near the centre of the ingot is probably most suited. Eight plates showing crystal defects are included.

537.311.33 : [546.28 + 546.289 **3776**

Note on Hydrogen in Germanium and Silicon.—J. H. Crawford, Jr, H. C. Schweinler & D. K. Stevens. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 839–840.) Crystal-growing techniques for Ge and Si normally involve use of a hydrogen atmosphere; possible mechanisms of dispersal of the excess hydrogen in these materials are discussed.

537.311.33 : 546.289 **3777**

Vapor-Phase Crystal Growth of Germanium from Thermally Decomposed Germane.—M. Davis & R. F. Lever. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 835–836.) Single crystals of Ge heated to within 200°C of their melting point (936°C) have been exposed to controlled low pressures of germane (GeH_4) and the resulting crystal growths studied. Satisfactory conditions were not established for the preparation of p-n junctions by co-deposition of donor elements from their hydrides or by evaporation of acceptor elements. Photomicrographs are reproduced of several types of crystal growth observed.

537.311.33 : 546.289 **3778**

Slow Surface Reaction on Germanium.—S. R. Morrison. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1297–1301.) "An experimental study of the long decay time levels has shown that the reaction between the levels and the bulk germanium depends on the number of carriers in the germanium, on the oxygen pressure, and exponentially on the temperature. It is therefore suggested that the rate-limiting process is electron transfer over a surface barrier. A simplified model, based on this mechanism, yields adequate agreement with the present results and also with those obtained by Kingston."

537.311.33 : 546.289 **3779**

Annealing of Germanium supersaturated with Nickel.—P. Penning. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1414–1415.) The work of van der Maesen & Brenkman (3589 of 1954) is discussed and a brief report is given of experiments made to determine how the density of Ni acceptor levels changes during the annealing of a supersaturated Ge sample.

537.311.33 : 546.289 **3780**

Hole Trapping in Germanium bombarded by High-Energy Electrons.—R. G. Shulman. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, pp. 1451–1455.) From measurements of the time variation of photoconductivity in n-type Ge specimens previously bombarded by 3-MeV electrons, the existence of hole traps at a level 0·28 eV above the valence band was established. Trap densities ranged between $5 \times 10^{12}/\mathrm{cm}^3$ and $5 \times 10^{14}/\mathrm{cm}^3$ in the specimens studied.

537.311.33 : 546.289 **3781**

Copper in Germanium: Recombination Center and Trapping Center.—R. G. Shulman & B. J. Wyluda. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, pp. 1455–1457.) Measurements of the time-variation of photoconductivity of Cu-doped n- and p-type Ge specimens over the temperature range 130°–293°K indicate the presence at the lower temperatures of hole traps in the n-type specimens but not in the p type. Trap concentrations agree with the concentrations of Cu atoms to within a factor of 2, and are at least 100 times higher than for undoped crystals. The trapping level is 0·2 eV above the valence band. While the capture cross-section for holes is independent of temperature, the capture cross-section for electrons is temperature-dependent; as a result, the 0·2 eV Cu level changes from a recombination centre at room temperature to a hole trap at lower temperatures.

537.311.33 : 546.289 : 537.29 **3782**

The Field-Dependence of Electron Mobility in Germanium.—J. B. Gunn. (*J. Electronics*, July 1956, Vol. 2, No. 1, pp. 87–94.) Pulse current measurements were made on filaments and rectangular bars of 2-Ω.cm n-type Ge with uniform cross-sections of about 0·5 mm^2. Results indicate that the electron drift velocity v becomes constant for values of electric field strength E between $4{\cdot}5 \times 10^3$ and 9×10^3 V/cm. At higher values of E, v increases approximately as $E^{0\cdot134}$, avalanche multiplication apparently setting in at $E = 6{\cdot}3 \times 10^4$ V/cm.

537.311.33 : 546.289 : 537.312.8 **3783**

Weak-Field Magnetoresistance of *n*-Type Germanium.—C. Goldberg & R. E. Davis. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1254–1257.) Results of measurements over the temperature range 77°–320°K support the validity of the model which assumes that the energy surfaces are (111) ellipsoids. The most consistent analysis indicates that the mass ratio is nearly constant at about 11·9 in this temperature range but the scattering mechanism is temperature-dependent.

537.311.33 : 546.289 : 539.163 **3784**

Disintegration of Ge.—B. Crasemann, D. E. Rehfuss & H. T. Easterday. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1344–1346.)

537.311.33 : 546.289 : 541.135 **3785**

The Anode Behavior of Germanium in Aqueous Solutions.—D. R. Turner. (*J. electrochem. Soc.*, April 1956, Vol. 103, No. 4, pp. 252–256.) Results of experiments indicate that a voltage barrier forms with anodes of n-type Ge but not with p-type. Effects observed during anodic dissolution are consistent with two electrons and two holes being involved for each Ge atom dissolving.

537.311.33 : 546.3-1-28-289 **3786**

Galvanomagnetic Effects in a Semiconductor with Two Sets of Spheroidal Energy Surfaces.—M. Glicksman. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, pp. 1496–1501.) "The conductivity, Hall coefficient, and low-field magnetoresistance are calculated for a semiconductor with conduction in two sets of spheroids, one set oriented along [100] directions, the other along [111] directions in reciprocal lattice space. These calculations are used in an analysis of experimental data on alloys of twelve to seventeen percent silicon in germanium. A good fit to the data is obtained assuming such a conduction band, with the shape of the [111] spheroids similar to that found in germanium and the shape of the [100] spheroids like those in silicon. Some interband scattering is introduced to give the observed mobility variation with composition. The calculated energy separations of the [111] and the [100] minima depend strongly on the scattering assumed."

537.311.33 : 546.368.63 : 537.533.8 **3787**

Secondary Emission from Antimony-Caesium Cathode at Low Primary-Electron Energies.—E. S. Mashkova. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 260–261.) Brief report of experimental results. The threshold level for the secondary electron emission was found to coincide with the photoelectric work function; this indicates that the secondary electrons originate in the filled zone of Cs_3Sb.

537.311.33 : 546.472.21 3788

Adsorption and Surface Potential of Semiconductors: Part 2—Surface Vacancies and its Reaction with Oxygen on ZnS.—A. Kobayashi & S. Kawaji. (*J. phys. Soc. Japan*, April 1956, Vol. 11, No. 4, pp. 369–375.) Part 1: 3299 of 1955.

537.311.33 : 546.48.241.1 3789

Electrical Properties of Cadmium Telluride.—B. I. Boltaks, P. P. Konorov & O. A. Matveev. (*Zh. tekh. Fiz.*, Nov. 1955, Vol. 25, No. 13, pp. 2329–2335.) Experiments have shown a large variation in the values of activation energy for different specimens and also, for some specimens, a decrease of this energy at high temperatures. A possible explanation of these phenomena is given.

537.311.33 : 546.48.241.1 3790

The Dielectric Constant of CdTe.—D. de Nobel & D. Hofman. (*Physica*, March 1956, Vol. 22, No. 3, p. 252.) Values of ϵ obtained by measurements on p-type crystals with room-temperature resistivity $1\cdot5 \times 10^3$ Ω.cm are $10\cdot9 \pm 0\cdot3$ at 20°K and $11\cdot0 \pm 0\cdot3$ at 77°K, at frequencies up to 100 kc/s; tan δ is also tabulated.

537.311.33 : 546.482.21 3791

Evidence for Hole Mobility in CdS.—G. Diemer & W. Hoogenstraaten. (*Physica*, March 1956, Vol. 22, No. 3, p. 172.)

537.311.33 : 546.482.21 : 621.396.822 3792

Electronic Noise in CdS Single Crystals at High Field Strengths.—K. W. Böer, U. Kümmel & G. Molgedey. (*Ann. phys., Lpz.*, 30th April 1956, Vol. 17, Nos. 6–8, pp. 344–355.) Measurements were made of noise at field strengths in the region of breakdown, using a wide-band amplifier; the frequency range covered was 200 c/s–60 kc/s. The results are discussed in relation to Gisolf's theory of the fluctuations of conduction electrons (667 of 1950).

537.311.33 : [546.682.19 + 546.682.86 3793

Effective Electron Mass in Indium Arsenide and Indium Antimonide.—R. P. Chasmar & R. Stratton. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, pp. 1686–1687.) Values derived from measurements of Hall effect and thermoelectric power are discussed briefly.

537.311.33 : 546.682.86 3794

Hall Effect and Electrical Resistivity of InSb in Strong Magnetic Fields and at High Pressures.—J. Gielessen & K. H. v. Klitzing. (*Z. Phys.*, 17th April 1956, Vol. 145, No. 2, pp. 151–155.) Measurements supplementary to those of Long (161 of January) and Keyes (162 of January) are reported. The variations of Hall coefficient and resistivity with pressure are similar; it is deduced that the number of charge carriers is strongly dependent on the pressure, while the mobility is only weakly dependent.

537.311.33 : 546.811-17 3795

Hall Effect in Gray Tin Filaments.—E. E. Kohnke & A. W. Ewald. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, pp. 1481–1486.) Continuation of previous experiments [2330 of 1955 (Ewald & Kohnke)] on wires of diameter 0·1 mm. Measurements were made over the temperature range from 70° to 270°K. Expressions are derived for the temperature dependence of the charge-carrier mobilities and the energy gap, and a value is hence deduced for the effective carrier mass. There is no indication of extremely high mobility ratios such as those found in InSb.

537.311.33 : 621.396.822 3796

Electronic Noise in Semiconductors.—K. M. van Vliet & J. Blok. (*Physica*, March 1956, Vol. 22, No. 3, pp. 231–242.) The presence of three sources of fluctuations is deduced from the continuity equation for one independent variable; these fluctuations are briefly considered. A matrix equation is derived, from which the variances and covariances of several stochastic variables can be calculated if all generation and recombination probabilities are known.

538.1 : 538.22 3797

Theory of Ferro-, Para- and Ferri-magnetism.—N. S. Akulov. (*C. R. Acad. Sci. U.R.S.S.*, 1st June 1956, Vol. 108, No. 4, pp. 603–606. In Russian.)

538.22 3798

Magnetic Properties of Colloidal Nickelous Oxide.—J. T. Richardson & W. O. Milligan. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1289–1294.) Measurements of the magnetic susceptibility over the temperature range 4°–550°K are reported. The results indicate that this material may have ferromagnetic properties.

538.22 3799

Ferrimagnetism of Mn$_4$N.—R. Juza & H. Puff. (*Naturwissenschaften*, May 1956, Vol. 43, No. 10, p. 225.) A brief note on the structure and magnetic properties of the material; the effects of substituting C for the N and Cu for the Mn are discussed.

538.22 : 621.318.134 3800

An Antiferromagnetic Transition in Zinc Ferrite.—J. M. Hastings & L. M. Corliss. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, pp. 1460–1463.) From neutron diffraction measurements over the temperature range 2·7°–300°K it is inferred that Zn ferrite undergoes a transition from a paramagnetic to an antiferromagnetic state at around 9°K. A model consisting of an antiferromagnetic alternation of ferromagnetic 'bands' is discussed in relation to the observed line intensities.

538.221 3801

Temperature Dependence of the Hall Coefficients in some Copper Nickel Alloys.—F. E. Allison & E. M. Pugh. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1281–1287.)

538.221 3802

Domain Structure as affected by the Uniaxial Ferromagnetic Anisotropy induced in Cubic Solid Solutions.—M. Yamamoto, S. Taniguchi & K. Aoyagi. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1295–1297.) Experimental evidence indicates that the perminvar-type properties of Co-Ni alloys are due to stabilization of the domain walls by uniaxial anisotropy induced when the material is cooled slowly from above its Curie temperature in the absence of an external magnetic field.

538.221 3803

New Magnetic Anisotropy.—W. H. Meiklejohn & C. P. Bean. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1413–1414.) Exchange anisotropy resulting from an interaction between ferromagnetic cobalt particles and a coating of antiferromagnetic cobaltous oxide has been observed.

538.221 3804

New Low-Temperature Ferromagnets.—A. N. Holden, B. T. Matthias, P. W. Anderson & H. W. Lewis. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, p. 1463.)

Large positive susceptibilities and ferromagnetic remanence have been observed in complex cyanides of elements of the 3*d* transition group at very low temperatures.

538.221 **3805**

Powder Patterns and Magnetization Processes in High-Coercivity Alnico Magnets.—A. Kussmann & J. H. Wollenberger. (*Z. angew. Phys.*, May 1956, Vol. 8, No. 5, pp. 213–216.) The existence of domain structure has been demonstrated by means of the Bitter technique in oriented alnico specimens with a coercive force of 670 oersted. The patterns form stripes roughly in the direction of the magnetic field applied during the cooling process.

538.221 : 536.631 **3806**

Specific Heat of a Magnetite Crystal at Liquid Helium Temperatures.—J. S. Kouvel. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, pp. 1489–1490.)

538.221 : 536.7 **3807**

Components of the Thermodynamic Functions of Iron.—R. J. Weiss & K. J. Tauer. (*Phys. Rev.*, 15th June 1956, Vol. 102, No. 6, pp. 1490–1495.)

538.221 : 546.73.241 **3808**

Note on the Ferromagnetism of CoTe.—E. Uchida. (*J. phys. Soc. Japan*, April 1956, Vol. 11, No. 4, pp. 465–466.) The conclusions drawn previously (488 of February) are shown to be unjustified; the magnetic behaviour found is explained on the basis that CoTe$_x$ ($1{\cdot}00 \leqslant x \leqslant 1{\cdot}20$) is a eutectic mixture of metallic Co and a nonmagnetic compound CoTe$_{1\cdot20}$.

538.221 : 621.318.134 **3809**

Nickel Copper Ferrites for Microwave Applications.—L. G. Van Uitert. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 723–727.) Materials with relatively high density and high d.c. resistivity ($> 10^9$ Ω.cm) can be prepared by sintering Ni-Cu ferrites having a deficiency of Fe combined with small additions of Mn or Co. Magnetic saturation at room temperature varies linearly with Cu content. An anomalous break in the d.c.-resistivity/composition curve occurs at the point where the Cu/Ni ratio is 1 : 2.

546.82 : 534.86 **3810**

Application of Metal Titanium to the Acoustic Instruments, in Japan.—T. Hayasaka, K. Masuzawa, S. Nagai & M. Suzuki. (*Rep. elect. Commun. Lab., Japan*, April 1956, Vol. 4, No. 4, pp. 39–54.)

549.514.51 : [539.31 + 537.226 **3811**

Anelasticity and Dielectric Loss of Quartz.—R. K. Cook & J. H. Wasilik. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 836–837.) Additional experimental evidence is presented indicating that the effects reported by Cook & Breckenridge (1838 of 1954) and Stuart (1474 of May) are caused by the same physical mechanism.

621.3.035.4 **3812**

The Linearity of Electrolytic Impedances.—G. S. Buchanan & F. Gutmann. (*C. R. Acad. Sci., Paris*, 23rd July 1956, Vol. 243, No. 4, pp. 374–378.) It has been observed that the conductance of an electrolyte measured at a given frequency is totally independent of the presence or absence of a field at a different frequency. This phenomenon is explained as resulting from the presence of a double layer which introduces a capacitance so large that its reactance is negligible in comparison with the series resistance of the solution, even at very low frequencies.

621.3.066.6 **3813**

Electrical Contacts.—J. T. Pender. (*Elect. J.*, 6th April 1956, Vol. 156, No. 4060, pp. 1064–1068.) Aspects of theory, design and choice of materials are discussed. See also *ibid.*, pp. 1069–1071.

621.315.61 : 539.16 **3814**

Impact of High-Energy Radiation on Dielectrics.—A. E. Javitz. (*Elect. Mfg*, June 1955, Vol. 55, No. 6, pp. 85–104.) A survey of the mechanical and electrical effects of particle irradiation on various dielectric materials, particularly plastics.

621.315.612.4 : 546.431.824-31 **3815**

Antimonates as Additives to Barium Titanate Dielectric Bodies.—W. W. Coffeen. (*J. Amer. ceram. Soc.*, 1st April 1956, Vol. 39, No. 4, pp. 154–158.) Additions of the antimoniates of Na, Li, Ba, Sr and Pb to BaTiO$_3$ caused depression of the Curie peak; dielectric constants of 2 000 or less were observed for these compounds, showing little variation with temperature. Addition of Mg$_2$Sb$_2$O$_7$ produced a marked downward shift in the temperature of the Curie peak.

621.315.613.1 **3816**

X-Ray Diffraction Studies of some Mica Species of India.—N. S. Nampoothiry & R. V. G. S. Rao. (*J. Indian Inst. Sci.*, Section A, April 1956, Vol. 38, No. 2, pp. 100–107.)

621.315.616 : 621.396.822 **3817**

Some Recent Studies of Random Noise between Metals and Dielectrics.—S. I. Reynolds. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 728–734.) Experiments supplementary to those described previously [e.g. 3478 of 1952 (Bauss & Boyer)] were made to determine the origins of noise in thin layers of polymeric insulating materials. Application of a direct voltage of 300 V to dry films was sufficient to give rise to a steady noise voltage if the electrodes were not in intimate contact. Noise observed on reversing a voltage up to 1 425 V applied to a two-phase dielectric ceased when the current reached its steady value. The methods described are useful for detecting ionization in very small voids.

621.791.3 : 546.28 **3818**

Five Metal Hydrides as Alloying Agents on Silicon.—M. V. Sullivan & J. H. Eigler. (*J. electrochem. Soc.*, April 1956, Vol. 103, No. 4, pp. 218–220.) The hydrides of Ti, V, Zr, Nb and Ta are found to be effective as fluxes in soldering contacts to both *n*- and *p*-type Si.

MATHEMATICS

517.632 **3819**

Inverse Laplace Transforms expressed as Neumann Series.—E. Cambi. (*J. Math. Phys.*, April 1956, Vol. 35, No. 1, pp. 114–122.)

517.9 **3820**

On the Classification of the Ordinary Differential Equations of Field Theory.—P. Moon & D. E. Spencer. (*Quart. appl. Math.*, April 1956, Vol. 14, No. 1, pp. 1–10.)

517.9 : 681.142 **3821**

Extension of Field of Application of Relaxation Methods of Computation.—B. E. Knight: D. N. de G. Allen. (*Nature, Lond.*, 25th Aug. 1956, Vol. 178, No. 4530, pp. 433–434.) The possibilities of solving linear and nonlinear partial differential equations by relaxation methods, using computers, are discussed.

MEASUREMENTS AND TEST GEAR

53.087.9 3822

A Semi-automatic Pen-Recorder Chart Analyser.—C. W. Spencer & G. H. Bazzard. (*J. sci. Instrum.*, June 1956, Vol. 33, No. 6, pp. 228–229.) The contact arm of a multi-contact switch connected to a pulse generator is made to follow the chart trace. Counters brought into circuit by the moving switch arm record pulse counts proportional to the time the trace is between pre-selected levels.

531.761 + 529.7 + 621.3.018.41(083.74) 3823

Standards of Time and Frequency.—G. M. Clemence. (*Science*, 6th April 1956, Vol. 123, No. 3197, pp. 567–573.) Basic concepts are reviewed. Problems involved in the concurrent use of an atomic and an astronomical standard are discussed. See also 1153 of April.

621.317.3 : 537.311.33 3824

Contactless Method for the Estimation of Resistivity and Lifetime of Semiconductors.—H. K. Henisch & J. Zucker. (*Rev. sci. Instrum.*, June 1956, Vol. 27, No. 6, pp. 409–410.)

621.317.3.029.63 : 621.396.822 3825

Noise Measurements in the 3-cm Waveband using a Hot Source.—H. Sutcliffe. (*Proc. Instn elect. Engrs*, Part B, Sept. 1956, Vol. 103, No. 11, pp. 673–677.) "The method discussed uses the noise power produced in a waveguide termination at temperatures up to 600°C as a standard source of low-level power. A suitable type of hot source and associated waveguide and detecting circuits are described. Some experimental results are given of measurements on the effective temperature of a gas-discharge tube used as a secondary standard source."

621.317.32 : 621.396.621 : 621.376.3 3826

Measurements of Interference Radiation from F.M. Receivers, carried out in Switzerland by a Group of Experts of the International Electrotechnical Commission Subcommittee 12-1 (Radio Communications—S.C. Measurements).—J. Meyer de Stadelhofen. (*Tech. Mitt. schweiz. Telegr.-Teleph Verw.*, 1st April 1956, Vol. 34, No. 4, pp. 158–166. In French.) Measurements were made on 14 f.m. receivers from six different countries, using various methods, the main features of which are tabulated. Measurements at distances of 30, 10 and 3 m give practically equivalent results. The Seright-Anderson method, in which the measurements are made at a distance of 3 m, is probably most suitable for standardization.

621.317.6 : 519.272.1 3827

Technique for Approximate Measurement of Correlation Coefficients.—T. P. Goodman. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 773–775.) "This method makes use of simple analog-computing elements to obtain the coefficient of linear regression of one variable on the other. Its use in connection with an oscilloscope display of the two variables is described, and the relation between these displays and the Lissajous figure formed by two sinusoids is discussed. A possible design for a direct-reading correlation meter is suggested."

621.317.6 : 621.396.822 3828

Calculating Noise Level in Radar Receivers.—D. W. Haney. (*Tele-Tech & Electronic Ind.*, May 1956, Vol. 15, No. 5, pp. 74–75 . . 123.) For a receiver in which the second detector is a valve diode, the r.m.s. noise level is derived simply in terms of equivalent input voltage from the r.f.-input/second-detector-output characteristic. The method is based on the theory of Rice for nonlinear detectors (2168 and 2169 of 1945); its application to the present case is justified theoretically and an experimental verification is described.

621.317.7.029.63 : 537.54 : 621.396.822 3829

Absolute Calibration of a Standard-Temperature Noise Source for Use with S-Band Radiometers.—V. A. Hughes. (*Proc. Instn elect. Engrs*, Part B, Sept. 1956, Vol. 103, No. 11, pp. 669–672.) "To provide a standard-temperature noise source for use with S-band radiometers, the noise power from the argon discharge tube CV1881 has been calibrated at 2 860 Mc/s using radiometer techniques. The absolute value of the effective temperature of the tube with a discharge current of 180 mA, when mounted across a waveguide parallel to the E-plane and properly matched, is 11 140°K (15·73 dB) with a maximum error of 260°K (0·10 dB), and represents a considerable improvement in accuracy over previous measurements. Since this tube shows a high degree of stability and consistency it is suggested that it could be used as an absolute standard of noise source for the measurement of the noise factor of receivers."

621.317.7.087.6 3830

Servo-Operated Recording Instruments.—A. J. Maddock. (*Proc. Instn elect. Engrs*, Part B, Sept. 1956, Vol. 103, No. 11, pp. 617–632.) A historical review of these instruments is presented, followed by a detailed discussion of the principal modern types, classified according to the circuit component which is varied to produce balance; this may be a resistor, a capacitor, or an electromagnetic device. Function plotters, scanning recorders and other special types are included.

621.317.715.087 3831

Wide-Amplitude String Galvanometer for Direct Recording.—L. B. Browder. (*Rev. sci. Instrum.*, June 1956, Vol. 27, No. 6, pp. 363–368.) The use of compliant end supports for the string makes possible an extended frequency range; a string 10 cm long, having a resonant frequency of 230 c/s, can be made to vibrate with an amplitude of 2·5 cm.

621.317.725/.726 3832

The Modern Valve Voltmeter and its Uses.—G. Hitchcox. (*Brit. Commun. Electronics*, May 1956, Vol. 3, No. 5, pp. 238–242.) The short survey presented includes descriptions of seven modern types of instrument and a guide to the selection of instruments for various applications. The characteristics of 27 instruments, mainly of British manufacture, are tabulated.

621.317.729.1 : 681.142 3833

An Automatic Electron-Trajectory Tracer.—H. I. Pizer, J. G. Yates & K. F. Sander. (*J. Electronics*, July 1956, Vol. 2, No. 1, pp. 65–86.) Field measurements are made using an electrolytic tank, and the equations of electron motion are hence derived using a specially designed digital computer. The results of the computation are fed back to the tank so that the measuring probes automatically trace the required trajectory.

621.317.74 : 621.397.6.001.4 3834

Portable Color-Signal Generator.—J. R. Popkin-Clurman. (*Electronics*, Sept. 1956, Vol. 29, No. 9, pp. 170–172.) The circuit described provides a signal including a horizontal synchronizing pulse, a 3·58-Mc/s reference burst and black, colour and white bars.

621.317.77 3835

A Fast-Acting Phase-Conscious Indicator.—D. L. Davies. (*Electronic Engng*, Sept. 1956, Vol. 28, No. 343, pp. 385–387.) A phase-sensitive rectifier circuit consists of two similar cathode followers connected in parallel and gated by applying to the grids rectangular-waveform voltages of signal frequency, 180° out of phase. In an instrument designed to operate over the frequency range 60 c/s–24 kc/s, second- and third-harmonic rejection and quadrature-signal rejection were all > 100/1.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

531.768 : 551.51 3836

Transit-Time Accelerometer.—L. M. Jones. (*Rev. sci. Instrum.*, June 1956, Vol. 27, No. 6, pp. 374–377.) A device is described for measuring the drag acceleration of spheres dropped from rockets, thus permitting the density and temperature of the upper atmosphere to be determined. A bobbin is periodically held and released within a cavity contained in the falling sphere; the time taken for the released bobbin to reach the cavity wall is measured. A range from $5 \times 10^{-3}\,g$ to $5\,g$ is covered.

535.82 : 621.397.6 3837

Television Microscopy.—W. Köhler. (*Optik, Stuttgart*, 1956, Vol. 13, No. 4, pp. 186–191.) Apparatus combining an ordinary microscope with electronic pickup and reproduction of the image is discussed. Both photoemissive and photoconductive pickup tubes have been used. One of the advantages of the system over the usual optical projection system is that contrast can be controlled to some extent, leading to improved resolution in some cases.

539.172.4 : 621.317.7 : 621-52 3838

Control of Nuclear Reactors.—(*Proc. Instn elect. Engrs*, Part B, Sept. 1956, Vol. 103, No. 11, pp. 564–616.) Four papers and discussion dealing with experimental reactors are presented:—

The Control and Instrumentation of a Nuclear Reactor.—A. B. Gillespie (pp. 564–576).

The Control of Nuclear Reactors.—R. J. Cox & J. Walker (pp. 577–589).

Nuclear-Reactor-Control Ionization Chambers.—W. Abson & F. Wade (pp. 590–596).

Some Design Aspects of Nuclear-Reactor Control Mechanisms.—G. E. Lockett (pp. 597–607).

Discussion (pp. 607–616).

550.837 : 538.556.2.029.42 3839

Possibility of using the Intrinsic Electromagnetic Field Impedance of the Earth for investigating its Upper Layers.—A. N. Tikhonov & D. N. Shakhsuvarov. (*Bull. Acad. Sci. U.R.S.S., sér. géophys.*, April 1956, No. 4, pp. 410–418. In Russian.) The use of v.l.f. e.m. waves for investigating stratified conducting media is considered theoretically and some quantitative calculated results are given.

621.316.825 : 616-7 3840

Thermistor Hypodermic Needle for Subcutaneous Temperature Measurement.—J. Krog. (*Rev. sci. Instrum.*, June 1956, Vol. 27, No. 6, pp. 408–409.)

621.317.39 : 531.77 3841

Potentiometer Tachometer has High Sensitivity.—G. M. Davidson & M. Pavalow. (*Electronics*, Sept. 1956, Vol. 29, No. 9, pp. 158–161.) By using a linear potentiometer transducer to feed a differentiating operational amplifier a direct output voltage proportional to the input rate is obtained. Rotation in either direction may be measured by using duplicate channels suitably switched. An accuracy within about 0·5% is obtained without special temperature compensation; the minimum speed measurable is 1/200 rev/min, with a range of 16 000 : 1.

621.327.43 : 535.376 3842

The Voltage Drop through Phosphor Screens and its Bearing on Performance of Cathodoluminescent Lamps.—Koller. (See 3756.)

621.365.55 3843

The Electric Field of a Dielectric Heating Work Circuit.—N. H. Langton & E. E. Gunn. (*J. Brit. Instn Radio Engrs*, Aug. 1956, Vol. 16, No. 8, pp. 414–424.) A theoretical investigation is made of work circuits in which the lower capacitor plate is larger than the upper; the fringing effect and the relation between specimen and capacitor-plate dimensions are studied. Some experiments on field plotting using an electrolytic analogue are described.

621.383.5 : 531.745 3844

Balloon-Borne System for tracking the Sun.—H. D. Edwards, A. Goddard, Jr, M. Juza, T. Maher & F. Speck. (*Rev. sci. Instrum.*, June 1956, Vol. 27, No. 6, pp. 381–385.) Photoelectrically controlled apparatus weighing 125 lb is described, capable of pointing a 20-lb load at a predetermined elevation and azimuth with an accuracy of ± 15′. Results of balloon flights attaining an altitude > 100 000 ft are given.

621.384.6 : 621.319.339 3845

Some Problems on the Design and Construction of Nuclear-Physics Particle Accelerators for Particle Energies of a few MeV.—K. Simonyi. (*Nuovo Cim.*, 1956, Vol. 3, Supplement, No. 3, pp. 345–362. In German.) Particles of energies down to 0·03 MeV are useful for research and practical applications. The range of applications corresponding to different ranges of energy values is shown graphically; for energies up to a few MeV, direct accelerators with cascade or Van de Graaff generators are used. A model with a Van de Graaff generator developed at Budapest is described. The same material is presented in two consecutive papers, in German, in *Acta tech. Acad. Sci. hungaricae*, 1956, Vol. 15, Nos. 1/2, pp. 191–204.

621.384.612 3846

Storage-Ring Synchrotron: Device for High-Energy Physics Research.—G. K. O'Neill. (*Phys. Rev.*, 1st June 1956, Vol. 102, No. 5, pp. 1418–1419.) Increased energy is made available, in an accelerator with a strong, well focused external beam, by means of two 'storage rings' comprising focusing magnets with straight sections built near the accelerator and operated at a high fixed field strength. Each ring contains a set of foils shaped so as to prevent the beams striking the inflectors.

621.385.83 : 621.386.1 3847

Electron Optics of X-Ray Tubes and the Design of Unbiased Sharply-Focusing Cathodes.—A. R. Lang & D. A. G. Broad. (*Brit. J. appl. Phys.*, June 1956, Vol. 7, No. 6, pp. 221–226.)

621.385.833 3848

Investigation of Nonrotationally Symmetrical Electrostatic Electron Optical Lenses.—R. F. Whitmer. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 808–815.) Analysis is presented for a two-cylinder lens.

621.385.833 3849

Practical Realization of a Magnetic Four-Pole Lens for Very-High-Frequency Particles.—A. Septier. (*C. R. Acad. Sci., Paris*, 9th July 1956, Vol. 243, No. 2, pp. 132–135.) A lens for focusing 50-MeV protons, with a focal length variable between 0·8 and 3 m, uses an electromagnet with four pole pieces formed by portions of circular cylinder.

621.387.4 : 621.374.32 3850

A Direct-Reading Counting-Rate Ratio Meter.—H. Miwa. (*J. phys. Soc. Japan*, April 1956, Vol. 11, No. 4, pp. 458–462.) A nonlogarithmic instrument for determining the ratio between two radiation-counting rates comprises a sawtooth voltage generator whose output is proportional to the period of one pulse train and is used to modulate the height of rectangular pulses synchronized with the second pulse train.

621.398 3851

Bandwidth Requirements of F.M./F.M. Telemetering.—J. C. Carpenter, Jr. (*Tele-Tech & Electronic Ind.*, May 1956, Vol. 15, No. 5, pp. 79 . . 147.)

621.385.833 3852

Handbuch der Physik, Band 33: Korpuskularoptik. [Book Review]—S. Flügge (Ed.). Publishers: Springer, Berlin, 1956, 702 pp., D.M. 122.50. (*Nature, Lond.*, 11th Aug. 1956, Vol. 178, No. 4528, pp. 285–286.) A comprehensive treatment of the optics of charged particles and of the electron microscope.

PROPAGATION OF WAVES

621.396.11 : 551.510.5 3853

Turbulent-Mixing Theory applied to Radio Scattering.—R. A. Silverman. (*J. appl. Phys.*, July 1956, Vol. 27, No. 7, pp. 699–705.) Scattering due to refractive-index fluctuations in the troposphere and ionosphere is discussed using statistical theory developed by Obukhov (1928 of 1949) and applied by Krasil'nikov (2024 of 1949). For the ionospheric case, the theoretical results are in order-of-magnitude agreement with the observed scattered power if the refractive-index fluctuations are attributed to electron-density fluctuations produced by turbulent mixing at the lower edge of the E layer. For the tropospheric case, order-of-magnitude agreement is obtained, except for the summer months, by attributing the refractive-index variations to temperature variations. Humidity and its fluctuations are important during the summer and at low scattering heights. The results are compared with those obtained by Villars & Weisskopf (244 of January).

621.396.11 : 551.510.535 3854

Ionospheric Prediction Methods and the Probable Sources of Error.—S. S. Baral. (*Indian J. Phys.*, April 1956, Vol. 30, No. 4, pp. 189–205.) Methods in current use for forecasting ionospheric characteristics are reviewed. An indication is given of the reduction of errors to be expected as greater accuracy is achieved in forecasting sunspot numbers and diurnal and seasonal variations, and in estimating geographical variations.

621.396.11 : 551.510.535 3855

Equatorial Ionospheric Absorption.—N. J. Skinner & R. W. Wright. (*J. atmos. terr. Phys.*, Aug./Sept. 1956, Vol. 9, Nos. 2/3, pp. 103–117.) Vertical-incidence absorption measurements made at Ibadan during the period December 1953–December 1954 are studied. Nondeviative absorption appears to vary inversely with frequency; total absorption varies as $(\cos \chi)^n$, where χ is the sun's zenith distance and n is about 0·7. These variations are accounted for by assuming that the nondeviative absorption takes place in a Chapman-type D layer at a level where the electron collision frequency is of the same order as the angular frequency of the exploring signal. The frequency and seasonal variations at Singapore are similar to those at Ibadan.

621.396.11 : 551.510.535 : 537.533.1 3856

Theory of Nonlinear Effects in the Ionosphere.—S. A. Zhevakin & V. M. Fain. (*Zh. eksp. teor. Fiz.*, March 1956, Vol. 30, No. 3, pp. 518–527.) A theory of the Luxemburg and other nonlinear effects is developed on the basis of work noted in 79 of January (Fain). The self-demodulation effect [e.g. 1167 of 1954 (Cutolo)] could be utilized in an experimental determination of the effective electron-collision frequency.

621.396.11.029.51.08 3857

Low-Frequency Ground Waves. Equipment for the Measurement of the Phase Change with Distance.—G. E. Ashwell & C. S. Fowler. (*Wireless Engr*, Oct. 1956, Vol. 33, No. 10, pp. 245–250.) "The equipment described was developed to investigate the phase change with distance of a low-frequency wave passing over ground of finite conductivity and, in particular, the changes that occur near a boundary between grounds of different conductivities or across a coastline. The method employs a u.h.f. link between a fixed monitor station and a mobile measuring station to provide a reference signal against which the phase of the low-frequency signal is compared at the measuring station. The equipment is capable of operating over distances of up to 50 km and measures the phase to an accuracy of 2° at a frequency of 127·5 kc/s."

621.396.11.029.53/.55 : 523.78 3858

Sweep-Frequency Oblique-Incidence Experiments over a Distance of 1 320 km.—H. G. Möller. (*J. atmos. terr. Phys.*, Aug./Sept. 1956, Vol. 9, Nos. 2/3, pp. 155–156.) A preliminary note giving the main results of an investigation into the effects of the solar eclipse of 30th June 1954 on propagation between Lindau and Helsinki.

621.396.11.029.55 3859

An Estimate of the Size of the Antipodal Area in Short-Wave Radio Propagation.—H. A. Whale. (*J. atmos. terr. Phys.*, Aug./Sept. 1956, Vol. 9, Nos. 2/3, pp. 159–161.) From measurements made at Seagrove, Auckland, N.Z., of the elevation and bearing angles of arrival of transmissions on a frequency of 14·975 Mc/s from Slough, England, it is deduced that the antipodal area was about 550 km in radius, centred on the geometric antipodal point.

621.396.11.029.6 3860

Extended Transmission Ranges at Metre, Decimetre and Centimetre Wavelengths.—H. Poeverlein. (*Z. angew. Phys.*, May 1956, Vol. 8, No. 5, pp. 244–254.) A survey of typical modes of propagation giving rise to extended-range reception; over 60 references.

621.396.11.029.64 3861

Radio Transmission Experiments of Microwaves over the Sea.—M. Onoue, M. Nenohi, R. Usui & H. Irie. (*J. Radio Res. Labs, Japan*, April 1956, Vol. 3, No. 12, pp. 141–147.) Measurements of signal strength and direction of arrival for transmissions on a frequency of 9·375 kMc/s, over a distance of 77 km during the period September 1954–September 1955 are reported. Duct propagation is indicated.

621.396.11.029.65 : 535.343.4 **3862**

Measurement of Atmospheric Attenuation at Millimeter Wavelengths.—A. B. Crawford & D. C. Hogg. (*Bell Syst. tech. J.*, July 1956, Vol. 35, No. 4, pp. 907–916.) Technique is described in which a variable-frequency oscillation from a klystron generator is radiated from a horn aerial and reflected back by a pair of spaced corner reflectors whose relative reflecting properties are known. Absorption measurements in the wavelength range 5–6 mm are reported; the results are in good agreement with Van Vleck's theory of oxygen absorption (3098 of 1947).

621.396.812.3 : 551.510.535 **3863**

Study of the Selective Fading appearing on the *fct*-Traces.—H. Uyeda & Y. Nakata. (*J. Radio Res. Labs, Japan*, April 1956, Vol. 3, No. 12, pp. 119–133.) Records of the variation of critical frequency with time for the F_2 and E_s layers show evidence of selective fading caused by interference between waves reflected from the sides of ripples in the layers. The mechanism of the fading and its bearing on layer structure are discussed.

RECEPTION

621.396.621 : 621.376.3 : 621.317.32 **3864**

Measurements of Interference Radiation from F.M. Receivers, carried out in Switzerland by a Group of Experts of the International Electrotechnical Commission Subcommittee 12-1 (Radio Communications—S.C. Measurements).—Meyer de Stadelhofen. (See 3826.)

621.396.621 : 621.376.33 **3865**

F.M. Receiver Design.—L. W. Johnson. (*Wireless World*, Oct. 1956, Vol. 62, No. 10, pp. 497–502.) Methods are reviewed for improving the capture ratio of f.m. receivers, with the object of overcoming multipath, co-channel and other types of interference. The bandwidth required in the circuits following the limiter depends on the desired capture ratio as well as on the frequency deviation. Principles developed at the Massachusetts Institute of Technology are explained and their application in receiver design is illustrated. Desirable characteristics can be obtained by use of wide-band modifications of the ratio detector in conjunction with preceding limiters. Use of the Type-6BN6 gated-beam valve simply as a limiter is recommended. Locked-oscillator and counter-type detectors are also discussed.

621.396.621.54 **3866**

Alignment Problems with Tuned Circuits in Superheterodyne Receivers.—W. Rotkiewicz. (*Hochfrequenztech. u. Elektroakust.*, April 1956, Vol. 64, No. 5, pp. 144–154.) Design formulạe are derived for the r.f. and oscillator circuits. A method is developed in which the alignment errors are analysed first and the tuned circuits are then calculated. The interaction between a fixed-tuned primary and a variable-tuned secondary circuit is considered in relation to the alignment.

621.396.82 + 621.397.82 **3867**

Radio and Television Interference.—M. Smith. (*J. Brit. Instn Radio Engrs*, Aug. 1956, Vol. 16, No. 8, pp. 444–449. Discussion, pp. 449–452.) "A survey is given of the principle causes of interference to domestic radio and television; methods of detection and suppression of the various types of interference are also described, with particular reference to the work of the British Post Office investigating branch."

621.396.821 : 551.594.6 **3868**

The Level of Interference due to Atmospherics in the Very-Long-Wave Range, and its Diurnal and Seasonal Variations.—E. A. Lauter. (*Z. Met.*, April 1956, Vol. 10, No. 4, pp. 110–121.) Measurement procedure and definitions are discussed on the basis of observations of the frequency distribution of atmospherics at Kühlungsborn and the geographical distribution of the sources. Observations made over the period 1952–1954 on frequencies of 14, 27 and 48 kc/s are analysed and correlated with ionospheric propagation conditions. Results indicate that in winter the frequency dependence of the propagation conditions is the predominating influence on the diurnal variation of the atmospherics level, whereas in summer the approach of the disturbance centres is more important. Interdiurnal variations, twilight effect and solar-flare effect are mentioned briefly.

621.396.822 : 621.317.6 **3869**

Calculating Noise Level in Radar Receivers.—Haney. (See 3828.)

621.396.822 : 621.396.62 : 621.396.96 **3870**

Technical Possibilities for Noise Reduction in the Reception of Weak Radar Signals.—Borg. (See 3743.)

STATIONS AND COMMUNICATION SYSTEMS

621.39 : 534.7 **3871**

Speech Communication Research Symposium.—(See 3608.)

621.39 : 534.78 **3872**

The Intelligibility of Amplitude-Limited Speech.—Schneider. (See 3614.)

621.39 : 534.78 **3873**

A Development of the Collard Principle of Articulation Calculation.—D. L. Richards & R. B. Archbold. (*Proc. Instn elect. Engrs*, Part B, Sept. 1956, Vol. 103, No. 11, pp. 679–691.)

621.39 : 534.78 **3874**

Bandwidth and Channel Capacity Necessary to transmit the Formant Information of Speech.—J. L. Flanagan. (*J. acoust. Soc. Amer.*, July 1956, Vol. 28, No. 4, pp. 592–596.)

621.39.001.11 **3875**

A New Interpretation of Information Rate.—J. L. Kelly, Jr. (*Bell Syst. tech. J.*, July 1956, Vol. 35, No. 4, pp. 917–926.)

621.39.001.11 **3876**

Interference Stability of Systems with Correcting Codes.—V. I. Siforov. (*Radiotekhnika i Elektronika*, Feb. 1956, Vol. 1, No. 2, pp. 131–142.) Relations are derived connecting the interference stability of communication systems with the parameters of the correcting codes used.

621.395.97 : 621.395.82 **3877**

The Influence of Long-Wave Transmissions on High-Frequency Diffusion of Programs on Overhead Telephone Lines.—R. Kallen. (*Tech. Mitt. schweiz. Telegr.-TelephVerw.*, 1st April 1956, Vol. 34, No. 4, pp. 145–157. In German.) An investigation was made of the possibility of improving signal/noise ratio while retaining the use of ordinary unstranded conductors. Both from theoretical considerations and from measurements, it appears that artificial balancing of the overhead lines would be ineffective. Arrangements for obtaining the best inherent symmetry are indicated.

621.396.41 : 621.376.55 3878

New Developments in Time-Sharing Multiplex Systems for Regional [radio] Telephone Links.—L. J. Libois. (*Électronique*, April 1956, No. 113, pp. 18–23.) For short-distance links, time-sharing systems with up to 24 channels are suitable. An a.m. carrier of 2 kMc/s or a f.m. carrier of 7 kMc/s is used in conjunction with p.p.m. The pulse waveform is symmetrical about zero, thus there is no d.c. component; this waveform is advantageous as regards signal/noise ratio. Appropriate transmitting and receiving equipment is outlined; a common aerial is used. The performance is adequate for transmission over some hundreds of km, using a number of sections. Systems of this type have been provisionally standardized by the C.C.I.R.; a link is installed between Bagnères-de-Bigorre and the Pic du Midi, about 15 km away.

621.396.65.029.62 : 621.396.41 3879

A Long-Distance V.H.F. Radio Link.—P. Brocklesby & P. Robinson. (*A.T.E. J.*, April 1956, Vol. 12, No. 2, pp. 78–88.) Four separate radio links on frequencies between 40 and 50 Mc/s are provided over a 200-mile path between the Shetlands and Norway, the path attenuation being 155 dB with 20 dB fading. Twelve f.m. carrier channels and four service channels are available, with a maximum modulation frequency of 12·2 kc/s.

621.396.712.3 : 534.86 3880

Modern Broadcasting Studios: Marseilles.—Pujolle. (See 3625.)

621.396.813 : 534.861 3881

The Receiving Side of a Radio Broadcast Transmission and its Influence on the Audio-Frequency Bandwidth.—W. Ebert. (*Tech. Mitt. schweiz. Telegr.-Teleph Verw.*, 1st April 1956, Vol. 34, No. 4, pp. 166–171. In German.) The effect of the different parts of the transmission chain on reproduction quality, previously discussed by Furrer et al. (1787 of 1949), is re-assessed in relation to f.m. v.h.f. systems. The loudspeaker still constitutes the most critical element from the point of view of bandwidth. It seems unlikely that any substantial improvement of quality would result if the a.f. transmission band were increased from 10 to 15 kc/s, except in the case of receivers equipped with suitable loudspeaker combinations.

621.396.93 : 621.396.6 3882

Generation of Transmission and Local-Oscillator Frequencies in [mobile] Transmitters and Receivers.—F. Läng. (*Bull. schweiz. elektrotech. Ver.*, 12th May 1956, Vol. 47, No. 10, pp. 458, 467–475.) Frequency-stability requirements are formulated on the basis of an examination of the effects of instability on signal/noise ratio and transmission quality. Only f.m. and ph.m. systems for the frequency band 30–500 Mc/s are considered. Methods of deriving the transmission frequency from quartz oscillators are outlined. Problems connected with channel switching and with the production of parasitic frequencies are discussed.

621.396.93.029.51 : 621.314.7 3883

Transistor-Operated Personnel Paging System.—(*Brit. Commun. Electronics*, May 1956, Vol. 3, No. 5, pp. 252–253.) The system comprises a 25-W transmitter, crystal-controlled on any one of up to 50 channels and feeding a loop surrounding the building, together with up to 50 pocket-size selective transistor receivers. The frequency band used is 75–87 kc/s; channel separation is 250 c/s. Apparatus serving a similar purpose is described in *Wireless World*, Nov. 1956, Vol. 62, No. 11, pp. 520–521.

621.396.931.029.62 3884

Mobile Radio Development.—J. R. Humphreys. (*Wireless World*, Oct. 1956, Vol. 62, No. 10, pp. 481–485.) The problem of channel congestion in the 71·5–88 and 156–184-Mc/s bands in the U.K. is reviewed with reference to the impending reduction of the upper limit to 174 Mc/s. Frequency stability, permitted power, geographical spacing of stations and the use of split channels are discussed in relation to equipment design for a suggested basic channel spacing of 25 kc/s.

621.396.933 3885

Symposium on Aeronautical Communications.—(*Trans. Inst. Radio Engrs*, May 1956, Vol. CS-4, No. 2, pp. 3–143.) The text is given of 17 papers presented at a symposium held at Utica, New York, in November 1955. Abstracts of most of these papers are given in *Proc. Inst. Radio Engrs*, July 1956, Vol. 44, No. 7, pp. 954–955.

SUBSIDIARY APPARATUS

621.311.6 : 537.311.33 : 535.215 3886

Theoretical Considerations governing the Choice of the Optimum Semiconductor for Photovoltaic Solar Energy Conversion.—Loferski. (See 3769.)

621.311.6 : 621.373.52 : 621.397.6 3887

C.R.T. Power Supply uses Transistor Oscillator.—P. M. Toscano & J. B. Heffner. (*Electronics*, Sept. 1956, Vol. 29, No. 9, pp. 162–165.) A 12·5-kc/s positive-feedback oscillator using a Ge transistor provides an output voltage which is doubled, rectified and stabilized at 10 kV. A collector supply of –30 V is the only external power required. For 1-mA output current the overall efficiency is 64%.

621.314.6 3888

Characteristics for Half-Wave Rectifier Circuits.—H. A. Enge. (*Electronic Engng*, Sept. 1956, Vol. 28, No. 343, pp. 401–406.) " Voltage regulation characteristics, form factor, first harmonic, and peak current values are given for half wave rectifiers with common type loads. All in non-dimensional variables."

621.314.63 : 546.28 3889

Silicon Junction Power Diodes.—D. E. Mason, A. A. Shepherd & W. M. Walbank. (*J. Brit. Instn Radio Engrs*, Aug. 1956, Vol. 16, No. 8, pp. 431–441.) Simplified semiconductor theory is presented and a description is given of three main methods of making *p-n* junction diodes and of the properties of the diodes. Advantageous features and appropriate applications of these rectifiers are indicated.

621.316.722.1 : 621.311.6 3890

Wide-Range Voltage Stabilizers.—F. A. Benson & L. J. Bental. (*Electronic Engng*, Sept. 1956, Vol. 28, No. 343, pp. 390–394.) A unit is described, based on a circuit by Admiraal (863 of 1954), which gives a stabilized output voltage adjustable within the range 0–300 V, with maximum load current of 180–200 mA; the stabilization ratio is about 2 000.

TELEVISION AND PHOTOTELEGRAPHY

621.397.242 3891

The Broadcasting House/Crystal Palace Television Link.—A. R. A. Rendall & S. H. Padel. (*Proc. Instn elect. Engrs*, Part B, Sept. 1956, Vol. 103, No. 11, pp. 644–650. Discussion, pp. 663–666.) This 9-mile link uses two 0·975-in. coaxial cables and provides two channels in each direction, only one of which is required initially. The system is d.s.b. a.m., and the carrier frequency is 15 Mc/s. The performance of the link is given in terms of the amplitude and differential-delay characteristics, transient response, linearity and signal/noise ratio.

621.397.6.001.4 : 621.317.74 **3892**

Portable Color-Signal Generator.—Popkin-Clurman. (See 3834.)

621.397.62 : 535.623 : 621.385.832 **3893**

The 'Apple' Television System.—(*Proc. Inst. Radio Engrs*, Sept. 1956, Vol. 44, No. 9.) Fuller details of the receiver described previously (3232 of October) are given in the following three papers:

A New Beam-Indexing Color-Television Display System.—R. G. Clapp, E. M. Creamer, S. W. Moulton, M. E. Partin & J. S. Bryan (pp. 1108–1114).

A Beam-Indexing Color Picture Tube—the Apple Tube.—G. F. Barnett, F. J. Bingley, S. L. Parsons, G. W. Pratt & M. Sadowsky (pp. 1115–1119).

Current Status of Apple Receiver Circuits and Components.—R. A. Bloomsburgh, W. P. Boothroyd, G. A. Fedde & R. C. Moore (pp. 1120–1124).

621.397.621.2 : 535.623 : 621.385.832 **3894**

An Analysis of Focusing and Deflection in the Post-Deflection-Focus Color Kinescope.—C. P. Carpenter, C. W. Helstrom & A. E. Anderson. (*Trans. Inst. Radio Engrs*, Oct. 1955, Vol. ED-2, No. 4, pp. 1–7.) Colour-television picture tubes are considered in which an array of parallel wires close to the phosphor screen is used for focusing the beam and for deflecting it up and down to produce the colour changes. Expressions are derived for the deflection sensitivity and the focusing properties; the variation over the grid plane is shown by contour maps. The theoretical results are supported by observations.

621.397.7 : 621.396.67.029.62 **3895**

The Crystal Palace Television Transmitting Station.—F C McLean, A. N. Thomas & R. A. Rowden. (*Proc. Instn elect. Engrs*, Part B, Sept. 1956, Vol. 103, No. 11, pp. 633–643. Discussion, pp. 663–666.) Factors underlying the siting, planning and design of the station are indicated and an account is given of steps taken to attain a high standard of reliability. The self-supporting aerial tower has a total height of 668 ft; the radiating elements are single dipoles for the upper half of the aerial and double dipoles for the lower half; aerial performance figures are given. For a shorter account see 2896 of September.

621.397.82 + 621.396.82 **3896**

Radio and Television Interference.—Smith. (See 3867.)

VALVES AND THERMIONICS

621.314.63 : 621.372.632 **3897**

Two-Terminal *P-N* Junction Devices for Frequency Conversion and Computation.—A. Uhlir, Jr. (*Proc. Inst. Radio Engrs*, Sept. 1956, Vol. 44, No. 9, pp. 1183–1191.) "Design principles for semiconductor diodes are derived from the analysis of idealized *p-n* junctions. The analysis gives the superheterodyne conversion matrix and the large-signal admittance in terms of the small-signal diffusion admittances. Structures that minimize minority-carrier storage give minimum conversion loss under matched conditions in converting a high frequency to a low frequency, and are useful in logic circuits of computers. Examples are the emitter-base diode of a transistor and a small bonded or point contact. Amplification and improved power-handling capabilities can be obtained in converting a low frequency to a high frequency, if the geometry favors storage of minority carriers near the junction. Such structures can also be used as pulse amplifiers."

621.314.7 : 546.28 : 621.375.4 **3898**

Micro-power Operation of Silicon Transistors.—E. Keonjian. (*Tele-Tech & Electronic Ind.*, May 1956, Vol. 15, No. 5, pp. 76–78 . . 142.) Characteristics are presented for Si transistors at power levels of a few μW over the temperature range $-25°$ to $+75°$C. An experimental two-stage audio amplifier is described having an output power of 10 μW, with overall gain of 37 dB within ± 3 dB over the range 20 c/s–20 kc/s; current consumption is 65 μA from a supply of 1·5 V.

621.314.7 : 621.318.57 **3899**

***P-N-P-N* Transistor Switches.**—J. L. Moll, M. Tanenbaum, J. M. Goldey & N. Holonyak. (*Proc. Inst. Radio Engrs*, Sept. 1956, Vol. 44, No. 9, pp. 1174–1182.) Discussion of the design, manufacture and electrical characteristics of Si transistors with $\alpha > 1$, for switching purposes. Over the high-impedance portion of the characteristic the impedance depends chiefly on the capacitance of the junctions, which is of the order of tens of pF. Over the low-impedance portion, the slope resistance is a few ohms Suitable methods of manufacture include combinations of solid diffusion and alloying. Possible applications to function generators, relays, etc., are mentioned.

621.385.832 : 621.397.62 : 535.623 **3900**

The 'Apple' Television System.—(See 3893.)

621.385.832 : 621.397.621.2 : 535.623 **3901**

An Analysis of Focusing and Deflection in the Post-Deflection-Focus Color Kinescope.—Carpenter, Helstrom & Anderson. (See 3894.)

MISCELLANEOUS

621.3.049.75 **3902**

Printed Circuits.—(*Tele-Tech & Electronic Ind.*, Dec. 1955, Vol. 14, No. 12, pp. 68 . . 149.) This issue is a special one devoted largely to printed circuits; papers are given on the production of individual components and sub-assemblies, edge-dip soldering, assembly systems and special laminates; a directory of U.S.A. firms manufacturing printed circuits and related products is included.

ABSTRACTS AND REFERENCES INDEX

The Index to the Abstracts and References published throughout 1956 is in course of preparation and will be available with the March 1957 issue. Subscribers will receive the Index automatically. As usual, a selected list of the journals scanned for abstracting, with publishers' addresses, will be included.

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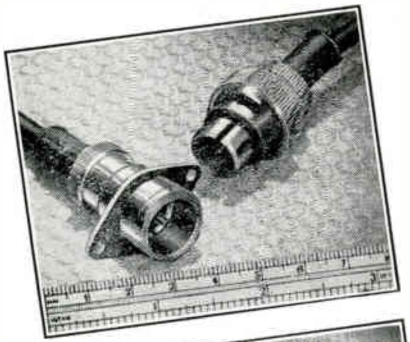
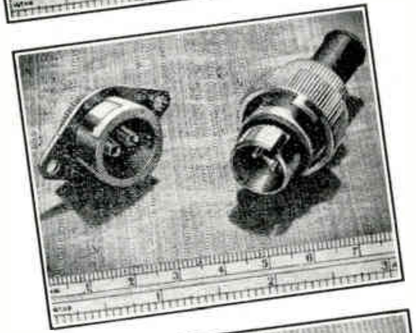
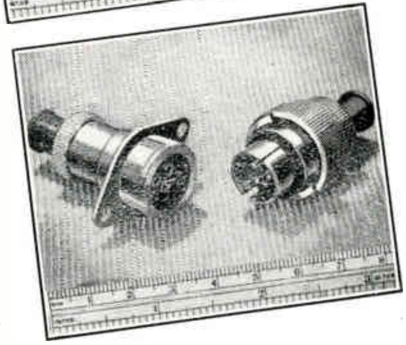
INDEX TO AUTHORS

"BELLING-LEE" "SCREENECTORS"







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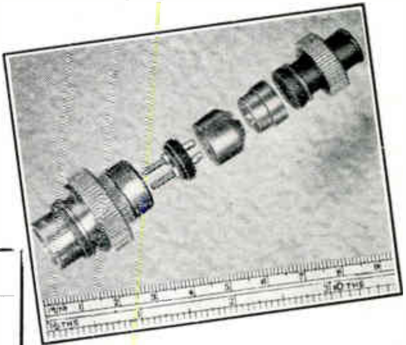

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Type	Characteristic impedance in ohms at approx. 1 mc/s.	Capacitance plug and socket rated at approx 1 mc/s.		Contact resistance at 1 amp.
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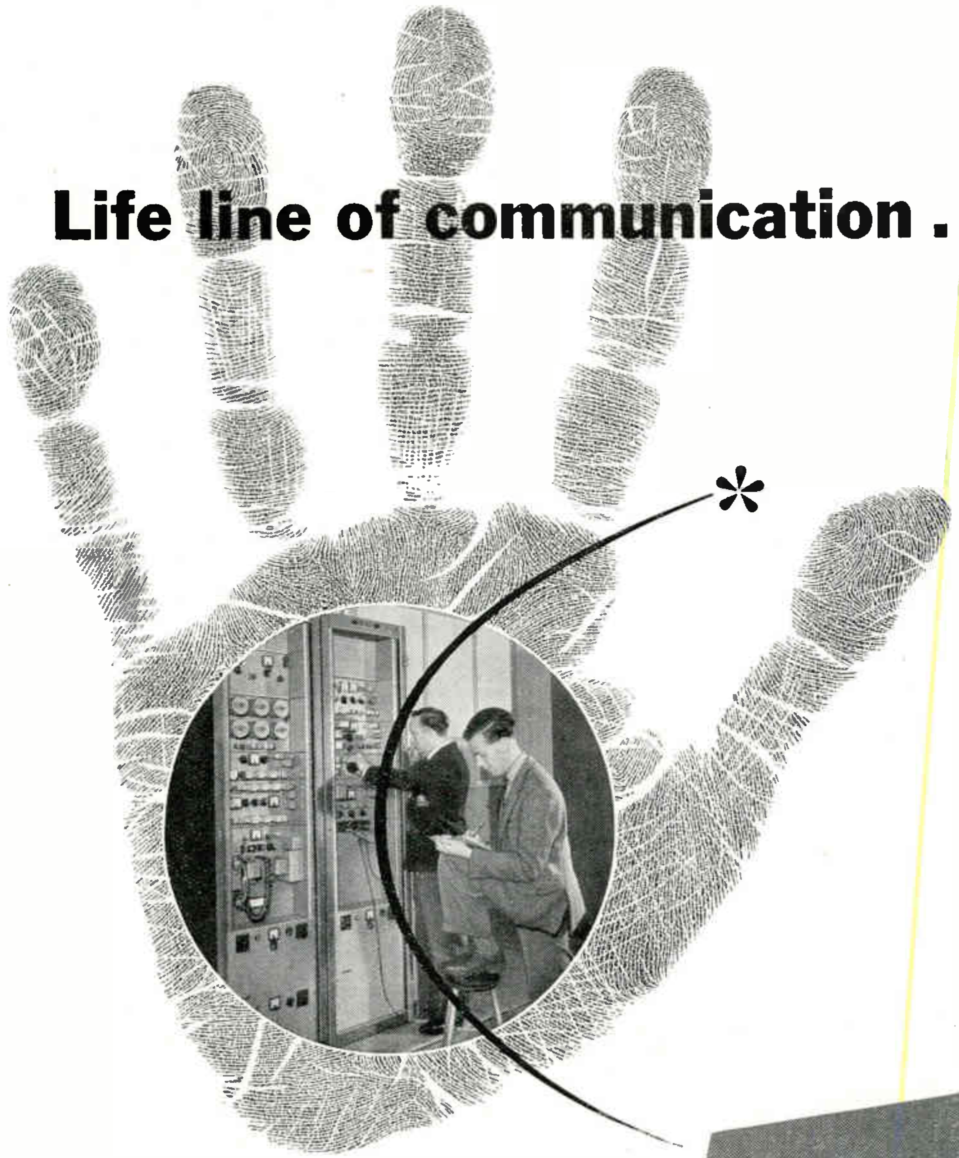

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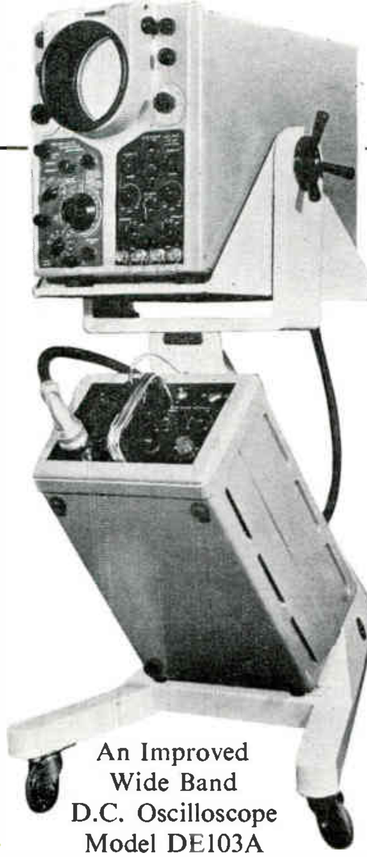

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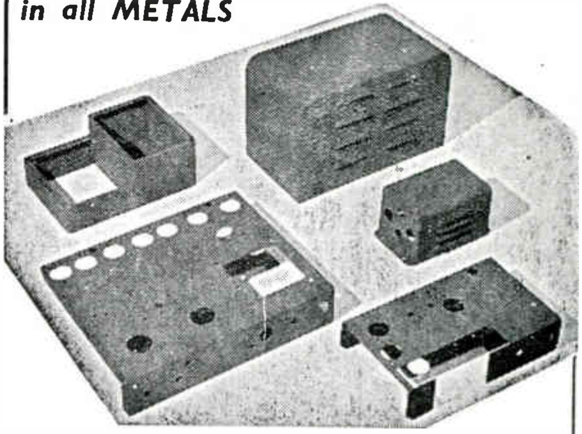

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"VARIAC" GENERAL Classification	CURRENT RATINGS (Amperes)			
	115 v. OPERATION		230 v. OPERATION	
	Rated (0-135 v. Output)	Maximum (0-115 v Output)	Rated (0-270 v. Output)	Maximum (0-230 v Output)
200-B	1.0	1.5	—	—
V-2	2.0	3.0	—	—
V-5: V5-H	5.0	7.5	2.0	2.6
V-6: V6H	6.0	7.5	3.0	3.75
V-10: V-10-H	10.0	13.0	4.0	5.2
100Q: 100-R	15.0	17.5	8.0	9.0
V-20: V20H	20.0	26.0	8.0	10.4
V-30-H	—	—	15.0	17.5
50A: 50-B	40.0	45.0	20.0	31.0
M-2	2.0	3.0	*For use on 350-1200 c/s.*	
M-5	5.0	7.5		
M-10	10.0	13.0		
60-V	5.0	7.5	*For use on 400-2600 c/s.*	

This table refers only to single winding toroidally-wound VARIACS *and does not include double wound types (Types 70 and 80) or ganged assemblies, or 3-phase types, etc.*

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Applications are invited for the appointment of **Lecturer** in the **Department of Aircraft Electrical Engineering.** Salary dependent on qualifications and experience within a range rising to £1,200 per annum with F.S.S.U. and family allowance. A university degree or equivalent in engineering or physics is desirable and candidates should preferably (though not essentially) have experience of one of the following: (a) electrical machine design, (b) aircraft electrical installations, or (c) electrical power systems. Successful candidate will be required to lecture at post-graduate level on aircraft and G.W. power systems and to assist in the equipping and supervision of laboratories. Opportunities exist for private research work. Applications (quoting reference EP/L) giving full particulars and the names of three referees should be forwarded to the Recorder, The College of Aeronautics, Cranfield, Bletchley, Bucks, from whom further particulars may be obtained.

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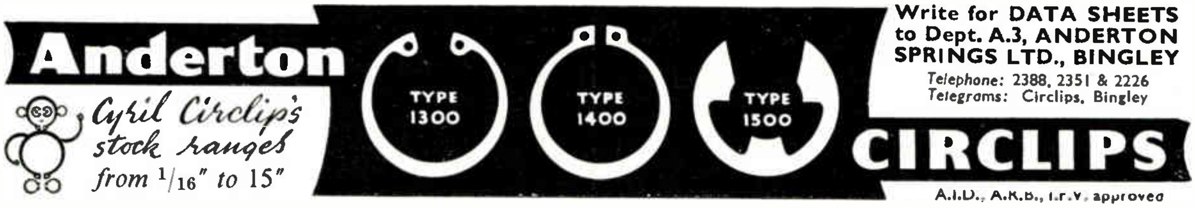

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