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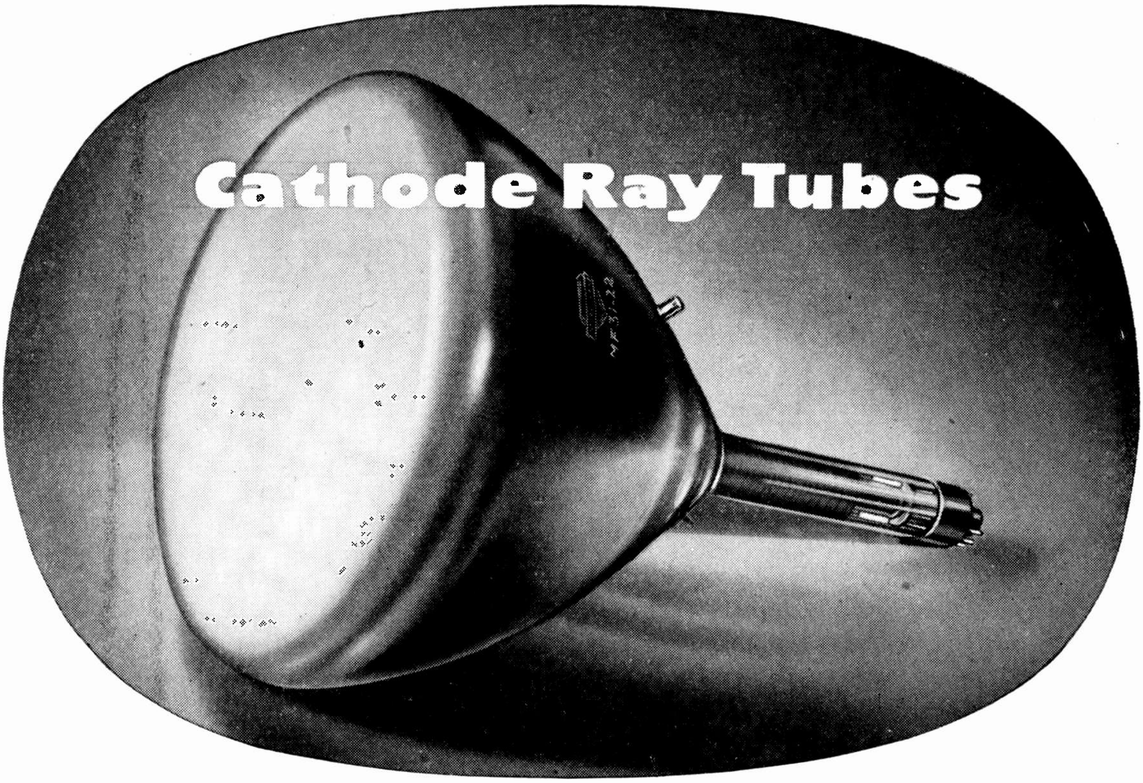

for Radar, Research and Industrial Applications

The cathode ray tube is now accepted as an essential component in all electronic equipments where it is required to obtain a rapid indication or display of physical phenomena. As such it forms the basis of oscilloscopes, test apparatus, monitors, flaw detectors and numerous other research, industrial and communications equipments. The Mullard range of cathode ray tubes has now been extended to meet all these applications.

TUBES FOR RADAR DISPLAYS.

Of particular importance among this range are the Mullard C.R. Tubes MF31-22 (12-in.) and MF13-1 (5-in.) both of which are designed to meet the continuous operation and arduous conditions of service encountered in marine radar applications. Having long-persistence aluminised fluoride screens, these tubes are suitable for use in P.P.I. systems.

SMALL TUBES FOR INSTRUMENTS

A variety of 1$\frac{3}{4}$-in. and 2$\frac{3}{4}$-in. electrostatic C.R. Tubes with green, blue or persistent screens are also available. These tubes are all characterised by low inter-plate capacitances and are designed for operation with voltages from between 800 and 1,000 volts. These features, coupled with the fact that the tubes are fitted with standard B9G bases and have a seated length of less than 6 ins., make them suitable for use in small, compact oscilloscopes, and in a variety of industrial, communications and research testing and measuring equipments. All these tubes can be obtained in versions suitable for either symmetrical or asymmetrical deflection.

For larger equipments, a high-grade electrostatic 5-in. tube is also available.

Abridged technical details on the tubes for radar displays are listed below. Full data on the complete range of cathode ray tubes is available on request.

Type	Description	Base	Max. Screen Diameter (mm.)	Max. Overall Length (mm.)	V_h (V)	I_h (A)	Va1 max. (V)	Va2 max. (KV)
MF13-1	5″ radar tube with metal-backed magnesium fluoride screen	Octal	127.5	292	6.3	0.3	450	11
MF31-22	12″ radar tube with metal-backed magnesium fluoride screen	B12A	308	471	6.3	0.3	400	11

Mullard

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Negative-Feedback Circuits

In Fig. 1 there are shown two negative-feedback amplifier circuits, from which d.c. blocking components have been omitted for simplicity. The required output is the current i in L. In circuit (a), feedback is obtained from the voltage drop across the resistance R_2; in (b) it is obtained from the voltage drop across L and R_2, but through the circuit R_1C, so that the actual feedback voltage is the voltage across C.

It is easily shown that if $CR_1 = L/R_2$ the ratio e_{IN}/i is identically the same for both circuits. In fact, for a unit-step input

$$i_L = \frac{\mu\, e_{IN}}{r_a + R_2(1+\mu) + pL(1 + r_a/R_1)}\, 1$$

$$= \frac{\mu\, e_{IN}}{r_a + R_2(1+\mu)} \cdot \left[1 - \exp\left(-t\,\frac{r_a + R_2(1+\mu)}{L(1 + r_a/R_1)}\right)\right]$$

The time constant of the circuit is that of an inductance L with a resistance $\dfrac{r_a + R_2(1+\mu)}{1 + r_a/R_1}$ and one is inclined to think that this resistance must be the output resistance of the amplifier. That is to say, with $e_{IN} = 0$ if one replaces the coil L by a generator e and measures the resulting current i, one would expect the value $e/i = Z_o$ to equal the foregoing resistance. In fact, however, it does not.

For the circuit of Fig. 1(a),

$$Z_o = R_2 + (r_a + \mu R_2)\frac{1 + pCR_1}{1 + pC(R_1 + r_a)}$$

whereas for Fig. 1(b)

$$Z_o = R_2 + r_a\frac{1 + pCR_1}{1 + \mu + pC(R_1 + r_a)}$$

If $R_1 \gg r_a$, then Z_o for Fig. 1(a) reduces to $r_a + R_2(1+\mu)$ and the resistance of the amplifier time constant also reduces to this same figure. This is, of course, equivalent to removing R_1 and C_1, which serve no useful purpose in this

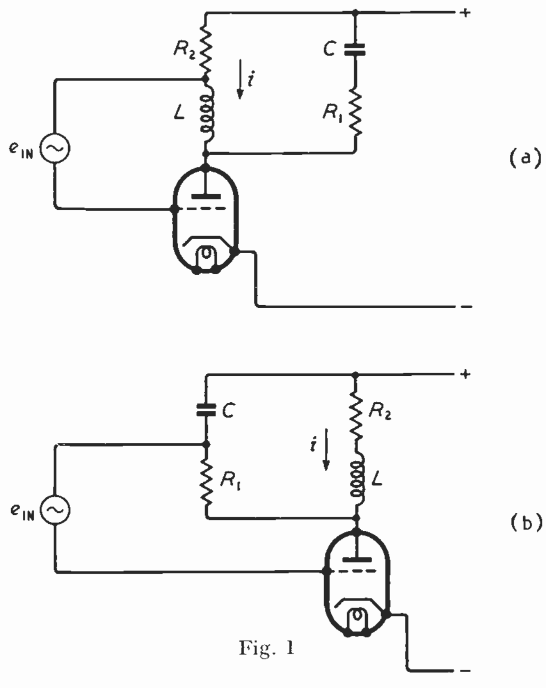

Fig. 1

circuit. In the case of Fig. 1(b), no such simplification is possible. However, if $pCR_1 \ll 1$ the impedance becomes $R_2 + r_a/(1+\mu)$, which is the normal figure for output impedance with voltage feedback.

The two circuits thus have different output impedances, as ordinarily defined, but the effective impedance which governs the decay of current in the inductance is a pure resistance and is the same for both circuits. There is an apparent discrepancy here, for one naturally expects the decay of current in L to be governed by the output impedance. After all, it is commonly said that voltage feedback is a good thing in an a.f. amplifier because it gives a low output impedance which damps the loudspeaker heavily.

When one thinks about it the answer is plain, however. The output impedances are true values which govern the current which flows as the result of an e.m.f. applied to the load terminals only. Z_o governs the current flowing as the result of a disturbance in the load circuit. Thus, in the case of an amplifier feeding a loudspeaker, if one moves the cone by hand the resulting current is governed by Z_o.

In the case of the response to an input e.m.f., however, the matter is different. It is true that the inductive back e.m.f. in L is a disturbance in the load circuit, but now it is not acting alone in the circuit. The input voltage is the prime cause of the current which in turn produces the back e.m.f. in L. When the amplifier is purely resistive, the output resistance and the damping resistance are the same, but when the amplifier contains a reactive element, like C, this is no longer true. Time is needed for the voltage across C to change and so the current in the amplifier cannot change instantaneously, apart altogether from the effect of L.

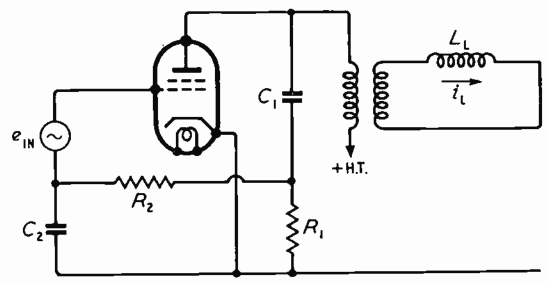

Fig. 2

It is plain, therefore, that it is not sufficient merely to state Z_o in order to specify the damping effect of an amplifier on a load circuit. It will specify it for a disturbance originating in the load circuit, but not necessarily for one originating in the amplifier.

We were brought to consider this by a feedback circuit which is commonly used in the frame time base of a television receiver. It is of the form of Fig. 1, but more elaborate. It is a circuit due to Blumlein and is used to give the equivalent of negative-current feedback in a case where it is impracticable to obtain it directly in the usual way.

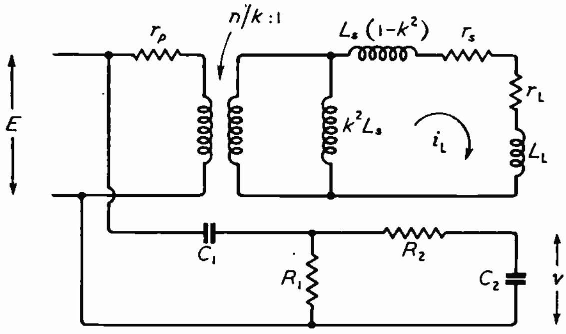

Fig. 3

In basic form it is shown in Fig. 2 and when the values of the components are properly related the voltage developed across C_2 has precisely the same waveform as the current in L_L. This is most easily seen from Fig. 3 where r_p, r_s and r_L represent the winding resistances of the transformer primary and secondary and of the deflector coil respectively; L_s is the transformer secondary inductance and k and n are its coupling coefficient and turns ratio respectively.

If we take E as a unit step of voltage we can write independent equations relating i_L and E for the LR half of circuit and v and E for the CR half. They are each polynomials in $p(= d/dt)$ and by equating the coefficients of equal powers of p in the two they can be made identical save for constant multipliers. This identity requires the relations

$$C_1R_1 = \frac{n^2L_s}{r_p}\,; \quad C_2R_2 = \frac{L_L + L_s(1-k^2)}{r_L + r_s}\,;$$

$$\frac{R_1}{R_2} = \frac{k^2L_s}{L_L + L_s(1-k^2)}\,; \quad \frac{C_1}{C_2} \doteq \frac{r_L + r_s}{r_p}$$

By eliminating E and the p-expression from the equations we find

$$v = i_L\frac{n}{k}(r_L + r_s)$$

which shows that for an input voltage E to the network the voltage appearing across C_2 is exactly the same as, but n/k times as great as, the voltage set up across r_L and r_s by the current i_L flowing through them.

Now r_L and r_s are winding resistances, so that the voltage drop across them is inaccessible and cannot be utilized. To obtain current feedback in the normal way it is necessary to insert additional resistance in series with L_L and, to obtain the same feedback voltage as with the circuit of Fig. 2, this resistance would have to be n/k times $r_L + r_s$. Since n may be 15 or more this means an enormous increase of the circuit resistance and in many cases true current feedback becomes impracticable.

The circuit of Fig. 3 thus offers an alternative arrangement by which a large feedback voltage can be obtained. If C_2 works on open-circuit there is no limit to the absolute magnitude of the components in the CR network and they can be chosen so that they draw negligible power from the main circuit.

The full expression for the unit-step response of this circuit is complex. However, k^2L_s and C_1 obviously have little initial effect. The initial change of current will, therefore, be very nearly governed by the conditions for Fig. 1, but with R_1 in shunt with the effective damping resistance of that circuit. This is usually sufficient knowledge in designing a time-base circuit, for all that one wants to know is that the effective damping resistance is high enough to enable a sufficiently rapid fly-back to be obtained.

W.T.C.

ELECTRON BEAMS AND ELECTRO-MAGNETIC WAVES

General Theory of Interaction

By R. Warnecke, O. Dohler and W. Kleen

(Centre de Recherches de la Compagnie Générale de T.S.F., Paris).

PART 1

1. Introduction

THIS paper is devoted to the theoretical study of the following system:—A multiplicity of rectilinear electron beams of different direct-current densities and velocities are injected in the field of an electromagnetic travelling wave. The wave propagates in a line in the direction of electron motion. It is assumed that all the forces of the h.f. electrical field have that direction only; i.e., the influence of the transverse electrical vector of the wave is disregarded. The different beams do not cross each other (laminar flow) but are intimately mixed. It is presumed, furthermore, that the longitudinal field is constant over the cross section of the space filled with current. The paper is restricted to the calculation of first-order terms (small-signal theory).

In the system under study, interaction between the beams and the wave is accompanied by an exchange of power between the beams of different speeds on the one hand, and between the beams and the electromagnetic wave on the other hand, the exchanges taking place simultaneously. These phenomena correspond (the influence of the radial vector apart) to the general conditions which exist in a travelling-wave tube (t.w.t.), in which, as a result of the continuous space-charge density and of the focusing longitudinal magnetic field, the direct-current beam velocity is not constant within each section.

However, the results of this study are not confined to this tube; we find a very general relation which describes the behaviour of the following systems:

(a) On assuming the coupling between the electrons and the line to be zero, and on disregarding the variations of speed of the electrons, the result describes the behaviour of an electron beam within the drift-space of a velocity-modulated tube. This representation corresponds to that which Hahn and Ramo[1] have given for the phenomena of bunching and debunching of a beam which is initially velocity modulated.

(b) On assuming the forces of repulsion of the bunches formed within the beam to be zero and on disregarding the differences of d.c. velocity, we arrive at the results of the theory of the t.w.t. in a form identical with that which has been given in the works of Pierce[2], Bernier[3] and other authors[4].

(c) On making the same simplifications as in (b), but on taking into account the effects of the h.f. repulsive forces of the electrons, we can describe the behaviour of the t.w.t. at high-current density, in which case the effect of the alternating space-charge considerably modifies the behaviour of the tube compared with the simplified theory, based on the hypothesis of (b).

(d) On disregarding the coupling between the beams and the line, our study leads to the relations for the behaviour of the electron-wave tube indicated by many other authors[5].

As has been stated, every one of these systems has already been studied in particular publications. Nevertheless, the possibility of considering all these phenomena from the same point of view and of developing for them all a general relation, from which emerges a simplified result for each

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particular system, is an adequate justification of this study. Furthermore, the general aim of this paper is not merely a generalization. As far as the t.w.t. is concerned it is known, from the publications of Chu and Jackson[6], Rydbeck[7] and Lapostolle[8], that the calculations necessary to take into account the influence of the alternating space charge are complex. In those publications, the calculation of the behaviour of the t.w.t. is only possible by graphical constructions and by replacing certain complicated functions by other simpler ones. It will be seen later that relations emerge from the present study which will be developed in a considerably simpler manner and, in particular, their application to the project of a tube is also much simplified. Some comparisons of our results with those of the publication of Chu and Jackson[6] have shown practically insignificant differences only. To sum up, the aim of this study is not only a generalization, but also, as far as the t.w.t. is concerned, a simplification of the method of calculation and of the results.

Principal Symbols

$j\Gamma_o = \gamma_o - jK_o$	Propagation constant of the wave in the absence of electron current.
$j\Gamma = \gamma - jK$	Propagation constant of the wave in the presence of electron current.
$K_o = \frac{\omega}{v_o}$	Phase constant of the wave in the absence of electron current.
$K = \frac{\omega}{v}$	Phase constant of the wave in the presence of electron current.
$K_e = \frac{\omega}{v_e}$	Phase constant related to the electron beam velocity.
γ_o	Attenuation constant of the wave in the absence of electron current.
γ	Attenuation constant of the wave in the presence of electron current.
ω	Radian frequency.
Ω	Plasma radian frequency.
v_{en}	Direct-current velocity of the beam.
v_o	Phase-velocity of the wave in the absence of electron current.
v_a	Alternating-current velocity.
v	Phase-velocity of the wave in the presence of electron current.
V_o	Voltage specifying the d.c. beam speed.
I	Unidirectional beam current.
ρ_o	Direct-current charge density.
E	Electric field acting on the beams in the direction of propagation.
R	Coupling field impedance (Ω/cm^2).
i	Alternating convection current.
r_o	Radius of the cylindrical space occupied by the electron beams.
ϵ_o	Dielectric constant of vacuum ($8{\cdot}84 \times 10^{-14}$ F/cm).
$\eta = \frac{e}{m}$	Charge to mass ratio of the electron.
G	Gain.

2. Hypothesis and Basis of Calculation

We are considering a multiplicity of electron beams moving in the direction z at different speeds v_{e1}, v_{e2}, etc. The electromagnetic wave guided by a line travels in the same direction z and, within the space filled by the electrons, has an electric vector in that direction. We assume the application of a longitudinal magnetic field of such intensity that the focusing forces of this field do not allow the electrons to follow the forces of a transverse h.f. electrical field. The system is of cylindrical symmetry.

The electric h.f. field contains at each place two different components. One component E_h originates from the wave guided by the delay line. The other component E_c is due to the forces of mutual repulsion, according to Coulomb's law, of the bunched electrons. To understand the course of the following calculation, a precise distinction must be made between these two components E_h and E_c. The debunching forces eE_c act only in the vicinity of the charges which create them; i.e., only within the electron beam and not at the surface of the walls of the guide, which we consider as being distant from the beams. Only the h.f. field E_h is coupled with the delay-line and the transfer of power from the beam to the guided wave occurs only through the intervention of this field. We then calculate the field excited by a power P travelling in the guide as if the electrons did not exist and superimpose on this field E_h the field E_c. The total field $E_{tot} = E_h + E_c$ causes density- and velocity-modulation of the beam and determines, therefore, the power transfered to the travelling wave by the deceleration of the h.f. electron current in the field E_h. We believe that this hypothesis and the method of calculation which results therefrom are justified. One may compare this method of calculation with that of an electrostatic system into which one introduces a small probe and within which the primitive field is not modified by the charge of this probe except in its vicinity and not on the walls of the system itself.

For small signals, the h.f. electric field, alternating space charge, h.f. velocity, etc., may be written in the following form

$$A = A_o \exp(j\Gamma z + j\omega t) = A_o \exp(\gamma z) \times \exp(j\omega t - jKz)$$

where $j\Gamma = \gamma - jK$ is the propagation constant of the wave with the attenuation constant

$$\gamma = -\operatorname{Im}(\Gamma)$$

and the phase constant

$$K = -\operatorname{Re}(\Gamma)$$

In considering first of all one beam only, we obtain, according to the force equation

$$\frac{dv_a}{dt} = \frac{\delta v_a}{\delta t} + \frac{\delta v_a}{\delta z} \cdot \frac{dz}{dt} = \eta E_{tot}$$

$$j(\omega + \Gamma v_{e1}) v_a = \eta E_{tot}$$

$$v_a = -j\,\frac{\eta E_{tot}}{\omega + \Gamma v_{e1}}$$

where v_{e1} is the d.c. velocity of the electrons of this beam.

The conservation of the charge

$$\mathrm{div}(\rho v) = -\frac{\delta\rho}{\delta t}$$

gives

$$\rho_{01}\Gamma v_a + \rho v_{e1}\Gamma = -\omega\rho$$

$$\rho = -\rho_{01}\frac{\Gamma v}{\omega + \Gamma v_{e1}} \quad .. \quad .. \quad .. \quad (1.2)$$

It follows by the introduction of (1.1) into (1.2)

$$\rho = j\rho_{01}\eta E_{tot}\frac{\Gamma}{(\omega + \Gamma v_{e1})^2} \quad .. \quad .. \quad (1.3)$$

For the multiplicity of beams we have in a similar manner

$$\rho_n = j\rho_{0n}\eta E_{tot}\frac{\Gamma}{(\omega + \Gamma v_{en})^2} \quad .. \quad .. \quad (1.4)$$

As stated, E_{tot} contains the components E_h (originating from the wave guided by the delay line) and E_{c1}, E_{c2} . . . due to the h.f. space charge. According to (1.4) we shall have for each beam 1, 2 . . . the equation

$$\rho_n = j\rho_{0n}\eta(E_h + \sum_v E_{cv})\frac{\Gamma}{(\omega + \Gamma v_{en})^2} \quad (1.5)$$

3. Space-charge Field

In order to calculate the electric field produced by the alternating space charge we must introduce into (1.5) an expression linking the two. This expression is developed on the lines adopted by Warnecke, Bernier and Guenard[9] which we have already utilized in a preceding study[10] of the same subject. We repeat here the calculation[10] in a slightly modified form.

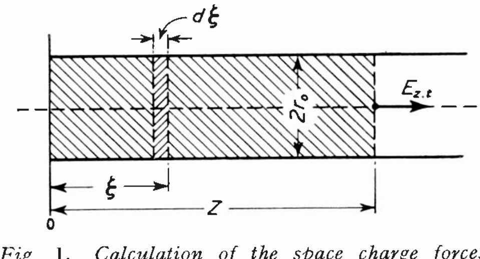


Fig. 1. Calculation of the space charge forces in the interior of an electron beam.

Let us consider a single beam progressing in the direction $+z$ (see Fig. 1). It has been shown[9] that the axial electric field acting on the electrons located at point z and produced by the alternating space charge of a section $d\xi$ located at ξ may be represented in the following form

$$dE_{z,\xi} = \frac{\rho}{2\epsilon_0}e^{q|z-\xi|}d\xi \quad .. \quad .. \quad (1.6)$$

$$\text{with} \quad q = \frac{1{\cdot}18}{r_0} \quad .. \quad .. \quad .. \quad .. \quad (1.7)$$

We have according to (1.4) with $E_{tot} = E_{otot}$ $\exp j(\Gamma\xi + \omega t)$ for the space charge at ξ

$$\rho = j\rho_{01}\eta\frac{\Gamma}{(\omega + \Gamma v_{e1})^2}E_{otot}\exp j(\Gamma\xi + \omega t) \quad (1.8)$$

We introduce (1.8) into (1.6) and thus obtain the axial electric field at point z at time t, which is produced by the space charge located at ξ at time t_1

$$dE_{z,\xi,t_1} = j\rho_{01}\frac{1}{2\epsilon_0}\eta E_{otot}\frac{\Gamma}{(\omega + \Gamma v_{e1})^2}e^{-q|z-\xi|} e^{+j(\Gamma\xi + \omega t_1)}d\xi \quad (1.9)$$

The force $eE_{z,\xi,t}$ acts only in the vicinity of its source. Every disturbance of the field, be it in the free space, or in a guide, progresses at first with the velocity of light c; the characteristic phase-velocity in the guide is the result of an interference phenomenon which occurs only after the wave has travelled a distance comparable to the transverse dimensions of the guide. The time t is, therefore, linked to t_1

$$\text{for } z > \xi \text{ by } t = t_1 + \frac{z - \xi}{c} \quad .. \quad (1.10a)$$

$$\text{for } z < \xi \text{ by } t = t_1 + \frac{\xi - z}{c} \quad .. \quad (1.10b)$$

We thus obtain for the field produced at time t, point z, by the space charge which is located between $\xi = 0$ and $\xi = \infty$

$$E_{z,t} = j\rho_{01}\cdot\frac{1}{2\epsilon_0}\cdot\eta E_{otot}\frac{\Gamma}{(\omega + \Gamma v_{e1})^2} \times\left[\exp\left\{-qz + j\omega\left(t - \frac{z}{c}\right)\right\}\int_0^z \exp\left\{\left[q + j\left(\Gamma + \frac{\omega}{c}\right)\right]\xi\right\}d\xi + \exp\left\{qz + j\omega\left(t + \frac{z}{c}\right)\right\}\int_z^\infty \exp\left\{\left[-q + j\left(\Gamma - \frac{\omega}{c}\right)\right]\xi\right\}d\xi\right] \quad (1.11)$$

The equation (1.11) is integrated; in the result we disregard e^{-qz} compared with unity, permissible in view of the fact that the influence of the space charge is small in the vincinity of the input of the tube (small bunching) and take furthermore

$$\gamma \ll q,\ \gamma \ll K,\ K \gg \omega/c$$

and in the expressions which have Γv_{e1} as factor

$$\Gamma \approx -K_{e1}$$

All these simplifications correspond to the actual practical conditions. It follows that the field due to the alternating space charge is given by

$$E_{z,t} = \rho_{01} \frac{\eta}{\epsilon_0} \frac{1}{(\omega + \Gamma v_{e1})^2} \frac{K_{e1}^2}{q^2 + K_{e1}^2} E_{o'ot} e^{j(\Gamma z + \omega t)} \quad \ldots \quad \ldots (1.12)$$

$$= \Omega_1^2 \alpha_1^2 \frac{1}{(\omega + \Gamma v_{e1})^2} (E_h + \sum_v E_{c,v})$$

with $\Omega_n^2 = \eta \dfrac{\rho_{on}}{\epsilon_o}$

and $\alpha_n^2 = \dfrac{K_{en}^2}{q^2 + K_{en}^2}$

We repeat that this is the field produced at point z and at time t by the h.f. alternating space-charge of the entire beam No. 1.

4. H.F. Current

Starting from the equation (1.12) we get

$$E_{tot} = E_h + \sum_v E_{cv} = E_h \frac{1}{1 + \sum_v a_v} \quad \ldots (1.13)$$

with $a_v = \Omega_v^2 \alpha_v^2 \dfrac{1}{(\omega + \Gamma v_{ev})^2} \quad \ldots \quad \ldots (1.14)$

We introduce E_{tot} in (1.5)

$$\rho_n = j \rho_{on} \eta E_h \frac{1}{1 + \sum_v a_v} \frac{\Gamma}{(\omega + \Gamma v_{en})^2} \quad \ldots (1.15)$$

a relation which no longer contains E_{tot} or E_c but only E_h.

We now include the variations of d.c. velocity small in relation to the velocities themselves, and introduce

$$\rho_{on} = \frac{I_n}{f v_{en}} \quad \ldots \quad \ldots \quad \ldots (1.16)$$

where I_n is the current of the beam n with the speed v_{en}, f being the section of the system filled by the current. The alternating electron current is given by

$$i = f \sum_n (\rho_n v_{en} + v_{an} \rho_{on}) \quad \ldots \quad \ldots (1.17)$$

It follows, therefore, according to (1.1), (1.14) and (1.15)

$$i = -j \eta E_h \frac{1}{1 + \sum_v a_v} \sum_n \frac{I_n K_{en}}{(\omega + \Gamma v_{en})^2} \quad \ldots (1.18)$$

5. Balance of Power

We characterize the coupling between the wave guided by the line and the beams by a coupling field impedance R defined by the square of E_h and the electromagnetic power P travelling in the guide

$$R = \frac{|E_h|^2}{2P}$$

R, independent of point z, has the dimension Ω/cm^2 and is a value determined only by the geometrical dimensions of the guide. We have discussed this hypothesis in Section 2. If $j\Gamma$ is the propagation constant of the wave in interaction with the alternating electron current, $j\Gamma_o$ the propagation constant in the absence of the electron beam, it is generally valid that

$$-i = j \frac{2}{R} (\Gamma - \Gamma_o) E_h \quad \ldots \quad \ldots (1.19)$$

this relation having been previously developed[4]*. In applying (1.18) to (1.19) we have

$$\Gamma - \Gamma_o = \tfrac{1}{2} \eta R \frac{1}{1 + \sum_v a_v} \sum \frac{I_n K_{e2,}}{(\omega + \Gamma v_{e,n})^2} \quad (1.20)$$

or

$$\Gamma - \Gamma_o = \tfrac{1}{2} \eta R \frac{\dfrac{I_1 K_{e,1}}{(\omega + \Gamma v_{e,1})^2} + \dfrac{I_2 K_{e,2}}{(\omega + \Gamma v_{e,2})^2} + \cdots\cdots}{1 - \left[\dfrac{\alpha_1^2 \Omega_1^2}{\omega + \Gamma v_{e,1}} + \cdots\cdots\cdots\cdots\right]} \quad \ldots \quad \ldots (1.21)$$

This complex equation enables one in principle to calculate the complex value of $j\Gamma$ if ω, R, Ω_n, $v_{e,n}$, I_n and Γ_o are given.

6. Physical Signification of the Results

We discuss the physical signification of equation (1.21), which describes in a general way the behaviour of the travelling-wave tube with beams of different d.c. velocities. It may be simplified in certain cases:

(a) There is no delay-line and only one beam: This means that $\Gamma_o = 0$, $R = 0$, $\Omega_{n+1} = 0$, $I_{n+1} = 0$ for $n = 0$ and corresponds to the behaviour of an electron beam in the drift space of a velocity-modulated tube (Hahn and Ramo[1]). If Γ is finite it follows on the basis of these assumptions and according to (1.21)

$$1 - \alpha_1^2 \Omega_1^2 \frac{1}{(\omega + \Gamma v_{e1})^2} = 0 \quad \ldots \quad \ldots (1.22)$$

(b) Two electron beams are progressing without a delay-line. This means that $\Gamma_0 = 0$, $R = 0$ and we take from (1.21) the characteristic equation for the electron wave tube

$$1 - \left[\frac{\alpha_1^2 \Omega_1^2}{(\omega + \Gamma v_{e1})^2} + \frac{\alpha_2^2 \Omega_2^2}{(\omega + \Gamma v_{e2})^2}\right] = 0 \quad (1.23)$$

* In Ref. 4 we have chosen Γ for the constant of propagation in the place of $j\Gamma$ here.

(c) All the particles have the same speed and progress within a delay-line with which they are coupled. We suppose that the effects of the h.f. space charge are insignificant. These assumptions are those which have previously been made in the theory of the travelling-wave tube[2,3,4]. It thus follows according to (1.21) and with $I = \Sigma I_n$, $v_{e1} = v_e$

$$\Gamma - \Gamma_o = \tfrac{1}{2}\eta R K_e I \frac{1}{(\omega + \Gamma v_e)^2} \quad .. \quad (1.24)$$

(d) The conditions are the same as under (c), except for the influence of the space charge, which is no longer insignificant. One thus obtains with

$$\Omega^2 = \eta \frac{\rho_o}{\epsilon_o} = \eta \frac{I}{\epsilon_o v_{ef}}$$

$$\Gamma - \Gamma_o = \tfrac{1}{2}\eta R K_e I \frac{1}{(\omega + \Gamma v_e)^2 - \alpha^2 \eta \dfrac{I}{\epsilon_o v_{ef}}} \quad .. \quad .. \quad (1.25)$$

The results of this equation must be compared with those which Chu and Jackson[6], Rydbeck[7], Lapostolle[8] have given in a considerably more complicated form in their publications on the theory of the travelling-wave tube.

PART 2

Application to Klystron Theory

In this part we only wish to show that our calculations lead to results similar to those of the theory of the klystron established by Hahn and Ramo[1].

We start from the equation (1.22)

$$\frac{\alpha^2 \Omega^2}{(\omega + \Gamma v_e)^2} = 1$$

which gives us two real roots of Γ

$$\Gamma_1 = -\frac{\omega}{v_e}\left(1 + \alpha \frac{\Omega}{\omega}\right) \quad .. \quad .. \quad (2.1a)$$

$$\Gamma_2 = -\frac{\omega}{v_2}\left(1 - \alpha \frac{\Omega}{\omega}\right) \quad .. \quad .. \quad (2.1b)$$

On account of

$j\Gamma = \gamma - jk$ and

$$A = A_o \exp\{j(\omega t + \Gamma z)\}$$

$$= A_o \exp\left[j\left\{\omega t - \left(\frac{\omega}{v_e} \pm \alpha \frac{\Omega}{\omega}\right) z\right\}\right] \quad (2.2)$$

these values of Γ describe two waves progressing in direction z of the electron beam with amplitudes independent of z. For $\alpha\Omega \ll \omega$ the speeds of the two waves are very close to the speed v_e of the electrons, but slightly different, one of the speeds being a little greater, the other slightly less than v_e. The alternating electron current is given by an equation of the form of equation (2.2).

Ramo has, amongst others, dealt with the same problem assuming that the electron beam entirely fills the circular section of a cylinder of radius b and for $v_e \ll c$ he obtains an expression similar to our equation (2.1) where α is given by

$$\alpha^2_R = \frac{K_e^2}{K_e^2 + p_{m,n}/b^2}$$

$p_{m,n}$ being the mth root of the Bessel function order n. This difference is clear: the walls of the drift space have an influence on the bunching of electrons, which is not included in our hypothesis.

As a result of this propagation of two waves of slightly varying speeds, there follows as beating, the periodical variation of current density and speed along the beam with the maximum of h.f. current at

$$z = (2n + 1)\,\frac{\pi}{2}\,\frac{v_e}{\alpha\Omega}$$

at which point the output circuit is located. These phenomena are well known and need not be discussed in detail here. This discussion, as has previously been stated, has no other aim but to demonstrate the similarity of our result to those of Hahn and Ramo.

PART 3

1. Gain of Single-beam Tube

We deal in this part with the theory of the t.w.t. based on the calculations of the first part. We disregard the differences of speed within the electron current, but we take into account the debunching effects of the alternating space charge. We start from equation (1.25) which corresponds to these assumptions and which with $I = \Sigma I_n$ has the form

$$\Gamma - \Gamma_o = \frac{1}{2}\eta R K_e I \frac{1}{(\omega + \Gamma v_e)^2 - \alpha^2 \Omega^2}$$

This complex equation is of the third degree. It has, therefore, necessarily three complex or real roots for $K_e > 0$, and three other roots for $K_e < 0$. Every excitation, be it at the entrance or at the exit (e.g., by reflection) has as its result the excitation of the three waves.

We introduce

$$j\Gamma = \gamma - jK$$

and normalize the equation in writing

$$\gamma_{opt} = \sqrt{3}\left(\frac{K_e I R}{32 V_o}\right)^{1/3}$$

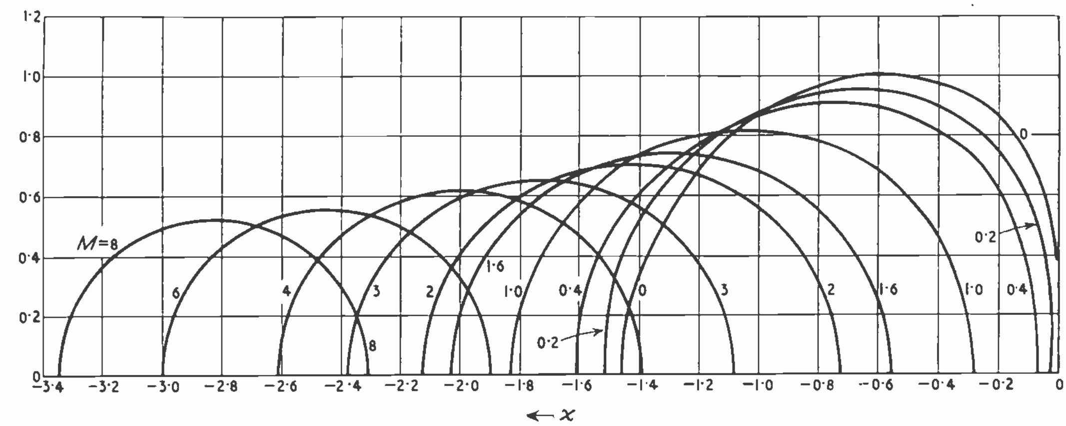
$$y = \frac{\gamma}{\gamma_{opt}}, \quad x = \left(1 - \frac{v_e}{v}\right)\frac{K_e}{\gamma_{opt}}$$

$$u = \left(1 - \frac{v_e}{v_o}\right)\frac{K_e}{\gamma_{opt}}, \quad s = \frac{\gamma_o}{\gamma_{opt}} < 0$$

It is to be noted that in these relations γ_{opt} is the maximum of the real part of the propagation constant of the amplified wave in a t.w.t. without the influence of alternating space charge and where the delay-line possesses no attenuation $\gamma_o < 0$; v_o is the velocity of propagation of a wave which is not coupled to the beam.

$$y - s = -\frac{8}{3^{3/2}}\frac{2xy}{(y^2 - x^2 + M)^2 + 4x^2y^2} \quad (3.3)$$

$$\frac{K - K_o}{\gamma_{opt}} = \frac{8}{3^{3/2}}\frac{y^2 - x^2 + M}{(y^2 - x^2 + M)^2 + 4x^2y^2} = u - x \quad (3.4)$$



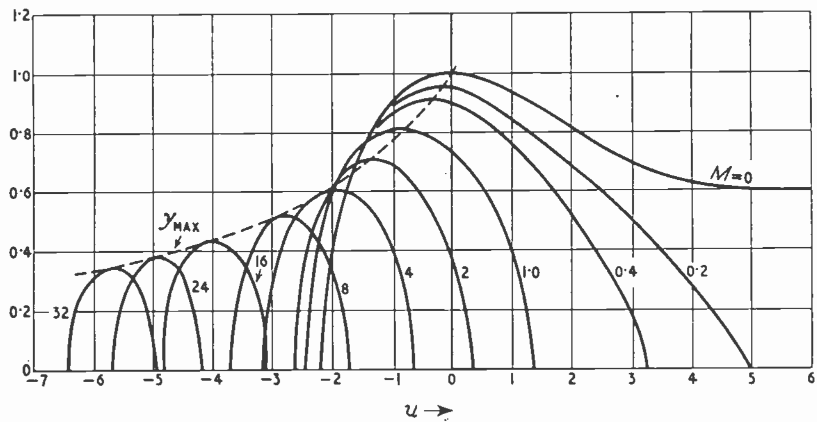


Fig. 2 (above). Normalized attenuation constant $y = \gamma/\gamma_{opt}$ of the amplified wave in a travelling-wave tube. The abscissa

$$x = \left(1 - \frac{v_e}{v}\right)\frac{K_e}{\gamma_{opt}}$$

measures the difference between d.c. electron velocity and phase velocity of the amplified wave. The parameter is $M = \frac{\alpha^2\Omega^2}{\gamma_{opt}v_e^2}$ and proportional to the square of the radian plasma frequency.

Fig. 3. As Fig. 2, but with $u = \left(1 - \frac{v_e}{v_o}\right)\frac{K_e}{\gamma_{opt}}$ as abscissa which measures the difference of the d.c. electron velocity of the wave in the absence of the electron beam.

With this notation we arrive at the complex equation

$$\frac{\Gamma - \Gamma_o}{\gamma_{opt}} = -\frac{8}{3^{3/2}}\frac{1}{(y + jx)^2 + M} \quad (3.1)$$

with

$$M = \frac{\alpha^2\Omega^2}{\gamma_{opt}^2\, v_e^2} = C\left(\frac{I}{R^2K_e^2V_o^{5/2}}\right)^{1/3}\frac{K_e^2}{K_e^2 + q^2}\frac{1}{f}$$

$$C = \frac{32^{2/3}}{3\cdot 2^{3/2}}\ \frac{1}{\epsilon_o(e/m)^{1/2}} = 3\cdot 2 \times 10^5\ \frac{\Gamma^{3/2}}{A} \quad (3.2)$$

where γ, K_e are measured in cm^{-1}, R in Ω/cm^2, f in cm^2 and V_o (steady voltage of the line) in V.

The equation (3.1) gives us two real equations or for $s = 0$

$$y = -\frac{8}{3^{3/2}}\frac{2xy}{(y^2 - x^2 + M)^2 + 4x^2y^2} \quad (3.3a)$$

$$u - x = \frac{8}{3^{3/2}}\frac{y^2 - x^2 + M}{(y^2 - x^2 + M)^2 + 4x^2y^2)} \quad (3.4a)$$

u and M are parameters predetermined by the dimensions and the operating conditions of the tube. The three *real* roots y and x of equations (3.3) and (3.4) are normalized values of the positive or negative attenuation and of the phase constant of the excited waves in the delay-line which progress in interaction with the beam.

1.1 *Line Without Attenuation*

We have, according to equation (3.3a) a root $y_3 = 0$ with a propagation velocity according to (3.4a) given by the relation

$$x + \frac{8}{3^{3/2}} \frac{1}{M - x^2} = u \qquad \ldots \quad \ldots \quad (3.5)$$

The amplitude of this wave is, therefore, not influenced by the electron current.

The two other roots y_1, y_2 of equation (3.3a) are equal but of inverse signs

$$y_{1,2} = \pm \sqrt{-\left[(M + x_{1,2}^2) - \sqrt{\left\{4Mx_{1,2}^2 - \frac{16}{3^{3/2}} x_{1,2}\right\}}\right]} \quad (3.6)$$

We have, therefore, two other waves with the same phase velocity, $(x_1 = x_2)$ one amplified $(y_1 > 0)$, the other attenuated $(y_2 < 0)$.

In Fig. 2 we have shown $y_1 = f(x)$ with M as parameter. We always have $x < 0$: for $x > 0$ the roots become imaginary and they have no physical significance. These two waves, therefore, propagate at a speed below that of the electrons, a fact that can be understood from the physical point of view: the transfer of power from the beam to the wave being only possible if the electrons are decelerated by the electric vector of the wave, which demands an excess of speed of the electrons.

By introducing the values of y_1 and x_1 of Fig. 2 into equation (3.4a) we arrive at $y_1 = f(u)$ shown in Fig. 3 for different values of M. We see that $y_1 > 0$ exists only in a restricted range Δu of u. Furthermore, if M increases, u must be more negative; i.e., the steady potential of the line must be increased to obtain the maximum of $y_1 = \gamma_1/\gamma_{opt}$.

Fig. 4 can be derived from Figs. 2 and 3, representing as a function of M the behaviour of the tube under the conditions of maximum gain, y_{max}, u_{max} and x_{max}. We can describe the shape of these curves by some fairly simple expressions, valid with a maximum margin of error of about 10% (see Table 1 and Fig. 4).

This table shows clearly the influence of the space-charge on the gain and the optimum conditions. For low currents γ is proportional to $I^{1/3}$ and $R^{1/3}$; for high currents it is proportional to $I^{1/4}$ and $R^{1/2}$. For low currents, the radius r_o of the beam does not intervene in γ. For $M \geqslant 1$ the influence of the radius is described by the factor

$$[f(K_o^2 + q^2)]^{1/4} = \pi^{1/4}(1{\cdot}18^2 + K_o^2 r_o^2)^{1/4}$$

This expression assumes a constant axial field within the section of the beam; this field, however,

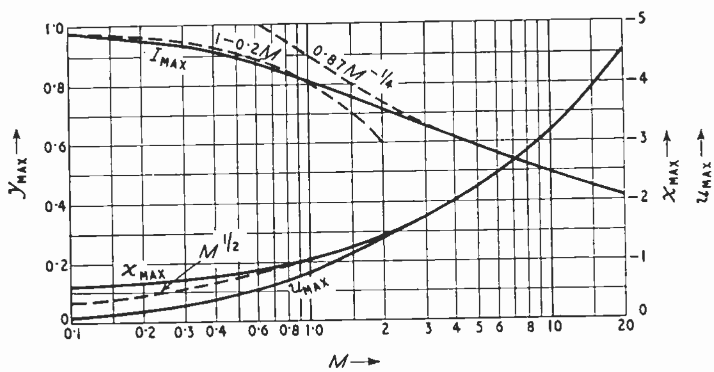


Fig. 4. Optimum working conditions of the travelling-wave tube as function of M.

TABLE 1 (Dimensions V, A, cm, s.)

	$M \leqslant 1$	$M \geqslant 1$
y_{max}	$1 - 0{\cdot}2M$	$\sqrt{\frac{4}{3^{3/2}}}\, M^{-1/4} = 0{\cdot}87 M^{-1/4}$
$-u_{max}$	$0{\cdot}9M$	$M^{1/2}\ (= -x_{max})$
$-x_{max}$	$\frac{1}{\sqrt{3}} + \left(1 - \frac{1}{\sqrt{3}}\right) M$	$M^{1/2}$
γ_{max}	$\sqrt{3}\left(\frac{K_o I R}{32 V_o}\right)^{1/3} - 3{\cdot}5 \times 10^{-4}\left(\frac{I^2 K_o^5}{R^2 V_o^{7/2}}\right)^{1/3} \times \frac{1}{(q^2 + K_o^2) f}$	$2 \times 10^{-2}\left[\frac{IR^2}{V_o^{1/2}} f(q^2 + K_o^2)\right]^{1/4}$
u for $\gamma = 0$		$u_{max} + 2y_{max}$

grows in a cylindrical system from the axis towards the edges according to

$$E = E_0 I_0(K_0 r)$$

We have previously shown[11] that this effect may be taken into account by multiplying R by

$$A = I_0^2(K_0 r_0) - I_1^2(K_0 r_0) \approx 1 + \tfrac{1}{4}K_0^2 r_0^2$$

This means that the factor $F = [f(K_0^2 + q^2)]^{1/4}$ in the relation for $\gamma(M \gg 1)$ must be replaced by

$$F \approx 1{\cdot}5[1 + 1{\cdot}2K_0^2 r_0^2]^{1/4} \quad \ldots \quad \ldots \quad (3.7)$$

Consequently if $K_0^2 r_0^2$ is small r_0 has only a slight influence on the gain, while for $K_0^2 r_0^2 \gg 1$, γ becomes approximately proportional to the square root of the radius.

We have also indicated in the table for $M \gg 1$ the limits of u where γ becomes zero. The range Δu of amplification is equal to $4\gamma_{max}$; i.e., the range Δu of finite gain is so much the smaller as M is higher.

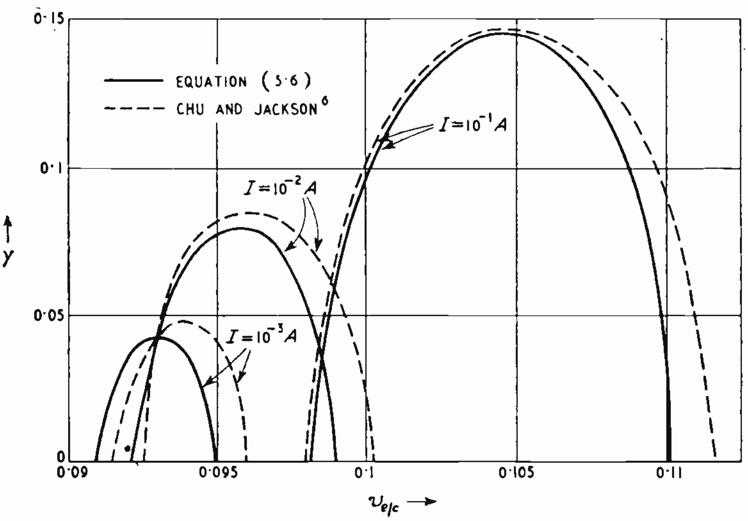


Fig. 5. Comparison between the gain of a travelling-wave tube calculated according to the results of the present paper and those of a publication of Chu and Jackson[6].

It is of interest to compare the results of our calculations with those of other publications. For $M \ll 1$ the approximation for γ given in the Table corresponds to that given by the authors in a previous publication [10]. The proportionality of γ_{max} with $I^{1/4}$ for $M \gg 1$ is also indicated in the publications of Chu and Jackson[6], Rydbeck[7] and, for the values of current which are not too high, in the publication of Lapostolle[8] too, who, however, for very high currents, finds that γ_{max} grows approximately proportional to $I^{1/5}$. As regards the influence of the beam radius on γ_{max} we find considerable disagreement in the different publications. Jackson shows an approximate proportionality of γ_{max} with $r_0^{1/3}$, whereas we find a variation in the form of $\gamma_{max} \approx (1 + 1{\cdot}2\, K_0^2 r_0^2)^{1/4}$. Rydbeck and Lapostolle, however, show a sensibly greater influence of r_0 on γ_{max} [e.g., $\gamma_{max} \approx r_0^3$ in Ref. (7)]. We cannot explain here these differences.

We have made a quantitative comparison with some figures and curves of the publication of Chu and Jackson[6], who have calculated as function of the velocity of the electrons the figures of a t.w.t. with

helix radius r_h	0·5 cm
angle of pitch	5°
wavelength	16 cm
electron beam radius	0·1 cm
beam current	10^{-3}, 10^{-2} and 10^{-1} A.

It follows that $c/v_0 = 10{\cdot}92$ (we are already in the region of a small dispersion of the velocity of propagation in the helix). The value of the coupling field impedance R has been calculated for comparison on the basis of the indications of Pierce[2]. We can write, using Pierce's notation F

$$R = F^3 \frac{2\pi^2}{\lambda^2}\left(\frac{c}{v_0}\right)^3$$

with $F = 7{\cdot}15 \exp\left[-\frac{4\pi}{3}\frac{c}{v_0}\frac{r_h}{\lambda}\right]$

where λ = wavelength,

and we obtain for the tube of above dimensions $R = 515\Omega/\text{cm}^2$. We point out that in the establishment of a project for a t.w.t., the calculation of R is apparently the least precise factor of the calculations. The finished diameter of the helix wire cannot yet be taken into account, but it has certainly a very marked influence on the h.f. field and, therefore, on R.

In Fig. 5 we have given $\gamma = f\left(\frac{v_0}{c}\right)$ for three values of the beam current $I = 10^{-3}$ A($M = 1{\cdot}2$), $I = 10^{-2}$ A($M = 2{\cdot}6$), $I = 10^{-1}$ A($M = 5{\cdot}6$). The solid curves are those which result from the equations of the present study, the dashed curves are those of Fig. 8 of Chu and Jackson. The similarity is satisfactory.

(1.2) *Delay-line with Attenuation*

The solution of the equations of the fifth degree (3.3) and (3.4) being too complicated, we shall limit ourselves to the discussion of the influence of the attenuation of the delay-line under the conditions of maximum gain. We know that the introduction of an attenuation γ_o brings a reduction of γ to less than $|\gamma_o|$.

We write $y_{o,max}$, $x_{o,max}$ the variables of maximum gain in a line without attenuation and wish to calculate

$$\delta y = y_{s,max} - y_{o,max} < 0$$
$$\delta x = x_{s,max} - x_{o,max}$$

$y_{s,max}$ and $x_{s,max}$ are the corresponding normalized values for the tube with attenuation

$$s = \frac{\gamma_o}{\gamma_{opt}} < 0.$$

For M small, we have $y_{o,max} = 1$, $x_{o,max} = 1/\sqrt{3}$. Writing equation (3.3) for M small in the following form

$$y_{o,max} + \delta y - s = -\frac{8}{3^{3/2}} \frac{2(x_{o\,max} + \delta x)(y_{o\,max} + \delta y)}{[(y_{o\,max} + \delta y)^2 + (x_{o\,max} + \delta x)^2]^2}$$

we find $\delta y = \dfrac{s}{3} < 0$ .. .. .. (3.8a)

and according to equation (3.4)

$$\delta x = 0 \qquad \text{.. .. .. .. (3.8b)}$$

For M great let us first assume that δx is zero as for $M = 0$. We thus obtain on the basis of (3.3) by introducing $x_{o,max} - \sqrt{M}$

$$y_{s,max} - s = \frac{16}{3^{3/2}} \frac{y_{s,max}\sqrt{M}}{y_{s,max} + 4My_{s,max}^2}$$
$$\approx \frac{4}{3^{3/2}} \frac{1}{y_{s,max}\sqrt{M}}$$

in consequence

$$y_{s,max} = \frac{s}{2} + \sqrt{\frac{4}{3^{3/2}} \frac{1}{\sqrt{M}} + \frac{s^2}{4}} \approx y_{o,max} + \frac{s}{2}$$

and, therefore, $\delta y = \dfrac{s}{2} < 0$ .. .. (3.9)

If one introduces δx into (3.4) it will be seen that $\delta x = 0$ for large values of x and M is justified. Therefore: through the introduction of an attenuation $\gamma_o < 0$ into the delay-line, the real part of the attenuation constant of the amplified wave is diminished by $\frac{1}{3}|\gamma_o|$ for small currents ($M \leqslant 1$), and by $\frac{1}{2}|\gamma_o|$ for large currents ($M \geqslant 1$). The propagation velocity of the amplified wave is not modified at a first approximation as a result of the introduction of attenuation.

2. Initial Conditions

For the establishment of initial conditions it is necessary to take into account the fact that, according to the discussion of the assumptions made at the beginning of Part 1, only the field $E_h = E_{tot} - E_c$ is coupled to the delay-line. Input and output power are transferred by this field while the fields $E_{c,n}$, which correspond to the repulsive forces of the electrons, do not share in the repartition of the generator field on the excited waves and do not contribute to the output power. These latter fields do not affect the initial conditions except through the intermediary of the speeds and currents of the electrons (which are modified as a result of the existence of E_c).

We would mention that we characterize the values at the entrance by the sign e, at the exit by the sign s; the three waves will have the sign 1, 2, 3 of which the sign 1 is valid for the amplified wave. The input power is

$$P_g = \frac{E_g^2}{2R} \qquad \text{.. .. .. .. (3.10)}$$

(Eg = field produced by the generator). Furthermore we call

$$\xi_1 = \omega + \Gamma_1 v_e,\ \xi_2 = \omega + \Gamma_2 v_e,\ \xi_3 = \omega + \Gamma_3 v_e$$

The output power is given by

$$P_s = \frac{E_{h\,1,s}^2}{2R} \qquad \text{.. .. .. .. (3.11)}$$

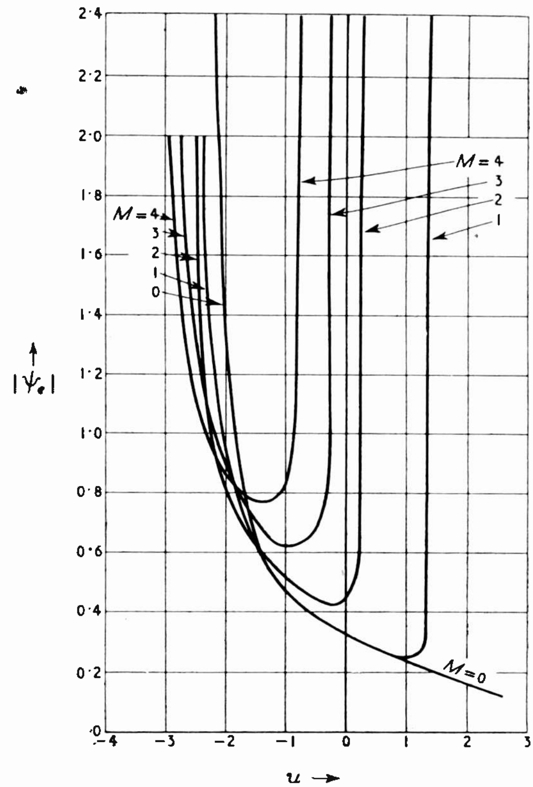


Fig. 6. Factor $|\psi_e|$ determining the repartition of the input field produced by the generator to the three excited waves.

and, in view of equation (1.13) and (1.14)

$$E_h = E_{tot}(1 + a_1) \quad .. \quad .. \quad .. \quad (3.12)$$

$$P_s = \frac{|1 + a_1|^2 E^2_{tot,1,s}}{2R} = |1 + a_1|^2 \frac{E_{tot,1,e}}{2R} e^{2\gamma z}$$

$$= |\psi_s|^2 \frac{E^2_{tot,1,e}}{2R} e^{2\gamma z}$$

We have at the entrance the sum of the fields $E_{h,e}$ equal to the field E_g and with equation (1.13)

$$E_g = \sum_{\mu=1}^{3} E_{h,\mu,e} = \sum_{\mu=1}^{3} (1 + a_\mu) E_{tot,\mu,e} \quad (3.13)$$

and, also $\sum_{\mu=1}^{3} v_{\mu,a} = 0, \sum_{\mu=1}^{3} i_{\mu,e} = 0$ therefore,

$$\sum_{\mu=1}^{3} \frac{E_{tot,\mu,e}}{\xi_\mu} = 0 \quad .. \quad .. \quad (3.14)$$

$$\sum_{\mu=1}^{3} \frac{E_{tot,\mu,e}}{\xi_\mu^2} = 0 \quad .. \quad .. \quad (3.15)$$

From these three conditions the following complex equation emerges

$$E_{tot,1,e} = E_g \frac{1}{(1 - \xi_2/\xi_1)(1 - \xi_3/\xi_1)} \quad .. \quad (3.16)$$

and, therefore, according to (3.12)

$$P_s = \frac{E_g^2}{2R} |\psi_s|^2 |\psi_e|^2 e^{2\gamma z} = \frac{E_g^2}{2R} |\psi|^2 e^{2\gamma z} \quad (3.17)$$

The power gain of the tube is in consequence given by

$$G = \frac{P_s}{P_g} = |\psi_e|^2 |\psi_s|^2 e^{2\gamma z} = \psi e^{2\gamma z} \quad .. \quad (3.18)$$

with $\psi_e = \dfrac{1}{(1 - \xi_2/\xi_1)(1 - \xi_3/\xi_1)}$ .. .. (3.19)

and

$$\psi_s = 1 + a_1 = 1 - \Omega^2 \frac{K_o^2}{K_o^2 + q^2} \frac{1}{(\omega + \Gamma_1 v_e)^2} \quad .. \quad .. \quad .. \quad (3.20)$$

We have introduced into the preceding relations the two values ψ_e and ψ_s, which appear to be necessary for physical reasons. According to (3.16) ψ_e describes the repartition of the field of the generator on the three excited waves. The current of the beam intervenes in ψ_e only to the extent to which ξ_1, ξ_2, ξ_3 are modified. This is clear from the physical point of view: at the entrance, the field produced by the forces of repulsion of the electrodes is always insignificant, even for high currents, in view of the small bunching in the vicinity of the input. In Fig. 6 we have traced $|\psi_e|$ as function of u. The expression $\psi_s = 1 + a_1$ is defined by the fields located at the output, where the field coming from the Coulomb forces is no longer insignificant for large currents. We believe that these conceptions, leading to the introduction of ψ_s, are fully justified from the physical point of view and this conception appears moreover to be confirmed by corresponding relations in Rydbeck's publication[7] which contains a factor equivalent to our ψ_s. In Fig. 7 we have traced $|\psi_e| |\psi_s| = |\psi| = f(u)$ which for low currents is equal to $|\psi_e|$ ($M = 0$, h.f. space-charge negligible), whereas for $M > 1$ $|\psi_s| \neq 1$, $|\psi| \neq |\psi_e|$. For the values of u for which $\gamma \rightarrow 0$ we have $|\psi| \rightarrow \infty$. But these high values of ψ are of no practical interest whatsoever. We have shown in Fig. 7 by small circles the values of u_{max}. In the vicinity of u_{max} (i.e., of γ_{max}) $|\psi| = 0{\cdot}3$ to $0{\cdot}5$ or -6 to -10 db.

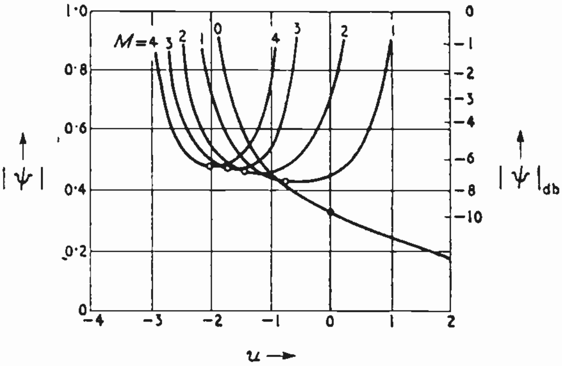


Fig. 7. Factor $|\psi|$ determining the output power of the travelling wave tube as dependent on the initial conditions at the entrance and the exit of the tube (see equation 3.18).

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DIELECTRIC AERIALS WITH SHAPED RADIATION PATTERNS

By D. G. Kiely, M.Sc., A.Inst.P.

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SUMMARY.—This article describes an application of solid dielectric radiators to the production of specially-shaped radiation patterns. In particular the empirical development of a 3·2-cm aerial with a beamwidth in the magnetic plane of 240° to 6 db points is described. The general method is claimed to be applicable to other aerial design problems where the existing techniques would present rather more difficulty.

Introduction

THE design of microwave aerials having specially-shaped radiation patterns frequently presents problems which are not readily solved by application of existing techniques. For example, the development of aerials having radiation patterns of rectangular shape (on rectangular Cartesian co-ordinates) and beamwidths between 180° and 360° presents certain design difficulties when approached theoretically, and considerable experimental work when approached empirically, using the technique involving flanges at the aperture of an electromagnetic horn.[1] Other types of specially-shaped radiation patterns present similar difficulties in aerial design which have been resolved in certain cases, such as the well-known squared co-secant pattern, by satisfactory design methods. It was felt that a more elastic empirical technique of aerial design for general application to those radiation patterns which were outside the scope of the known design techniques described in the literature would be useful in many instances. Accordingly, this article presents a new technique using shaped dielectric radiators for the production of shaped radiation patterns and illustrates the technique by describing the development of a 3·2-cm aerial with a magnetic plane beamwidth of 240° to 6 db points.

Experimental Procedure

The problem of designing centimetre aerials to have beamwidths greater than 180° and less than 360° can be solved by the use of plane flanges placed at the aperture of an electromagnetic horn, the beamwidth being largely governed by the lengths of the flanges and their included angles.[1]

The method here described employs the properties of dielectric-rod aerials and has the advantage that the aerial aperture is closed by the dielectric thus making the problem of weather-proofing considerably simpler. The method has the additional advantage that mechanical tolerances are larger than with flanges fitted to the aperture of a horn where the included angle of the flanges is critical. The dielectric aerial described below was developed at 3·2-cm wavelength and was scaled down to operate at a fifth of this wavelength with similar radiation-pattern characteristics.

It has been shown[2] that the radiation pattern of a tapered dielectric-rod aerial is made considerably broader if the rod is untapered. This effect is brought about by a change in the distribution of electromagnetic field amplitude along the rod due to the wave impedance in the rod being constant and not gradually tending to the free-space wave impedance which occurs when the rod is tapered. The broadening of the radiation pattern can be accentuated if the rod diameter is increased along its length from the excitation end. These facts provided the basis for development of the present aerial.

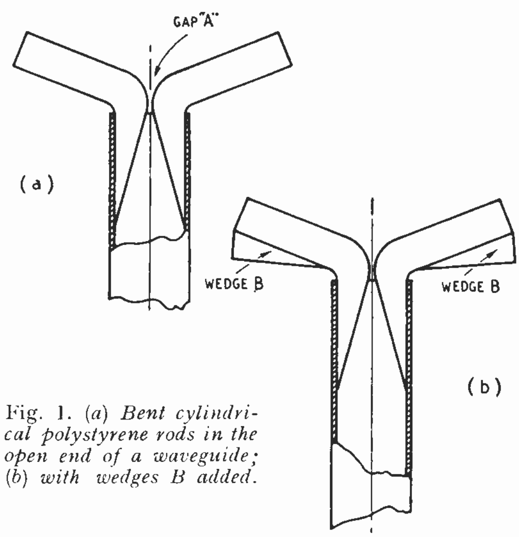

Fig. 1. (*a*) *Bent cylindrical polystyrene rods in the open end of a waveguide;* (*b*) *with wedges B added.*

Two cylindrical rods of polystyrene, bent in smooth curves, were inserted in the open end of a length of waveguide as shown in Fig. 1(a). The portions of the rods within the guide were tapered to points to provide a certain degree of matching.

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The H-plane radiation pattern of this system was measured and was found to be broader than the pattern of the open-ended guide alone. The rod widths were then increased progressively along their lengths by attaching wedge-shaped pieces of polystyrene by superstyrex adhesive as seen in Fig. 1(b). The radiation pattern of this system was measured and found to be wider than that of Fig. 1(a). Next, the importance of the gap A [Fig. 1(a)] was investigated by a series of experiments and the importance of the shape of the curve of the rods was also studied.

Eventually an optimum shape for maximum broadness of pattern was evolved and is shown dimensioned in Fig. 2. The radiation pattern of this system has a beamwidth of 240° to 6 db points and is shown in Fig. 3.

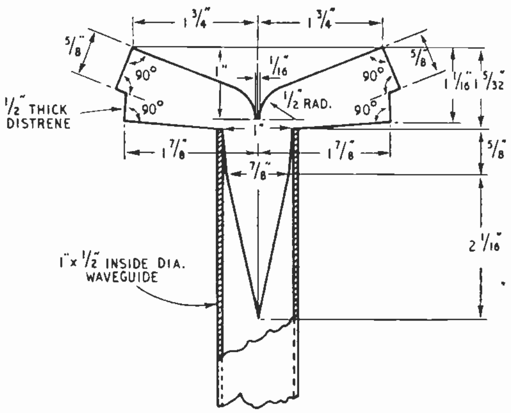

Fig. 2. *Optimum shape of dielectric aerial.*

It was found that the dimensions of the gap A exercised a considerable effect on the shape of the radiation pattern and that the pattern shape could be altered to quite a large extent by affixing wedges of varying sizes in different positions on the main rods. Thus, the general method, though largely empirical, is quite versatile for the production of radiation patterns of special shapes not normally obtained from conventional radiating elements. For example, the method could be applied to the production of asymmetrical radiation patterns such as the often-required cosec^2 pattern.

Scaling to a Smaller Operating Wavelength

The aerial system as seen in Fig. 2 was scaled down linearly from 3·2-cm wavelength to one-fifth of this wavelength. The dimensions of the scaled-down aerial were very small (about 0·5 in overall) and the contour of the dielectric was cut out by hand using a sharp knife. This meant that the accuracy of the contour was not very great and it was encouraging to note that the radiation pattern was similar to that at 3·2 cm. It is shown

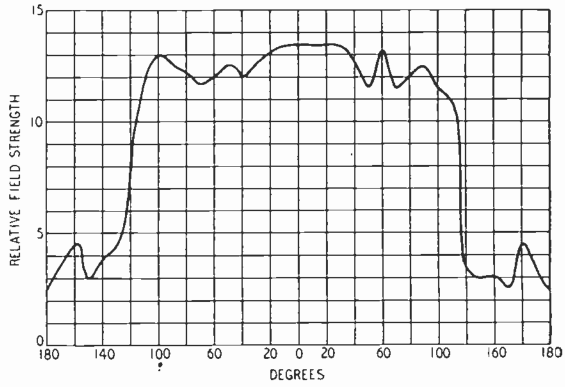

Fig. 3. *Radiation pattern of the aerial of* Fig. 2.

in Fig. 4. The two peaks in the pattern are most probably due to inaccurate scaling, particularly of the gap A.

Conclusion

A method of aerial design is described which employs the properties of dielectric-rod aerials and may be applied to the production of very wide or specially-shaped beams. The development of an aerial is discussed which has a beamwidth of 240° to 6 db points in the H-plane.

The method may equally well be applied to E-plane radiation patterns which have not, however, been investigated in the course of this work.

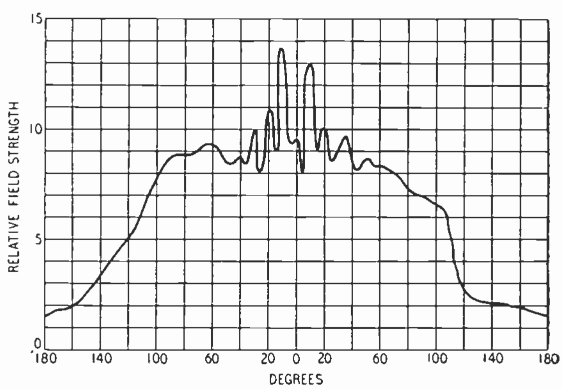

Fig. 4. *Radiation pattern of a scaled-down model of the aerial of* Fig. 2.

Acknowledgment

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

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PIEZOELECTRIC CRYSTALS IN FLEXURAL VIBRATION

Values of Equivalent Circuit Elements

By Hartmut Keller

SUMMARY.—The values of the equivalent circuit elements of several flexural vibrating piezoelectric crystals, slabs, double-T-shaped plates, and double strips, are calculated from the effective stiffness and mass, and the electromechanical coupling.

LIST OF SYMBOLS

C, C', C'' Equivalent capacitance; generally, of double strip with and without internal electrode.
C_0, C_0', C_0'' Corresponding shunt capacitances.
C_l, C_f Static capacitance of crystal free to vibrate longitudinally, flexurally.
D Directing moment.
d Piezoelectric coefficient.
E Young's modulus (in direction of length).
e Piezoelectric modulus (piezoelectric constant in Voigt's terminology[1]).
F Force.
f Natural frequency.
J_e Equatorial moment of inertia.
J_p Polar moment of inertia.
K_c, K_{flex}, K_l. Dielectric constant (in direction of thickness) of crystal clamped, free to vibrate flexurally, and free to vibrate longitudinally.
k Radius of gyration of cross section in Equ. (19).
$k = f\,l/N_l$ in Equs (47) and (49) and Fig. 11.
L, L', L'' Equivalent inductance; generally, of double strip with and of double strip without internal electrode.
l Length.
M, M_f Moments of rotation and flexion.
m Mass and effective mass.
$N_l = \frac{1}{2}\sqrt{(E/\rho)}$ Frequency constant for longitudinal vibrations (half of velocity of sound in direction of length).
n Order of mode of vibration.
P Dielectric polarization.
Q Electric charge.
R Resistance.
r Radius of curvature.
S Stiffness and effective stiffness.
s Deflection.
t Time in Equs (1) and (2). Thickness in all other equations.
V Potential difference, voltage.
w Width.
x, y Co-ordinates.
α Angle of inclination and rotation.
μ Resistance to friction.
ρ Density.
σ Stress.
ϕ Electromechanical coupling.

Introduction

It is well known that the electrical behaviour of a piezoelectric crystal, in the neighbourhood of its resonance (Butterworth[2]) can be represented by the electric circuit shown in Fig. 1, where the values of the elements C_0, C, L, and R are determined by the geometrical, mechanical, electrical, and piezoelectrical properties of the crystal. Cady,[3] Van Dyke,[4,5,6] Dye,[7] and others have shown this for longitudinal vibrating crystals and Dumesnil[8] for crystal plates excited to shearing vibrations in the major plane. In the present paper the equivalent circuit elements are calculated for flexurally vibrating crystals. As known, flexural vibrations are used for low frequencies, preferably lower than about 40 kc/s.

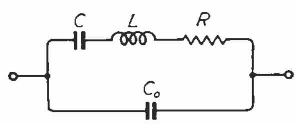

Fig. 1. *Equivalent electrical circuit of piezoelectric crystal.*

1. Electromechanical Analogy

The equivalent circuit and the determination of the values of its elements can be based on the analogy between the differential equation of the mechanical system

$$m\frac{d^2s}{dt^2} + \mu\frac{ds}{dt} + Ss = F \quad \ldots \quad \ldots \quad (1)$$

and the differential equation of the electrical circuit

$$L\frac{d^2Q}{dt^2} + R\frac{dQ}{dt} + \frac{Q}{C} = V \quad \ldots \quad \ldots \quad (2)$$

Exciting the mechanical system piezoelectrically, the force is proportional to the applied voltage, and the developed electrical charge* is proportional to the displacement

$$\frac{F}{V} = \phi_1, \quad \frac{Q}{s} = \phi_2 \quad \ldots \quad \ldots \quad (3), (4)$$

ϕ_1 and ϕ_2 have the dimensions of an electric potential, and according to the principle of thermodynamics[9]

$$\phi_1 = \phi_2 = \phi \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

ϕ is also called electromechanical coupling.

Multiplying the differential equation of the electric circuit (2) by $\phi_1 = F/V$, and substituting

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* Applied to the equivalent circuit of a piezoelectric crystal (Fig. 1) Q is related only to the branch C, L, R.

$\phi_2 s$ for Q according to equations (3), (4), gives with equation (5)

$$L\phi^2 \frac{d^2s}{dt^2} + R\phi^2 \frac{ds}{dt} + \frac{\phi^2 s}{C} = F \quad \ldots \quad (6)$$

The comparison of the coefficients of this equation (6) with those of equation (1) gives the values of the equivalent circuit.

$$L = \frac{m}{\phi^2} \quad \ldots \quad (7)$$

$$R = \frac{\mu}{\phi^2} \quad \ldots \quad (8)$$

$$C = \frac{\phi^2}{S} \quad \ldots \quad (9)$$

For rotary vibrations, the same calculation applies if the mass is replaced by the moment of inertia, the force by the moment of rotation, and the stiffness by the moment of rotation causing a rotation about the unit of angle.

Consequently, to calculate the values of the equivalent circuit elements of a piezoelectric crystal, it is necessary to determine the mechanical values, m, μ, S, and the electromechanical value ϕ. Therewith L, R, C are given by equations (7), (8), (9).

The resistance μ of a piezoelectric crystal depends not only on the viscosity of crystal and electrode material and the radiation of sound, but is much affected by the kind of mounting. An accurate calculation of R is therefore not possible. Consequently the main problem of a theory of the equivalent circuit of a piezoelectric crystal is reduced to the determination of the values of the equivalent inductance L and capacitance C. The value of the shunt capacitance C_o is given by the formula for a plate capacitor with the dielectric constant of the 'clamped' crystal.

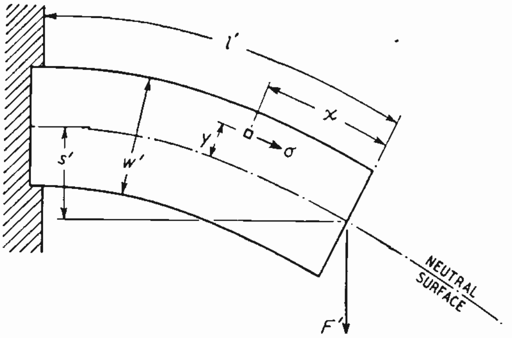

Fig. 2. *Illustrating the movement of a slab clamped at one end.*

A crystal with electrodes arranged for longitudinal vibration and mounted free to vibrate has the dielectric constant $K_l = K_c + 4\pi e^2/E$, measured with direct current or with alternating current of a frequency considerably lower than the resonant frequency. For a crystal with electrodes arranged for flexural vibrations, the formula

$$K_{flex} = K_l \Big/ \left(1 + \frac{\pi d^2 E}{K_l}\right)$$

can be used for ordinary vibrating slabs and for the bridge of double-T shaped plates in spite of its having been derived for double strips. [10] In this equation d is the piezoelectric coefficient (piezoelectric modulus in Voigt's terminology[1]).

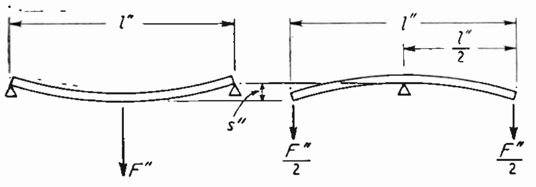

Fig. 3. *A slab held at each end and with an applied force F" at the centre is equivalent to a slab clamped in the middle with forces F"/2 applied at each end.*

2. Elasticity of Flexure

For the point in question the following well-known formulae and laws of elasticity of flexure are used.

Clamping a slab (Fig. 2) of length l', thickness t', and width w' at one end, and applying a force F' (in the direction of width) on the other end, the stress is

$$\sigma' = \frac{F' x y}{J_e} = 12 \frac{F' x y}{w'^3 t'} \quad \ldots \quad (10)$$

where x and y indicate the co-ordinates related to the free end and neutral surface. The deflection is given by

$$s' = 4 \frac{F' l'^3}{E t' w'^3} \quad \ldots \quad (11)$$

Laying a slab (l'', w'', t'') on both ends, and applying a force F'' (in the direction of w'') on its middle, the behaviour can be found by assuming the slab to be laid on its middle, and half of the force applied at each end (Fig. 3). Therefore the stress is

$$\sigma'' = \frac{F'' x y}{2 J_e} = \frac{6 F'' x y}{w''^3 t''} \quad \ldots \quad (12)$$

where x designates the distance from the nearer end of the slab. In this case the deflection is given by

$$s'' = \frac{1}{4} \frac{F'' l''^3}{E t'' w''^3} \quad \ldots \quad (13)$$

Moreover, the differential equation of flexural elasticity

$$\frac{d^2y}{dx^2} = \frac{M_f}{E J_e} = \frac{12 M_f}{E t w^3} \quad \ldots \quad (14)$$

is used.

3. Piezoelectric Laws

For the following reasons the fundamental piezoelectric laws can be simplified by using only one component of the electric-field strength (in the direction of the thickness of the crystal) or of the electric momentum, and only one component of the stress or strain (in the direction of the length of the crystal).

The stress is

$$\sigma = e\frac{V}{t} \quad \ldots \quad (15)$$

The field strength of a double strip with internal electrode is $2V/t$ and therefore the stress in a double strip

$$\sigma = 2\,e\,V/t \quad \ldots \quad (15a)$$

The polarization is

$$P = e\,\sigma/E \quad \ldots \quad (16)$$

It is presumed, that the electrodes are in contact with the crystal surfaces, and that the thickness of one crystal plate of a double strip is $t/2$.

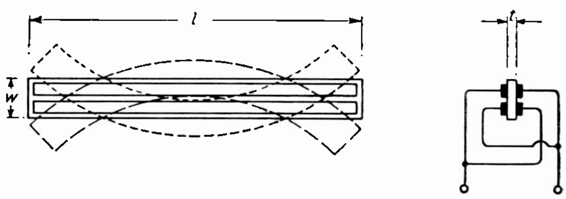

Fig. 4. *The most useful flexurally-vibrating crystal has two pairs of electrodes and vibrates as shown.*

4. Flexural Vibration

The ordinary and most used flexural vibrating crystals, introduced by Harrison[11] are rectangular-shaped slabs having two pairs of electrodes, as shown in Fig. 4. They are similar to the device of Giebe and Scheibe,[12] which is characterized by very short electrodes in order to show the luminous effect at resonance in various overtones, but Harrison used full-length electrodes for more efficient excitation of the first flexural mode. The flexion is due to the electric fields of opposite sign in the two halves of the crystal, thus causing an extension of one half of the bar and a contraction of the other half, with resulting flexion. The natural frequency of flexural vibration of a slab is much lower than that of longitudinal or shear vibration. This permits the use of these crystals for frequencies as low as about 1 kc/s.

For very low frequencies, for example lower than 1 kc/s and as low as about several hundred c/s, the mass and the (flexural) elasticity of the resonator are separated and concentrated at its ends and its middle respectively by the shape shown in Fig. 5, introduced by Gruetzmacher.[13] The ends of such a resonator have rotational vibration and the bridge flexural vibration as shown in Fig. 5 by dotted lines. Consequently, only the bridge is supplied with two pairs of electrodes, situated and connected together as in Harrison's and Giebe and Scheibe's device.

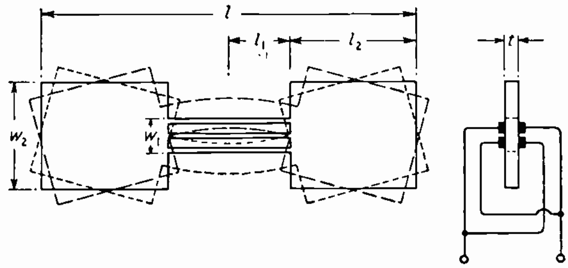

Fig. 5. *For very low frequencies the mass and elasticity of the resonator are separated.*

Moreover, the double strip (bilame, bimorph bender) of P. and J. Curie[14] is a flexural vibrating crystal which is frequently used in practice for non-resonant applications, conversion of electrical low-frequency currents into mechanical movements and vice versa, particularly in acoustic and motion-picture devices. The double strip was used as a resonator by Cady[15] in 1927 and later by de Gramont and Béretzki.[16]

It is shown in this paper, that the 'Curie strip' has also particular properties for use as a resonator. The double strip is composed either of two crystal plates of conformable orientation and three electrodes, as shown in Fig. 6, or of two crystal plates of opposite orientation (this means that the polar crystal axes have opposite directions in the two crystal plates), and two electrodes, as shown in Fig. 7. Opposite stresses in the two crystal plates are produced by opposite electrical fields in the two plates of conformable orientation (Fig. 6), or by electrical fields of conformable signs in the two plates of opposite orientation (Fig. 7).

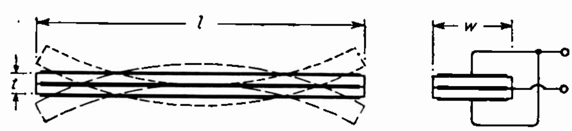

Fig. 6. *Double-strip resonator with two crystal plates and three electrodes.*

As shown, the electrical field is applied to all of these crystal resonators in the direction of thickness, but flexural vibrations can also be produced by electrical fields along the length of a slab or parallel to the main surface of a plate, and the stress can be a shearing stress. These devices are not discussed in this paper.

In the following derivations the mechanical equivalent (effective stiffness and mass) is based on a statical stiffness. By this stiffness, together with the resonant frequency, the effective mass is determined. It is to be noted that this determination of effective stiffness and mass only applies to flexural vibrations.

5. Flexural Vibrations in Slabs

5.1. *Effective Stiffness and Mass*

When a slab vibrates flexurally, it can be assumed that the total force F acts with $F/2$ in one direction on the middle of the slab and with $F/4$ on each end in the opposite direction, as shown in Fig. 8. The total deflection in both directions is $2s$. Therefore, according to equation (13) ($F'' = F/2$, $s'' = 2s$).

$$s = \frac{F\,l^3}{16\,E\,t\,w^3} \quad \ldots \quad (17)$$

The relation between the total force and the displacement is the effective stiffness

$$S = \frac{F}{s} = 16\,\frac{E\,t\,w^3}{l^3} \quad \ldots \quad (18)$$

The natural frequency of the flexural vibration is given by the well-known formula[17]

$$f = \frac{(n+1/2)^2\pi}{2}\,\frac{k}{l^2}\sqrt{\left(\frac{E}{\rho}\right)} \quad \ldots \quad (19)$$

(This equation is applicable when $n\,w/l < 0{\cdot}1$).

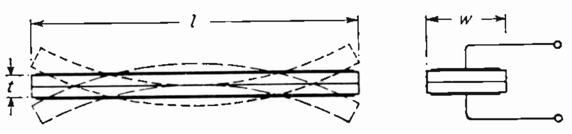

Fig. 7. *Double-strip resonator with two crystal plates and two electrodes.*

When the dimension in the direction of vibration is appreciable in comparison with the length, Mason,[18, 19] has considered the effects of rotary and lateral inertia, which are ignored in this paper. Equation (19) has also been examined and corrections are given by Harrison,[20] and Giebe and Scheibe.[21, 22, 23, 24]

For the fundamental mode ($n = 1$) and with $k = w/2\sqrt{3}$

$$f = \frac{3\sqrt{3}}{16}\pi\,\frac{w}{l^2}\sqrt{\frac{E}{\rho}} = \frac{2{\cdot}04w}{l}\cdot\frac{1}{2l}\sqrt{\frac{E}{\rho}} \quad \ldots \quad (20)$$

which is nearly the resonant frequency at longitudinal vibration in direction of length multiplied by 2·04 times the ratio of width to length.

From the well-known solution of the differential equation (1)

$$f = \frac{1}{2\pi}\sqrt{\frac{S}{m}} \quad \ldots \quad (21)$$

and from (18) and (20) we obtain for the effective mass

$$m = \frac{1024}{27\,\pi^4}\,l\,t\,w\,\rho \quad \ldots \quad (22)$$

5.2. *Electromechanical Coupling*

The electrical field strength V/t produces according to (15) the elastic stress

$$\sigma = e\,V/t \quad \ldots \quad (23)$$

At a distance y from the neutral surface, the moment of rotation is

$$dM = eVydy \quad \ldots \quad (24)$$

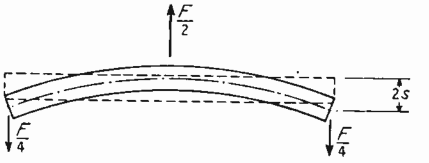

Fig. 8. *Slab in flexural vibration.*

opposed to the moment due to the elasticity

$$-dM' = \frac{\delta l}{\Delta l}\,Etydy \quad \ldots \quad (25)$$

where δl and Δl have the meaning shown in Fig. 9, from which it is evident that

$$\frac{\delta l}{\Delta l} = \frac{y}{r}\,. \quad \ldots \quad (26)$$

Assuming that $r \gg l$, (Fig. 10)

$$\frac{l^2}{4} + (r - 2s)^2 = r^2, \quad \ldots \quad (27)$$

and since $s^2 \ll 2rs$,

$$\frac{l^2}{4} = 4rs \quad \ldots \quad (28)$$

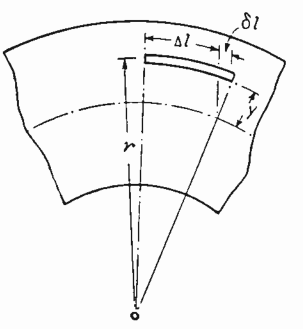

Fig. 9. *Illustrating the meaning of δl and Δl used in equation (25).*

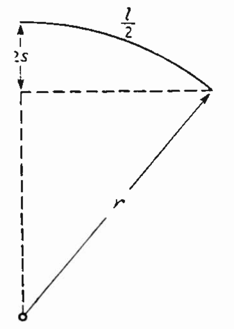

Fig. 10. *Symbols used in the equations for flexural vibration.*

Introducing the value for r from (28) into (26) the strain is

$$\frac{\delta l}{\Delta l} = \frac{16sy}{l^2} \quad \ldots \quad (29)$$

and (25) becomes

$$-dM' = \frac{16Est}{l^2} y^2 dy \quad .. \quad .. \quad (30)$$

The condition of equilibrium is $\int dM - \int dM' = 0$, or, from (24) and (30),

$$\int_0^{w/2} eVy dy - \int_0^{w/2} \frac{16Est}{l^2} y^2 dy = 0 \quad .. \quad (31)$$

Therefore from (3) (17) and (31) the ratio of force to voltage, is given by

$$\phi_1 = 3ew^2/l \quad .. \quad .. \quad .. \quad .. \quad (32)$$

The same value is obtained for ϕ_2. From (12) (with $F''/2 = F/4$, $w'' = w$, and $t'' = t$), the stress

$$\sigma = 3 \frac{Fxy}{w^3 t} \quad .. \quad .. \quad .. \quad .. \quad (33)$$

and from (13) (with $F''/2 = F/4$, $s'' = 2s$, and $l'' = l$)

$$\sigma = \frac{48 \ Esxy}{l^3}. \quad .. \quad .. \quad .. \quad .. \quad (34)$$

The total of the developed charge, given by the piezoelectric law (16), with the stress according to (34), is therefore

$$Q = 4 \int_0^{l/2} \int_0^{w/2} \frac{48es}{l^3} xy \, dx \, dy = \frac{3esw^2}{l} \quad .. \quad (35)$$

Consequently the ratio of charge to displacement (4), is

$$\phi_2 = 3ew^2/l \quad .. \quad .. \quad .. \quad .. \quad (36)$$

in agreement with (5) and (32).

It is to be noted that the calculation of ϕ_1 is based on a flexion according to the curvature of an arc, whereas the calculation of ϕ_2 is based on a flexion according to the curvature of the elastic line. In spite of this difference the values for ϕ_1 and ϕ_2 are equal.

5.3. *Equivalent Circuit Elements*

Equations (7) and (9), together with the effective stiffness and mass (18) and (22), the electromechanical coupling (5), and (32) or (36) give the equivalent inductance

$$L = \frac{1024}{243\pi^4} \frac{l^3 t \ \rho}{w^3 e^2} \quad .. \quad .. \quad .. \quad (37)$$

and the equivalent capacitance

$$C = \frac{9}{16} \frac{e^2 wl}{Et} \quad .. \quad .. \quad .. \quad .. \quad (38)$$

With the shunt capacitance

$$C_o = \frac{K_c lw}{4\pi t} \quad .. \quad .. \quad .. \quad .. \quad (39)$$

the ratio of capacitances is therefore

$$\frac{C_o}{C} = \frac{4}{9\pi} \cdot \frac{K_c E}{e^2} \quad .. \quad .. \quad .. \quad (40)$$

This is the ratio of capacitances of the same crystal vibrating longitudinally* multiplied by $128/9\pi^2$, in agreement with the value obtained by Mason[25] and established experimentally by Mason and Sykes.[26] In practice the effective ratio of capacitances is increased due to the stray capacitance in parallel with C_o. With flexural vibrations this increase is more than with longitudinal or thickness vibrations, due to the greater stray capacitance of the special arrangement of the four electrodes. However, for special cases, the stray capacitance can be nearly removed by shielding, as shown by Rohde and Handrek.[27]

6. Flexural Vibrations in Double-T-Shaped Plates.

6.1. *Effective Stiffness and Mass*

The moment of flexion in the bridge is independent of x and equal to the moment of rotation of each end mass. The angle of inclination at the end of the bridge is equal to the angle of rotation of each end mass and follows from (14)

$$\alpha = \frac{M_f l_1}{E \ J_e} = \frac{M_r l_1}{E \ J_e} \quad .. \quad .. \quad .. \quad (41)$$

where J_e is the equatorial moment of inertia of the cross-section of the bridge and M_r is the moment of rotation of one end mass. The relation between the total moment of rotation of the two end masses and the angle of rotation is therefore

$$D = \frac{2 \ M_r}{\alpha} = \frac{2 \ E \ J_e}{l_1} \cdot .. \quad .. \quad .. \quad (42)$$

Denoting the polar moment of inertia of one end mass of the crystal by J_p, and neglecting the mass of the bridge, the natural frequency is given by

$$f = \frac{1}{2\pi} \sqrt{\left(\frac{E \ J_e}{l_1 J_p}\right)} \quad .. \quad .. \quad .. \quad (43)$$

For a rectangular cross section of the bridge and rectangular ends (masses) of the crystal, the moments of inertia are known to be

$$J_e = \frac{t w_1^3}{12} \quad .. \quad .. \quad .. \quad .. \quad (44)$$

$$J_p = \frac{1}{12} \rho t \ (w_2 l_2^3 + w_2^3 l_2) \quad .. \quad .. \quad (45)$$

The lowest natural frequency is approximately obtained by

$$\frac{l_1}{l_1 + l_2} = 0{\cdot}3 \quad .. \quad .. \quad .. \quad (46)$$

In this case of practical importance the natural frequency can be written

$$f = N_l k/l \quad .. \quad .. \quad .. \quad .. \quad (47)$$

* The equivalent capacitance of a longitudinally vibrating slab is known to be $C_{long} = 8e^2 wl/(\pi^2 Et)$. The ratio of capacitances for longitudinal vibrations is therefore from (39) $C_o/C_{long} = \pi K_c E/(32e^2)$.

where N_l is the frequency constant for longitudinal vibrations (half of the velocity of sound) in the direction of l,

$$N_l = \frac{1}{2}\sqrt{\left(\frac{E}{\rho}\right)} \quad \ldots \quad (48)$$

and k is a factor depending on the shape,

$$k = 1\Big/\pi\sqrt{\left[0{\cdot}0525\left(\frac{w_2}{w_1}\right)^3\left\{0{\cdot}1225\left(\frac{l}{w_2}\right)^2 + 1\right\}\right]} \quad \ldots \quad (49)$$

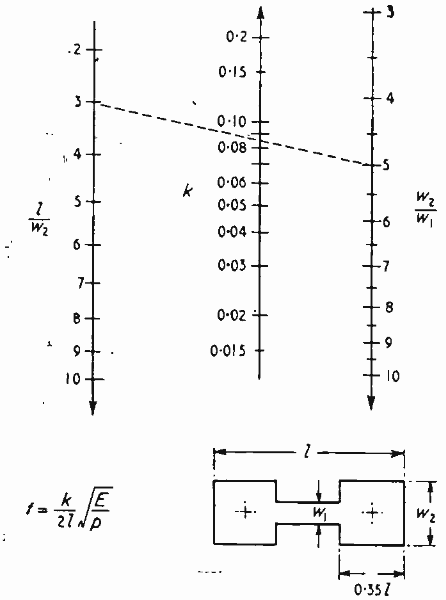

Fig. 11. *Abac for determining the shape factor k.*

To determine this factor k, a suitable diagram is given in Fig. 11. The correlation between k, l/w_2, and w_2/w_1 is obtained by placing a straightedge across the three lines of the Abac; if any two quantities are known the third can immediately be read off.

6.2. *Electromechanical Coupling*

For the rotatory vibrations of the ends of the crystal, ϕ_1 is the ratio of the produced moment of rotation to the applied voltage. The moment of rotation due to the electric field in the bridge is according to (24)

$$M = 2\int_0^{w_1/2} eVy\,dy \quad \ldots \quad (50)$$

This moment acts at both ends of the bridge. The total moment which rotates the two end masses of the crystal is therefore $2M$. Hence from (50) the ratio of the total moment of rotation to the voltage

$$\phi_1 = ew_1^2/2 \quad \ldots \quad (51)$$

The other electromechanical value, the ratio ϕ_2 of the developed electric charge to the angle of rotation of the end masses, can be computed in the following manner: Conformable with (26), the strain in the bridge is (from Fig. 9)

$$\frac{\delta l}{\Delta l} = \frac{y}{r} \quad \ldots \quad (52)$$

To introduce the angle of rotation instead of the radius of curvature, we find from Fig. 12

$$y^2 + x^2 = r^2 \quad \ldots \quad (53)$$

and because the angles are very small, it follows that

$$\alpha = \tan\alpha = \frac{dy}{dx} = -\frac{x}{\sqrt{(r^2 - x^2)}} \quad \ldots \quad (54)$$

where $x \ll r$, and the sign of the differential quotient is unessential. The angle of inclination at the ends of the bridge ($x = l_1$) or the angle of rotation of the end masses is therefore

$$\alpha = l_1/r \quad \ldots \quad (55)$$

Introducing the radius of curvature from (55) into (52) gives

$$\frac{\delta l}{\Delta l} = \frac{y\alpha}{l_1} \quad \ldots \quad (56)$$

From Hooke's Law

$$\frac{\delta l}{\Delta l} = \frac{\sigma}{E} \quad \ldots \quad (57)$$

the stress

$$\sigma = E\alpha y/l_1 \quad \ldots \quad (58)$$

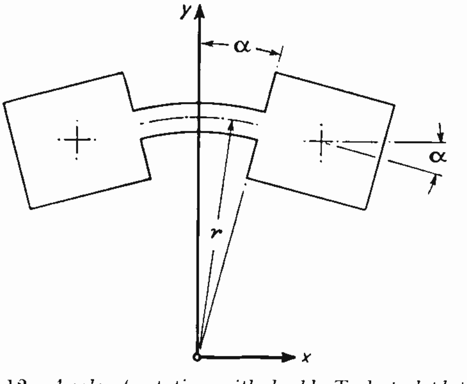

Fig. 12. *Angle of rotation with double T-shaped plates.*

This stress produces according to (16) the piezoelectric polarization

$$P = e\alpha y/l_1 \quad \ldots \quad (59)$$

Therefore in agreement with (5) and (51) the ratio of the developed electric charge to the angle of rotation is

$$\phi_2 = 4\int_0^{l_1}\int_0^{w_1/2}\frac{e}{l_1}y\,dx\,dy = \frac{ew_1^2}{2} \quad .. \quad (60)$$

6.3. *Equivalent Circuit Elements*

From (7) with m replaced by $2J_p$, (9) with S replaced by D, and from (42), (44), (45) and (51) respectively (60), the values of the electric elements are

$$L = \frac{2\rho t\,(w_2 l_2^3 + w_2^3 l_2)}{3e^2 w_1^4} \quad .. \quad .. \quad (61)$$

$$C = \frac{3}{2}\frac{l_1 e^2 w_1}{Et} \quad .. \quad .. \quad .. \quad (62)$$

The shunt capacitance

$$C_o = \frac{K_c l_1 w_1}{2\pi t} \quad .. \quad .. \quad .. \quad (63)$$

and therefore the ratio of capacitances

$$\frac{C_o}{C} = \frac{K_c E}{3\pi e^2} \quad .. \quad .. \quad .. \quad .. \quad (64)$$

In practice this value is increased by the stray capacitance, as mentioned in Section 5.3.

7. Double Strips

7.1. *Effective Stiffness and Mass*

The effective stiffness and mass (and the natural frequency) follow from (18), (22) and (20). It is to be noted that the direction of vibration of the slab (Fig. 4) is parallel to the width, whereas that of the double strip (Figs. 6 and 7) is parallel to the thickness

$$S = 16\,Et^3 w/l^3 \quad .. \quad .. \quad .. \quad (65)$$

$$m = \frac{1024}{27\pi^4}\,lwt\rho \quad .. \quad .. \quad .. \quad (66)$$

$$f = \frac{3\sqrt{3}}{16}\,\pi\,\frac{t}{l^2}\sqrt{\left(\frac{E}{\rho}\right)} \quad .. \quad .. \quad (67)$$

It is assumed that the double strip is vibrating freely; that is, clamped at the nodal points, as shown in Figs. 6 and 7, as is usual in a resonator.

7.2. *Electromechanical Coupling*

In a double strip with two external and one internal electrode (Fig. 6), the electric field $2V/t$ (the distance between two electrodes is $t/2$) produces the stress

$$\sigma = 2eV/t \quad .. \quad .. \quad .. \quad (68)$$

At a distance y from the neutral surface there is a moment of rotation

$$dM = \frac{2eV}{t}\,wy\,dy \quad .. \quad .. \quad .. \quad (69)$$

opposed to the moment due to the elasticity

$$-dM' = \frac{16Esw}{l^2}\,y^2\,dy \quad .. \quad .. \quad (70)$$

Equation (70) follows from equation (30) by changing t for w because the direction of vibration is parallel to t for equation (30) and parallel to w in the double strip. For this reason the deflection of the double strip given by equation (17) is

$$s = \frac{Fl^3}{16Et^3 w} \quad .. \quad .. \quad .. \quad .. \quad (71)$$

The ratio ϕ_1 of the developed force of the double strip with internal electrode to the applied voltage follows from the condition of equilibrium, given by the equations (69) and (70)

$$\int_0^{t/2}\frac{2eV}{t}\,wy\,dy - \int_0^{t/2}\frac{16Esw}{l^2}\,y^2\,dy = 0 \quad .. \quad (72)$$

and substituting for s from equation (71)

$$\phi_1' = \frac{6etw}{l} \quad .. \quad .. \quad .. \quad .. \quad (73)$$

For double strips without internal electrode the field stress is only V/t, therefore

$$\phi_1'' = \frac{3etw}{l} \quad .. \quad .. \quad .. \quad (74)$$

For the computation of the other constant ϕ_2 (ratio of the developed electrical charge to the displacement), we have again the stress by putting wt^3 for w^3t in equation (33)

$$\sigma = 3\,\frac{Fxy}{t^3 w} \quad .. \quad .. \quad .. \quad (75)$$

and substituting for F from equation (71)

$$\sigma = 48Esxy/l^3 \quad .. \quad .. \quad .. \quad (76)$$

The electrical charge of an area $w.dx$ of a little volume $w.dx.dy$ of the double strip is according to equations (16) and (76)

$$dQ = P\,w\,dx = e\,\frac{\sigma}{E}\,w\,dx = 48ewsxy\,dx/l^3 \quad (77)$$

The voltage along dy follows by dividing equation (77) by the capacitance $K_c w\,dx/4\pi\,dy$

$$dV = \frac{192\pi esxy}{K_c\,l^3}\,dy \quad .. \quad .. \quad .. \quad (78)$$

The total free charge of the double strip is its capacitance multiplied by its voltage. For double strips with two external and one internal electrode

$$Q = CV = \frac{K_c lw}{\pi t}\cdot\frac{2}{l}\int_0^{l/2}\int_0^{t/2}\frac{192\,\pi esxy}{K_c\,l^3}\,dx\,dy$$

$$= \frac{6estw}{l} \quad .. \quad .. \quad .. \quad .. \quad (79)$$

The ratio $Q/s = \phi_2'$ is therefore

$$\phi_2' = 6etw/l \quad \ldots \quad (80)$$

For double strips without internal electrode

$$Q = \frac{K_c l w}{4\pi t} \frac{2}{l} \int_0^{l/2} \frac{192\pi e s x}{K_c l^3} \left[\int_0^{t/2} y\,dy - \int_{-t/2}^{0} y\,dy \right] dx$$

$$= \frac{3eswt}{l} \quad \ldots \quad (81)$$

where the negative sign of the third integral is due to the opposed orientation of the two crystal plates. From (81)

$$\phi_2'' = 3ewt/l \quad \ldots \quad (82)$$

It will be noted that again $\phi'_1 = \phi'_2$, and $\phi'_1 = \phi''_2$ in agreement with equation (5), and the final paragraph of Section 5.2.

7.3. *Equivalent Circuit Elements*

For double strips with internal electrode the values of the equivalent network follow from (7), (9), (65), (66) and (73) or (80)

$$L' = \frac{256 l^3 \rho}{243 \pi^4 e^2 t w}, \quad \ldots \quad (83)$$

$$C' = \frac{9e^2 l w}{4Et}, \quad \ldots \quad (84)$$

and for double strips without internal electrode from (7), (9), (65), (66) and (74) or (82)

$$L'' = \frac{1024 l^3 \rho}{243 \pi^4 e^2 w t}, \quad \ldots \quad (85)$$

$$C'' = \frac{9e^2 l w}{16Et}. \quad \ldots \quad (86)$$

The shunt capacitances are

$$C_o' = \frac{K_c l w}{\pi t}, \quad \ldots \quad (87)$$

$$C_o'' = \frac{K_c l w}{4\pi t}. \quad \ldots \quad (88)$$

The ratio of capacitances of both kinds of double strips, with or without internal electrode, follows from (84), (86), (87) and (88)

$$\frac{C_o'}{C'} = \frac{C_o''}{C''} = \frac{4K_c E}{9\pi e^2}. \quad \ldots \quad (89)$$

It is also to be noted that the equivalent capacitance of the double strip without internal electrode (86), as well as the ratio of capacitances of both double strips (89), are in agreement with the values, obtained for an ordinary flexural vibrating slab (38) and (40).

Due to the relatively great shunt capacitance of a double strip, the stray capacitance has only a small effect on the ratio of capacitances.

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SWITCH AND STORAGE TUBES

Some Experimental Types

By L. S. Allard, B.Sc., A.Inst.P., and R. T. Hill

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

1. Switch Tubes

A SELECTION of switch tubes has been designed in which all the tubes are electrostatically focused while the deflection is either electromagnetic or electrostatic. They are all essentially high-impedance devices, and have been used in various applications; for example, obtaining a time sequence of pulses, angular discrimination, multiplication, and the analysis of the energy spectrum of particles resulting from nuclear disintegration.

The VCRX 264 (300-contact switch) shown in Fig. 1 is employed in computing circuits used in conjunction with radar equipment. The necessity of bringing out 300 separate leads is overcome by the use of a decade system of interconnections between the contacts. Thus every tenth contact of the 300 radial contacts (Fine) is connected and these 10 leads are brought out. A series of 30 circumferential contacts (Medium) are then inserted, each of these contacts covering 10 of the Fine contacts. Again, every tenth of the Medium contacts is connected and brought out. Finally, three more circumferential contacts (Coarse) are inserted, each of which covers 10 Medium and 100 Fine contacts. Therefore only 24 lead-out wires are required:—

10 Fine contacts;
10 Medium contacts;
3 Coarse contacts;
1 Central target plate, which can be suitably biased for collection of secondaries.

The contacts are assembled on a 5-in diameter mica disc, the electrical interconnections being made on that side of the disc farthest from the electron gun. This assembly is then welded on to the wires of a standard 24-wire, glass foot tube. Fig. 2 shows the target assembly before and after seal-in.

In operation the beam traverses a rotating radial path, and in one radial sweep a pulse appears on one of each of the coarse, medium and fine sets of contacts. By suitably analysing these pulses in the accompanying circuits, it is possible to determine the angular displacement of the beam from some fixed datum line. The accuracy in angular resolution is 1·2°.

The electron gun, which is similar to the wartime VCR 530, has magnetic deflection, and is capable of giving 100 μA beam current at 5 kV.

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Special techniques employed in the manufacture of this tube include the use of a low melting point glass solder for sealing the glass bulb containing the target assembly on to the main body of the tube.

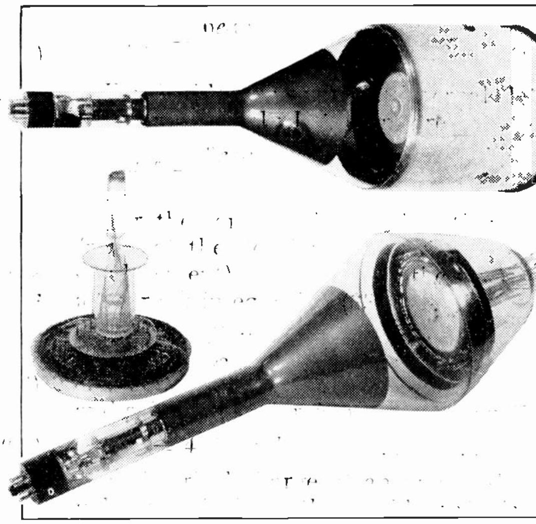

Fig. 1 (Top). *300 Contact Switch (VCRX 264)*; Fig. 2 (Bottom). *VCRX 264 and target assembly.*

A further tube employed in radar computors is the VCRX 281, which is a 16-sector switch; and has electrostatic focusing and deflection. In this tube the 16 target electrodes, each in the form of a sector of a circle, are held in position by 16 standard valve copper anodes which are sealed into the glass tube end. These copper anodes, which allow electrical connections to be made to the targets, are shown in Fig. 3. A fine-wire opened-spaced mesh is located immediately above the contacts and biased slightly positive to collect all the secondary electrons, so minimizing cross-talk between adjacent target electrodes. The connection for the mesh is also brought out by a standard copper anode which is located at the centre of the tube face. The target assembly and mesh are shown in Fig. 4. The glass solder technique is employed in joining the tube end to the main body of the bulb. The tube operates with 5 kV on the final anode and gives a current output of 20 μA.

Digital computors have also required switch tubes of varying description, probably the most important being the VCRX 265, which is shown in Fig. 5. It is a device for producing a series of equally spaced clock pulses. The original requirements were for 40 contacts capable of giving optical output in addition to electrical output. It had been intended to utilize the light output pulses in conjunction with a lens system and perforated cards, but at a later stage in the development this requirement was abandoned. The 40 contacts consist of specially designed metallic buckets to prevent cross-talk, and are spaced across the diameter of an 8-in disc of mica. In the original samples, the bottoms of the buckets were also mica, on to which was placed fluorescent powder, thus giving the light output pulses when the beam entered the bucket.

A metal guard ring is placed immediately in front of the contacts, and suitably biased to collect any stray secondary electrons. It was observed that to ensure a reasonably rapid rate of rise and fall on the electrical output pulse, the contacts had to be placed on an arc of a circle of radius equivalent to the distance between the contacts and the centre of the deflecting plates. This form of assembly is indicated in Fig. 6. The tube dimensions are 9-in external diameter, excluding the contact ring and 23-in overall length. It was on this tube that the glass solder method of joining was originally introduced. The requirement of

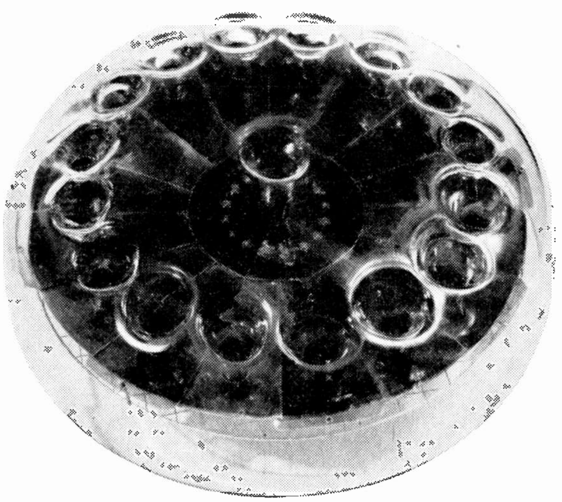

Fig. 3. *Connections for targets of VCRX 281.*

bringing out 41 contacts around the circumference of the 9-in diameter tube and ensuring a perfect vacuum-tight seal presented many difficulties. However, it was found possible to obtain such a seal by painting continuous silver strips on the inside, outside and lip of the bulb before joining with glass solder. This method has proved very satisfactory for bringing out the electrode contacts, the connections to which are obtained by pressure contact on the inside and outside of the bulb. The electron gun used in this tube is similar to that in the VCRX 281 and gives 20 μA at 5 kV.

A smaller version of this tube, in which only 16 contacts are required, is the VCRX 282. In this tube, the target assembly is mounted on a

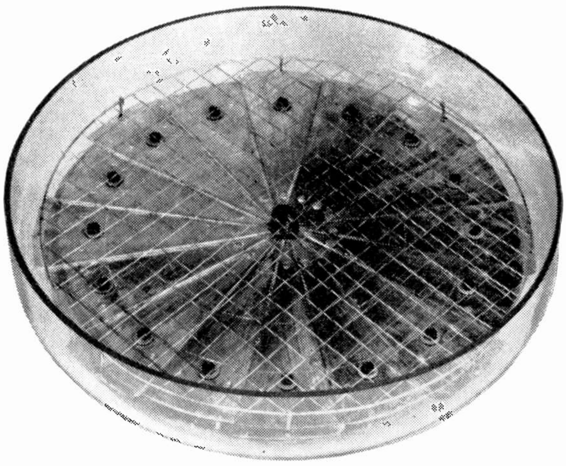

Fig. 4. *Target assembly for VCRX 281.*

standard foot tube and sealed into a length of 3-in diameter tubing. Gun characteristics are identical with the VCRX 265.

In all the previous tubes, the contacts in the form of buckets are spaced apart, usually so that the 'on-off' ratio is 1 : 1. There is, however, a requirement in which this spacing is not required, and where it is necessary to have the contacts overlapping so that the beam is always impinging on one or more of the contacts. A tube fulfilling this requirement is the VCRX 268, which is a 10-contact 'Kicksorter' tube and is used in determining the energy distribution of particles resulting from nuclear disintegration.

The contacts are again in the form of buckets, since cross-talk must be reduced to the very minimum, and are inclined to the tube axis as indicated in Fig. 7. This method of assembly ensures that the beam is always impinging on one or more of the contacts on its traverse across the tube diameter. Further requirements of this tube are that it should have the highest possible deflector-plate sensitivity, and the smallest spot size obtainable with a beam current of 10 μA. Some improvement in deflection sensitivity has been achieved by mechanical redesign of the deflectors, but the major gain is obtained by operating the tube with the lowest possible final anode voltage compatible with the spot size considerations. The tube, which is assembled in a length of 3-in diameter glass tubing, is 22-in long and operates with 2 kV applied to its final anode. The deflector plate sensitivity at this operating potential is 1 mm per volt.

A multiplication tube[2] (VCRX 314) employs combined electrostatic and electromagnetic deflection for its operation. The particular features of this tube are that it contains three pairs of deflector plates and two bucket contacts spaced so that the undeflected spot just covers the gap between the contacts. The first and third pairs of deflectors are electrically cross-connected so that the deflection of the first pair is cancelled by the deflection of the third pair, while the intermediate or second pair deflects the beam in a direction perpendicular to that produced by either of the other two pairs of deflectors. This second pair of deflectors is so placed that when a voltage is applied, the beam is deflected across the two contacts. Coincident with this second pair of deflectors is placed a coil capable of producing an axial magnetic field. The two quantities to be multiplied are represented, one as a voltage and the other as a current. The voltage is applied to the first set of deflector plates to produce an electrostatic field while the current is passed through the

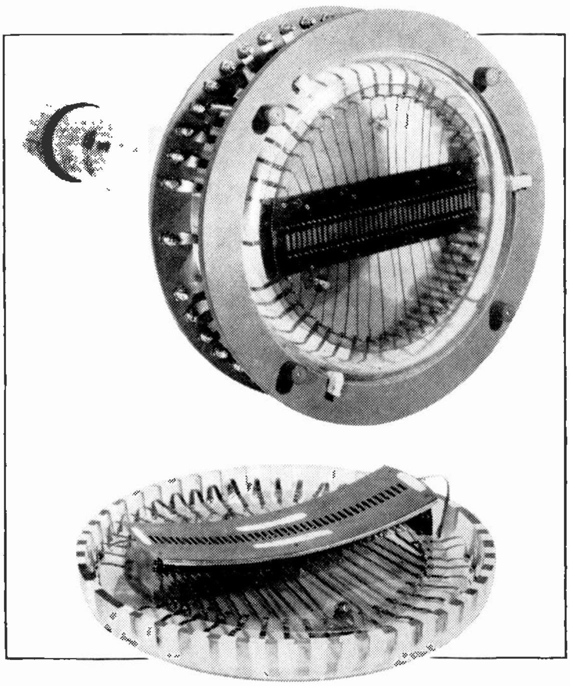

Fig. 5. (Top). 40 *Contact switch* (*VCRX* 265) ; Fig. 6 (Bottom). *Target assembly for VCRX* 265.

coil and produces an axial magnetic field. The resultant effect of these two fields is that the beam, which is normally flowing to a metal shield electrode between the two buckets, is deflected into one of the bucket electrodes. This action immediately actuates a deflecting-voltage circuit which applies to the second pair of deflectors a unidirectional shift voltage of sufficient value to restore the beam to its original position of equilibrium between the two bucket electrodes. The amplitude of this correcting voltage represents the desired product of the two quantities.

The tube is sealed into a $1\frac{1}{2}$-in diameter glass tube, having an overall length of 10 in. The operating anode voltage is 1 kV with a beam current of 20 μA.

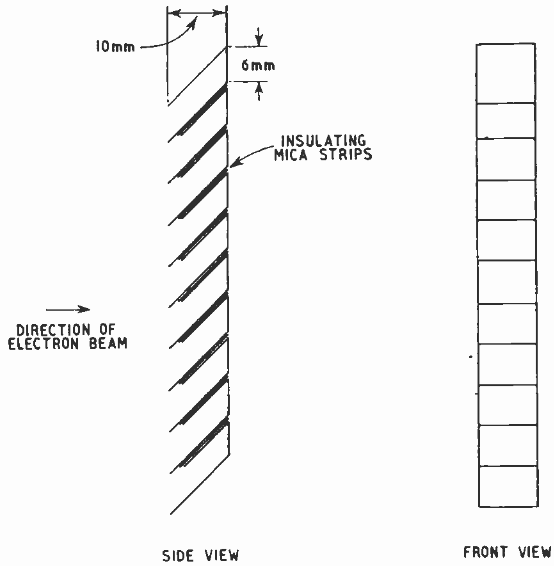

Fig. 7. *Target assembly for 'Kicksorter' tube* (*VCRX* 268).

Two scale-of-five counter tubes have also been developed, namely VCRX 297 and VCRX 302. These two tubes have effectively the same basic principle in design and differ only in constructional details in the endeavour to reduce all the inter-electrode capacitances in the VCRX 297 to a minimum. Thus, whereas the VCRX 302 has all the connections brought out at one end of the tube, the VCRX 297 has its target electrode connections brought out at the tube end opposite the electron-gun structure. Both tubes employ electrostatic focus and deflection.

The counting assembly, as shown in Fig. 8, consists of a common collecting plate placed immediately behind a target electrode containing a series of staggered slots. The normal traverse of the beam across these slots is interrupted at each slot until a pulse arrives on the other pair of deflector plates. This process repeats itself until the beam arrives at the large aperture at the end of the target plate, at which instant the beam flies back to commence the sequence of operations again, and a pulse is produced which can be applied, for example, to a further similar counting unit.

2. Storage Tubes

The development of cathode-ray storage tubes has proceeded along two main lines, namely, for use with digital computors and for radar purposes. In the cathode-ray tube binary-digital store[1], the information is deposited upon the fluorescent phosphor of a normal cathode-ray tube in the form of a charge distribution, the charge distributions corresponding to 0 and 1 being different. The memory of the tube, or the function of storing the information until required, is achieved by a process of regeneration. After the information has been deposited upon the insulating phosphor surface, the beam scans the fluorescent screen, and in conjunction with a feedback circuit is capable of redepositing the same charge distributions as before.

It was the original intention to utilize standard commercial cathode-ray tubes for the storage medium. Unfortunately, these tubes can produce spurious signals (commonly known as 'phoneys'), which could give rise to inaccuracies in the equipment. These spurious signals are due to small localized areas of the screen having a secondary emission coefficient differing from the remainder of the screen. The amplitude of the 'phoneys' is dependent upon the operating anode voltage of the tube, being smaller with reduced h.t., and is also dependent upon spot size. Because of these 'phoneys,' work has proceeded on special types of tube in an endeavour to obtain storage surfaces free from impurities. At the same time electron guns producing much smaller spots have been incorporated, thus allowing a greater number of digits to be stored on each tube. The VCRX 266, 269, 275, and 311 are variations of this type of digital-storage tube.

The elimination of 'phoneys' has involved a considerable amount of investigation into the various forms of insulator surfaces and also of their methods of preparation. It is known that foreign particles cause 'phoneys,' as also do any irregularities of the surface.

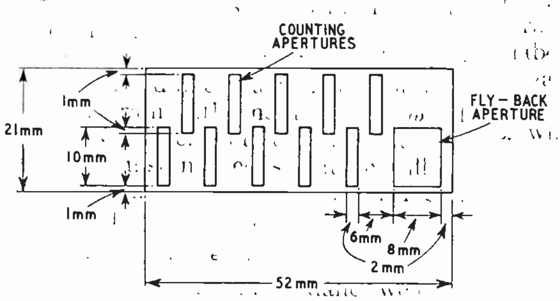

Fig. 8. *Target electrode for counter tubes* (*VCRX 297 and VCRX 302*).

It has been considered a desirable feature of the tube to retain, if possible, the fluorescent nature of the storage surface so that the position of the electron bombardment could be observed. The screens are specially prepared and applied extremely thickly to avoid 'pin-holes' in the screen, thus ensuring that the electron beam always strikes the powder and not the glass. In eliminating any particles of carbon which could settle on the screen and cause 'phoneys,' the normal interior conductive coating of graphite is replaced by a layer of silver. Thus, it is necessary to exercise very great care in making these tubes to ensure complete elimination of all foreign particles.

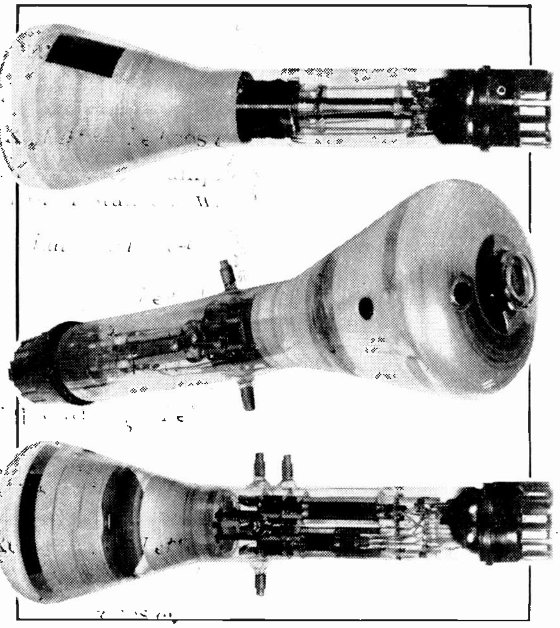

Fig. 9 (Top). *Storage tube* (*VCRX 266*) ; Figs. 10 & 11 (Middle and bottom respectively). *Storage tube* (*VCRX 280*).

The operating potential is governed mainly by the appearance of 'phoneys.' A satisfactory operating voltage is 1 kV, and at this voltage, the tube can easily store 2,000 digits, with a beam current of 1 μA or less. The VCRX 266 is shown in Fig. 9.

A further possible tube for use with a digital store is the VCRX 303. This is an all-electrostatic low-velocity scanning tube having for its storage surface fluorescent powder particles of varying size. These particles are deposited upon a continuous metallic plate. Two guns are employed in this tube, one of which is used for writing, and the other for stabilizing and reading. One of the advantages claimed with this type of tube is that no feedback circuit is required for regeneration of the stored information.

For radar purposes, storage tubes are also required to retain information for any desired interval of time. In developing such tubes a considerable number of experiments were conducted to determine the optimum type of insulating surface which could be used for storage purposes. Although the ultimate requirements were known to be such that two guns would be required in the tubes, much of the experimental work on storage surfaces was performed on single-gun tubes. The tubes VCRX 270 and 271 are tubes of this type, the former having a mica surface, while the latter contains an anodized-aluminium storage surface. The effect of the storage-surface thickness on the tube operation was fully investigated with the result that for the range of capacitances required, anodized aluminium of thickness between 5 and 10μ gave the best performance. These thicknesses can be readily obtained and maintained substantially uniform between different samples of anodized sheet which are prepared by any of the normal electrolytic processes. The dimensions of the target plate used at present in the storage tubes are 110 mm × 90 mm.

The standard type of two-gun storage tube in which these anodized-aluminium target plates are used is the VCRX 280 which is shown in Figs. 10 and 11. This tube contains two completely electrostatic electron guns, assembled on a 16-wire foot tube. The only electrodes which are joined electrically are the third anodes of the two guns. The connection to these is brought out through a side tube, as are also the connections to the deflector plates of the two guns. All other electrode connections to the guns are brought out through the foot tube. Fig. 12 illustrates the electrode assembly.

The target assembly is located and held in the bulb on a standard valve copper anode which is sealed into the front of the bulb. Two conductive ring coatings are applied on the inside surface of the bulb to which various bias potentials can be applied, if required, to ensure complete collection of secondary electrons.

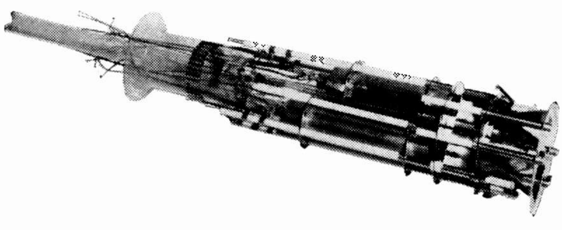

Fig. 12. *Electrode assembly for VCRX 280.*

The normal working conditions of the VCRX 280 are such that the writing gun operates at a potential above the second unity point on the graph relating secondary emission coefficient to primary beam voltage. This gun is capable of giving a beam current of several microamperes. The reading gun, however, operates at a relatively low voltage, below the second unity point referred to above, and has a beam current of 1 μA or less. Thus, those parts of the storage surface which become charged by the action of the writing gun are discharged by successive scans of the reading gun. The number of scans required for complete discharge can be varied by altering the beam current in the reading gun. Storage times varying between 3 seconds and 4 minutes, depending upon the reading-gun beam current, have been successfully obtained, although with the reading gun inoperative the information can be retained on the target surface for several days due to the very high surface resistance of the insulated surface.

Great care is needed when processing the tube to prevent any damage to the storage surface, common faults being crazing of the surface and 'black spots'. This latter defect manifests itself, as its name implies, as black spots on the intensity-modulated picture on the monitor tube.

It is important that for the successful operation of these tubes, the second unity point should not occur at too high a value of primary beam voltage, otherwise the electrode system insulation will break down and 'spark-over' will occur in the tube. These variations in the secondary emitting properties are usually associated with the technique employed by the various suppliers of the anodized-aluminium plates.

Typical operating conditions of the VCRX 280 are:—

Writing gun. 4 kV with a beam current of a few microamperes.

Reading gun. 500 V with a beam current of a fraction of a microampere.

3. Conclusions

Although the tubes described above have all been developed for some specific application, it has sometimes happened that a tube of an existing design could be adapted for a fresh requirement. In contrast with this, there have been instances when the operation of a special switch tube has enabled the circuit engineers to obtain a clearer mental picture of the method of solving a particular circuit problem. They have then been able to design simpler circuits employing ordinary electronic valves without using a complicated cathode-ray switch tube.

Acknowledgment

Much of this work was carried out on behalf of the Admiralty, whom it is desired to thank for permission to publish this paper.

REFERENCES

[1] "A Storage System for use with Binary-Digital Computing Machines," F. C. Williams and T. Kilburn, *Proc. Instn Elect. Engrs*, Vol. 96, Pt. III, No. 40, March 1949.

[2] "Multiplication and Division by Electronic Analogue Methods," E. M. Deeley and D M. Mackay, *Nature*, 23rd April 1949, Vol. 163, No. 4147, p. 650.

IMPEDANCE AND THE LAPLACE TRANSFORM

By Edward E. Ward

(The University of Birmingham)

1. Introduction

THE use of the Laplace Transform in applied science is spreading so quickly that its theoretical foundations are being accepted just as they were left by the mathematicians who worked them out. In the many problems where the physical system is linear and is initially at rest an alternative foundation for the theory is the idea of operational impedance which has been mentioned by Wagner, Carson and later writers. Such a foundation has two advantages, for it shows us steady-state response and transient response as two special cases of one general theory and it also offers a system of representation by the Argand diagram which is easier to grasp in visual imagery than the less tangible ideas of differential and integral.

2. Relation of Transform and Impedance

The idea of impedance is appropriate to the use of the Laplace transform because the transform is a method of assembling a transient from oscillations of the form $A\epsilon^{pt}$ where p is complex and may be written $p=(\alpha+j\omega)$. Our concern therefore is to find whether the word impedance may be given any consistent meaning for such oscillations and what that meaning is.

A sinusoidal voltage may be represented by the projection on any fixed line of a radius E rotating in an Argand diagram with angular speed ω. If the fixed line be so chosen as to coincide with the real axis then the instantaneous voltage will be $e=E\cos\omega t$ and will be the real part of $E\epsilon^{j\omega t}$. This may rigorously be written

$$e = \text{Re. } E\epsilon^{j\omega t}.$$

As an example of the nature of impedance we may consider the current fed to a capacitor; it will be represented by the projection on the real axis of a radius which will lead by 90° the radius E representing the voltage. For such an element the meaning of impedance is the relationship between the two rotating lines, the complex ratio of the voltage radius to the current radius; it has both modulus and argument and is invariant with time.

If, however, the current be written as $I\epsilon^{pt}$, which may be called a Laplacian oscillation, then the physical current will be its real projection and will have at every instant the value

$$i=\text{Re.}I\epsilon^{pt} = I\epsilon^{\alpha t}\cos\omega t$$

To continue the example, the voltage of a capacitor of elastance S will be

$$e = S\int i.dt = SI\int \epsilon^{\alpha t}\cos\omega t.dt$$

$$= \frac{SI\epsilon^{\alpha t}}{\alpha^2+\omega^2}\left\{\alpha\cos\omega t + \omega\sin\omega t\right\} \quad ..(1)$$

and this is the projection on the real axis of the complex quantity $\frac{S}{p}\,.\,I\epsilon^{pt}$ for

$$e = \text{Re.}\,\frac{S}{p}\,.\,I\epsilon^{pt}$$

$$= \text{Re.}\,\frac{S}{\alpha+j\omega}\,.\,I\epsilon^{pt}.(\cos\omega t + j\sin\omega t)$$

$$= \frac{SI\epsilon^{\alpha t}}{\alpha^2+\omega^2}(\alpha\cos\omega t + \omega\sin\omega t)$$

Corresponding relations may be deduced for inductive and resistive elements. The Laplacian current and the corresponding capacitor voltage may be represented by an extension of the usual Argand diagram. We have become accustomed to drawing one line in a fixed position to represent a radius in continuous rotation and it is useful to elaborate this idea so that we can think of the Argand diagram as not only steadily rotating with speed ω but also steadily expanding with exponent αt where α may be of either sign.

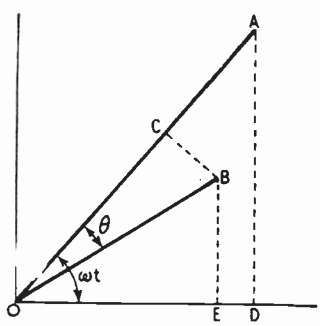

Fig. 1. *Typical Argand diagram in which OA represents $I\epsilon^{pt}$.*

On such a diagram the current $I\epsilon^{pt}$ will appear as a line OA at an angle ωt as shown in Fig. 1, and the capacitor voltage $\frac{S}{p}I\epsilon^{pt}$ may also be

MS accepted by the Editor, February 1950

represented by a single line OB having a length $OB = OA \cdot \frac{S}{|p|}$. The line OB will have a component $OC = \frac{\alpha IS}{\alpha^2 + \omega^2}$ along the direction of OA and a component $CB = \frac{-\omega IS}{\alpha^2 + \omega^2}$ at right angles. Then the instantaneous current will be $OD = \epsilon^{\alpha t}[I \cos \omega t]$ and the instantaneous capacitor voltage will be

$$OE = \epsilon^{\alpha t}[OB \cos(\omega t - \theta)]$$
$$= \epsilon^{\alpha t}\left[\frac{IS}{\alpha^2 + \omega^2}(\alpha \cos \omega t + \omega \sin \omega t)\right]$$

which is in agreement with equation (1). The line OB may therefore be said to represent the capacitor voltage; the relationship between the line OB and the current line OA is independent of time and may be recognized as the impedance of the capacitor; the complex ratio of OB to OA has the magnitude

$$|z| = \left|\frac{OB}{OA}\right| = \frac{S}{\sqrt{\alpha^2 + \omega^2}} = \frac{S}{|p|}$$

and the argument

$$\text{Arg } Z = \theta = -\tan^{-1}\left(\frac{\omega}{\alpha}\right) = \text{Arg}\left(\frac{S}{p}\right)$$

In short, on a diagram having rotation Im.p and expansion Re.p, the voltage E produced across an elastance S by a current I may be represented by a line of length $I\left|\frac{S}{p}\right|$ lagging behind I by an angle $\text{Arg}(S/p)$ and it is in this sense that the element may be said to have an impedance S/p. The impedance of an inductance will similarly appear as pL.

The relation of this impedance to the Laplace transform may be found by inspection. Taking an inductive element as our example, its voltage $v = L\frac{di}{dt}$ will transform into $\mathfrak{L}v = pLI'$. Here $I' = \mathfrak{L}i$ is the peak amplitude of the current component $\epsilon^{pt}.dp$, and each voltage component $V' = \mathfrak{L}v$, having the same form $\epsilon^{pt}.dp$, is the product of pL and the corresponding current component. The terms Generalized Impedance, Operational Impedance or Laplacian Impedance seem to be appropriate to the product pL.

Thus the general series network branch will have for Laplacian oscillations an impedance

$$Z_{(p)} = pL + R + \frac{S}{p}\,.$$

and the general parallel branch an admittance

$$Y_{(p)} = pC + G + \frac{\Gamma}{p}$$

where $\Gamma = 1/L$

and on this basis the current produced by a voltage $E\epsilon^{pt}$ in a general series branch will be the real part of

$$I = \frac{E\epsilon^{pt}}{pL + R + S/p}$$

and comprehensively

$$I = \frac{E\epsilon^{pt}}{Z_{(p)}}$$

3. The Laplacian Impedance in Analysis

To find the performance of a linear system initially at rest we are now able to write down one solution which, with minor changes, represents both the transient and the steady state information. Thus, taking as example the network of

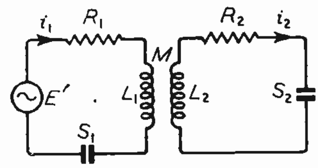

Fig. 2. Network used to illustrate the Laplacian impedance in analysis.

Fig. 2, we may find the voltage E_c across the secondary capacitor. Writing in the usual convention:

$$Z_1 i_1 + Z_m i_2 = E'$$
$$Z_2 i_2 + Z_m i_1 = 0$$
$$i_2 = E'\left\{\frac{Z_m}{Z_m^2 - Z_1 Z_2}\right\}$$
$$E_c = Z_c i_2 = E'\left\{\frac{Z_m Z_c}{Z_m^2 - Z_1 Z_2}\right\}$$

where the form of E' has yet to be specified.

Then we may write:

3.1 *For sinusoidal oscillations:*

$$E' = E\epsilon^{j\omega t}$$
$$Z_m = j\omega M$$
$$Z_1 = j\omega L_1 + R_1 + S_1/j\omega$$
$$Z_2 = j\omega L'_2 + R_2 + S_2/j\omega$$
$$Z_c = S_2/j\omega$$

$$E_c = E\left\{\frac{-S_2 M}{\omega^2 M^2 + (j\omega L_1 + R_1 + S_1/p)(j\omega L_2 + R_2 + S_2/p)}\right\}\epsilon^{j\omega t}$$
$$= E.f(\omega).\epsilon^{j\omega t}$$

where $f(\omega)$ is the quantity in brackets.

The magnitude of the capacitor voltage is

$$|E_c| = E \times |f(\omega)|$$

and its phase is

$$\text{Arg } E_c = \text{Arg } f(\omega)$$

E

3.2 *For Laplacian oscillations*:

$E' = E\epsilon^{pt}$

and similarly

initially at rest, then the capacitor voltage component having the same form and the output voltage as a time function will be respectively

$$E_c = E\left\{\frac{S_2M}{p^2M^2-(pL_1+R_1+S_1/p)(pL_2+R_2+S_2/p)}\right\}\epsilon^{pt} = E.f(p).\epsilon^{pt}$$

where $f(p)$ is the quantity in brackets.

On a diagram of rotation Im.p and expansion Re.p the magnitude of the capacitor voltage will be

$$|E_c| = E \times |f(p)|$$

$$E_{c(p)} = \frac{E}{p}\left\{\frac{S_2M}{p^2M^2-(pL_1+R_1+S_1/p)(pL_2+R_2+S_2/p)}\right\}\epsilon^{pt}$$

$$E_{c(t)} = \frac{1}{2\pi j}\int_{c-j\infty}^{c+j\infty} \cdot \left\{\frac{ES_2M}{p[p^2M^2-(pL_1+R_1+S_1/p)(pL_2+R_2+S_2/p)]}\right\}\epsilon^{pt}.dp$$

and its phase will be Arg E_c = Arg$f(p)$

3. *For a Step-Function of amplitude E*:

In the applied voltage the component $\epsilon^{pt}.dp$ has an amplitude E/p and if the system be

The latter may be integrated by partial fractions in the usual way. The value of the integral is independent of the constant c which should have a small positive value to ensure that all the singularities are enclosed.

CORRESPONDENCE

Voltage-Controlled Secondary-Emission Multipliers

Sir,—I have been reading A. J. W. M. van Overbeek's paper in your April 1951 issue in which there is a description of secondary-emission multipliers working at a temperature below 180°C. I would like to bring to your notice the fact that as far back as June 1937, in France, I and my associates G. Clavier and H. J. LeBoiteux pointed out in U.S. patent No. 2,226,696 that the cathodes of electron discharge devices could be kept at a temperature between 100 and 150°C.

P. F. M. Gloess.

Paris, France.
13th April, 1951.

BOOK REVIEW

Time Bases (2nd Edition)

By O. S. Puckle, M.B.E., M.I.E.E. Pp. 387 + xxi. Chapman & Hall, Ltd., 37 Essex Street, London, W.C.2. Price 30s.

The general arrangement and style of this book are substantially the same as in the first edition and most, if not all of the original material is still included. The changes in this new edition, therefore, are mainly the addition of new material.

Although a careful comparison of the two editions reveals changes throughout the body of the book, the new material comprises in the main a chapter on Miller Capacitance Time Bases, which includes the various forms of the phantastron and the sanatron, great expansion of Push-Pull Deflection, The Use of a Time-Base for Frequency Division and for Counting, and several new appendixes.

Perhaps the greatest merit of the book is that it gives a comprehensive review of the many forms of time-base with references to previously published descriptions or Patent specifications. There are very few time-base circuits which do not receive some mention.

The treatment, however, is patchy in that some circuits are dealt with in great detail while others receive little more than a passing reference. Some, of course, do not deserve more and, in general, the author has dealt most fully with the circuits of most practical value, which is as it should be. However, the blocking oscillator receives rather scurvy treatment and is confused with the squegging oscillator and the self-oscillating saw-tooth current generator.

The section headed "Blocking Oscillators" is of nearly seven pages and covers some of the older forms of time-base, starting with the squegging oscillator time-base of Appleton, Herd and Watson Watt. There is no detailed account of the squegging action nor of the blocking condition of modern circuits, but references are given to at least one paper which does include a very detailed account of the latter.

It is important to note that the author uses the term 'blocking oscillator', not in its usual modern sense of denoting a squegging oscillator which is allowed to oscillate for only one half-cycle of its natural frequency, but to denote any transformer-coupled time-base. If the reader bears this in mind he will not be confused by some of the references to blocking oscillators which appear in the text.

Although the book deals very fully with saw-tooth voltage generators and includes a good deal about push-pull amplifiers for electric deflection, there is relatively very little about circuits for magnetic deflection. Some of them are given but the explanations are far from adequate. Except for the actual voltage saw-tooth generators themselves, the book cannot be regarded as covering modern television time-bases.

These are minor points of criticism of what is really a very good book and one which will undoubtedly be of great utility to very many people. The sections on linearity, push-pull amplification and phantastrons are particularly valuable. Only a very few minor errors were noted, which says much for the care taken in preparation and proof-reading.

W. T. C.

BRITISH INSTITUTION OF RADIO ENGINEERS

At the first session of the 1951 Radio Convention to be held at University College, London, on 3rd and 4th July, the following papers will be read:—"Radiation and Particle Detectors in Modern Nuclear Instruments," Chairman's address (Denis Taylor, M.Sc., Ph.D.), at 3 p.m.; "Beta-ray Thickness Gauge for Industrial Use," by K. Fearnside, M.A., at 4 p.m.

WIRELESS ENGINEER

The Journal of Radio Research and Progress

Managing Editor: HUGH S. POCOCK. M.I.E.E.
Editor: W. T. COCKING, M.I.E.E. Technical Editor: Professor G. W. O. HOWE, D.Sc., LL.D., M.I.E.E.

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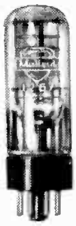
Mullard

REVIEW OF NEW AND CURRENT VALVES

COLD CATHODE THYRATRON 1267



The Mullard 1267 is a Cold Cathode valve of large current-carrying capacity, high stability and long life. These features result from improved cathode activation and relative freedom from photoelectric and temperature effects.

Using the 1267 as a simple switch, only microwatt powers need be interrupted in the grid circuit (acting as a non-inductive load) to close a relay in the anode circuit. In such applications the switch contacts in the grid circuit are relieved of large and destructive inductive loads, whilst the contact resistance may vary over a wide range without affecting the operation of the tube. Applied in this and similar ways, the Mullard 1267 is ideal for use in remote-controlled power switching systems; welding and industrial engineering timers; sequential timers; and a variety of alarm and protection systems.

PRINCIPAL CHARACTERISTICS

*Max. Peak Operating Anode Voltage	225V
Positive Grid Voltage for Ignition	70-90V
Max. Grid Current for Ignition (Va = 140V)	100μA
Valve Voltage Drop	70V
Max. Continuous Cathode Current	25mA
Max. Peak Cathode Current	100mA

*Above this voltage ignition may occur at Vg = 0

LONG LIFE MERCURY VAPOUR RECTIFIERS

Reliability, stable emission and long life are among the important features of the Mullard range of Mercury Vapour Rectifiers.

The high degree of reliability is ensured through closely controlled manufacturing processes, whilst stable emission is obtained through the use of special double spiral filaments so designed that the emissive coating is firmly keyed to the wire.

An important feature contributing to the long life of these valves, is the use of zirconium-coated anodes. This results in the elimination of " foreign " gases, thus reducing the positive ion bombardment of the cathode.

In addition to these important design features, the dependability in service of the Mullard range of Mercury Vapour Rectifiers is further ensured through the application of rigorous back-arc tests at high voltages.

TYPE	Vf (V)	If (A)	P.I.V. max. (KV)	Ia(av) max. (A)	Full load D.C. Output* (KV)	(A)
RG1-240A	4.0	2.7	6.5	0.25	2.0	0.5
RG3-250	2.5	5.0	10	0.25	3.15	0.5
RG3-1250	4.0	7.0	13	1.25	4.14	2.5

* Two valves in single-phase full wave circuit.

A RANGE OF COMPACT FLASH TUBES

In presenting their range of compact flash tubes, Mullard make available, to both research workers and industrial designers, a comprehensive series of reliable light sources of a high intensity and extremely short duration.

Characterised by their high luminous efficiency and ease of triggering, these tubes are capable of producing many thousands of flashes without deterioration in either quality or output of light. For those who require line source flash tubes, a full range of straight tubes is available.

LSD2	35 joule microsecond flash tube.
LSD3 / LSD3A	100 joule tube for portable equipment.
LSD5	1,000 joule tube for studio equipment.
LSD7	200 joule tube for portable equipment.
LSD8	Stroboscopic flash tube with a maximum dissipation of 30 watts.
LSD9	1,000 joule quartz tube for high power ultra-violet flash.

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ABSTRACTS and REFERENCES

Compiled by the Radio 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 the titles of journals are taken from the World List of Scientific Periodicals. Titles that do not appear in this List are abbreviated in a style conforming to it.

ACOUSTICS AND AUDIO FREQUENCIES

534.213.4 **1290**

Acoustic Waveguides.—Y. Rocard. (*C. R. Acad. Sci., Paris*, 5th Feb. 1951, Vol. 232, No. 6, pp. 485–487.) Theory is given relative to the propagation of sound waves in a medium filling an infinitely long cylinder, the velocity of sound in the medium being c_1 and in the material of the cylinder c. If $c_1 < c$, the waves will be propagated along the axis of the tube without exciting any appreciable radial propagation in the tube wall. Such conditions are easily realized approximately in practice by means of a series of small equidistant disks strung on a central rod, the surrounding medium being air. Experiments carried out in the Bell System laboratories have shown that such a system acts as an acoustic waveguide, even when the rod is curved.

534.321.9 : 534.232 **1291**

Ultrasonic Energy.—A. E. Crawford. (*Electronic Engng*, Jan. 1951, Vol. 23, No. 275, pp. 12–18.) The various methods available for producing ultrasonic energy are described briefly and compared. An outline of the elements of wave propagation at these frequencies includes tabulated values of the speed of longitudinal waves in common solids, liquids and gases.

534.321.9 : 534.25 : 621.315.616.9 **1292**

Ultrasonic Lenses of Plastic Materials.—D. Sette. (*Nuovo Cim.*, 12th March 1949, Vol. 6, No. 2, pp. 135–147.) The focusing properties of certain plastics for ultrasonic radiation were studied. When a plano-cylindrical or planospherical plastic lens is used, the energy required from the quartz generator, for the same intensity of radiation over a given region, may be reduced to 1/10 or 1/100 respectively of its original value. See also 3006 of 1949.

534.84 **1293**

Vibrations of Enclosed Spaces with Deformable Elastic Walls.—T. Vogel. (*J. Phys. Radium*, Nov. 1950, Vol. 11, No. 11, pp. 627–632.) Hypotheses used in simple geometric theory of acoustic resonance are not compatible with the wave equation in the case where a velocity potential exists. Under certain simplifying assumptions based on elasticity theory, the velocity potential is expressed as a convergent series of integral powers of a small parameter related to the absorption of the walls, the coefficients being the solutions of a succession of Neumann problems extended to the equation $(\Delta_2 + \lambda) u = 0$. A shorter version was noted in 800 of April.

534.846.3/.4 **1294**

Recent Developments in Speech-Reinforcement Systems.—P. H. Parkin & W. E. Scholes. (*Wireless World*, Feb. 1951, Vol. 57, No. 2, pp. 44–50.) Experimental results obtained in an open-air theatre confirm the conclusions reached in a review of previous investigations, which indicated that, to achieve realism and maximum intelligibility in a sound-reinforcement system, the time delay between hearing the direct and the amplified sounds should be 5–35 ms, and that the amplitudes should not differ by more than 7 db.

538.613 : 621.395.625.3 **1295**

Magneto-optic Transducers.—A. W. Friend. (*RCA Rev.*, Dec. 1950, Vol. 11, No. 4, pp. 482–507.) A magneto-optical playback system and head have been developed for use with magnetic-tape records. Signal amplitude is constant with frequency and linearity over the desired amplitude range is satisfactory, but the maximum signal/noise ratio available is only about 30 db. Means of improving this ratio are discussed. The effect of using more active magneto-optical material and of variations of the system parameters can be evaluated from a theoretical treatment of the system.

621.395.623.41 **1296**

The Ring-Armature Telephone Receiver.—E. E. Mott & R. C. Miner. (*Bell Syst. tech. J.*, Jan. 1951, Vol. 30, No. 1, pp. 110–140.) "A new type of telephone receiver is described in which the permanent magnet, the pole piece and the armature, which drives a light-weight dome, are all ring-shaped parts. This structure exhibits a substantially higher grade of performance than present receivers of the bipolar type, with regard to efficiency, frequency range, leakage-noise level, and response when held off the ear. In addition to showing the characteristics of this new receiver, an analysis of the various losses is given, and ideal performance limits are established. The advantage of providing an auxiliary path for the air-gap flux is indicated, and other applications of the device as a transducer are described."

621.395.813 : 621.39.001.11 **1297**

Application [to signal and information theory] **of Means Used for Assessing the Quality of Telephone Transmission.**—Chavasse. (See 1486.)

534.75.001.11 **1298**

Theory of Hearing. [Book Review]—E. G. Wever. Publishers: Wiley & Sons, New York, and Chapman & Hall, London, 1949, 484 pp., $6.00. (*Proc. phys. Soc.*, 1st Jan. 1951, Vol. 64, No. 373B, p. 90.) "The volume can be recommended unreservedly to all those interested in the subject of hearing in man and animals."

AERIALS AND TRANSMISSION LINES

621.392.09 **1299**

Predetermination of the Conditions of Propagation along a 3-Phase Symmetrical Line of a High-Frequency Wave applied between One Conductor and Earth, the Other Two Conductors being Loaded at the Ends with Equal Impedances.—A. Chevallier. (*C. R. Acad. Sci., Paris*, 5th Feb. 1951, Vol. 232, No. 6, pp. 490–491.)

621.392.09 **1300**

Surface-Wave Transmission Line.—H. M. Barlow. (*Wireless Engr*, Feb. 1951, Vol. 28, No. 329, p. 67.) Comment on 563 of February (Rust).

621.392 : 621.314.2 : 621.3.015.7† **1301**

Design of Exponential-Line Pulse Transformers.—E. M. Williams & E. R. Schatz. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 84–86.) Design procedures are described for pulse transformers consisting of exponential transmission-line sections, and data are included for an experimental unit with a nominal impedance ratio of 1 : 4. This unit will develop its full voltage ratio of 1 : 2 with a pulse of duration about 3 mμs. Its peak power capacity with dielectric of powdered Ba-Sr titanate is about 12·5 MW, but about 500 MW with nitrobenzene as dielectric.

621.392.26† **1302**

Expandability of a Wave-Guide Field in Terms of Normal Modes.—J. Van Bladel. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 68–69.) The fields in a waveguide can be expanded as a linear combination of normal modes. This is proved by showing (*a*) that this expansion is possible for the z components of the fields and modes, and (*b*) that in three dimensions the fields as a whole are equal to a linear expansion of modes with precisely the same coefficients as were found in the expansion of the z components.

621.392.26† **1303**

Slow Electric Waves in Gas-Filled Metal Tubes.—W. O. Schumann. (*Z. Phys.*, 7th Dec. 1950, Vol. 128, No. 5, pp. 629–634.) Low-velocity waves observed in h.f.-excited metal tubes filled with rarefied gas are related to the surface waves along the boundary of a plasma layer at the inner surface of the metal. The natural frequency of the plasma lies approximately between ω and $\sqrt{2}.\omega$ for the regions in which this slow propagation is possible, the waves being represented by the expression $e^{j(\omega t - \alpha x)}$.

621.392.26† : 621.3.09 **1304**

Electromagnetic Waves in Wave Guides.—In 565 of March, for "1851 of 1950" please read "1861 of 1950".

621.392.26† : 621.396.67 **1305**

Theory of the Circular Diffraction Antenna.—H. Levine & C. H. Papas. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 29–43.) "The circular diffraction antenna consists of a coaxial waveguide fitted with an infinite-plane conducting baffle, and open to free space. An equivalent-circuit description, appropriate to principal-mode propagation in the coaxial region, is investigated theoretically. Variational expressions for the circuit parameters are derived, and used for accurate numerical evaluation."

621.396.67 **1306**

Electric Dipoles in the Presence of Elliptic and Circular Cylinders.—W. S. Lucke. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 14–19.) Application of the Green's-function method yields expressions for the dipole field in the form of an integral in the complex plane which can be simplified by imposing the known far-zone conditions. Typical polar diagrams are calculated for the E and H fields for dipoles parallel and perpendicular to strips and cylinders.

621.396.67 **1307**

Radiation from Wide-Angle Conical Antennas fed by a Coaxial Line.—C. H. Papas & R. King. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 49–51.) An approximate expression for the radiation from spherically capped conical aerials is derived by the Fourier-Lamé eigenfunction method. Diagrams of the far-zone field as a function of zenith angle are shown for aerials of various lengths and flare angles.

621.396.67 **1308**

Applications of Potential Theory to the Design of Linear Arrays.—T. T. Taylor & J. R. Whinnery. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 19–29.) Schelkunoff's polynomial formulation of the linear-array problem, studied from the potential-theory point of view, leads to an electrical analogy which has made possible the construction of a successful analogue computer. This has been used for the synthesis of new arrays and the evaluation of existing ones. Several theorems concerning the roots of the polynomials are discussed.

621.396.67.011.2 **1309**

Mutual Impedance of Parallel Aerials.—R. G. Medhurst & S. D. Pool. (*Wireless Engr*, Feb. 1951, Vol. 28, No. 329, p. 67.) Comment on 648 of 1949 (Barzilai).

621.396.67 : 621.316.761.2 **1310**

Wide-Band Aerials and Resonant Circuits with Simple and Double Compensation.—O. Zinke. (*Fernmeldetech. Z.*, Dec. 1950, Vol. 3, No. 12, pp. 454–458.) See 818 of 1950.

621.392.26† **1311**

Principles and Applications of Waveguide Transmissions. [Book Review]—G. C. Southworth. Publishers: Van Nostrand, New York, 1950, 689 pp., $9.50. (*Electronics*, Jan. 1951, Vol. 24, No. 1, pp. 136 . . 144.) "Most of the emphasis is placed on the applications and this book will be invaluable to all development engineers employing or developing microwave components." See also 2973 of 1950.

CIRCUITS AND CIRCUIT ELEMENTS

621.3.016.35 **1312**

Concerning a Criterion of Stability.—M. Parodi. (*C. R. Acad. Sci., Paris*, 15th Jan. 1951, Vol. 232, No. 3, pp. 204–206.) The following empirical criterion is frequently applied: a square matrix $M = (a_{ij})$, of order n, with real elements, is in general positive definite if its determinant $\|M\|$ is positive and if $\min (a_{ii}) > \max |a_{ij}|$, where $i \neq j$ and $i, j = 1, 2, \ldots, n$. Owing to the excellence of the results given by use of this criterion, the question arises as to whether it is exact in all circumstances. It is here shown that this is not the case, but that the criterion can be applied to a large class of matrices. See also 3348 of 1949 (Korn) and 1443 of 1950 (Raymond).

621.314.2 : 621.3.015.7† : 621.3.012.8 **1313**

Some Studies of Pulse-Transformer Equivalent Circuits.—C. K. Hadlock & D. Lebell. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 81–83.) The equivalent circuit for a pulse transformer is derived from data obtained by direct tests on a typical transformer. The differential equations for the equivalent circuit are solved by means of a mechanical differential analyser for various values of the circuit parameters. Waveforms of transformer output voltage obtained from the analyser assist in the design of pulse transformers.

621.314.222.017.14 **1314**

The Determination of the Leakage Reactance of Transformers.—J. Lagasse. (*C. R. Acad. Sci., Paris*, 3rd Jan. 1951, Vol. 232, No. 1, pp. 48–50.) The resonance method of measuring transformer leakage reactance consists of varying the capacitance in the secondary circuit and noting values of this capacitance at which harmonic resonance occurs in the primary circuit. For simplicity of operation, the primary-current variation is observed with a direct-reading ammeter. By inserting an autotransformer between the mains and the unknown transformer and varying the applied voltage, it is found that the leakage reactance is practically unaffected by saturation.

621.314.3† **1315**

Saturable-Reactor Considerations.—F. H. Shepard, Jr. (*Proc. Radio Cl. Amer.*, 1950, Vol. 27, No. 3, pp. 3–9.) Elementary discussion of saturable-reactor characteristics and of methods of demonstrating them.

621.316.761.2 : 621.396.67 **1316**

Wide-Band Aerials and Resonant Circuits with Simple and Double Compensation.—O. Zinke. (*Fernmeldetech. Z.*, Dec. 1950, Vol. 3, No. 12, pp. 454–458.) See 818 of 1950.

621.318.572 : 621.385.832 **1317**

Deflection of Cathode-Ray Tubes in Sequence.—G. W. Gray & A. S. Jensen. (*RCA Rev.*, Dec. 1950, Vol. 11, No. 4, pp. 527–533.) A circuit is described which enables a parallel-connected system of 10 beam-deflection storage tubes, with different bias voltages, to be operated sequentially as the signal amplitude varies.

621.318.572 : 621.387.422 **1318**

A Magnetic Scaling Circuit.—H. Hertz. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 107–108.) Description of the operation of a circuit including two thyratrons coupled by coils wound on a ring-shaped iron core. Pulses applied to the grid of the first thyratron trigger the discharge of a capacitor through one of the coils on the iron core, thus producing a voltage pulse on the grid of the second thyratron. Circuit component values are chosen so that the second thyratron fires only after n such pulses. Stable operation is obtained for values of n up to about 10.

621.385.2 : 546.289 **1319**

The Inverse-Voltage Characteristic of a Point Contact on *n*-Type Germanium.—Hunter. (See 1530.)

621.385.2 : 546.289 **1320**

Pulse Measurement of the Inverse-Voltage Characteristic of Germanium Point Contacts.—Bennett & Hunter. (See 1531.)

621.385.3.012.8 **1321**

Triode Transmission Networks under Linear Negative-Grid Conditions.—A. W. Keen. (*Wireless Engr*, Feb. 1951, Vol. 28, No. 329, pp. 56–66. Correction, *ibid.*, March 1951, Vol. 28, No. 330, p. 98.) "The small-amplitude alternating-current signal behaviour of the negatively-biased triode valve is represented by a Π configuration in which the grid-anode element is allowed to assume negative values in its real component in order to avoid the use of fictitious voltage or current generators. The value of the grid-anode impedance is computed for the six possible orientations of the valve in three types of circuit configuration and the validity of the representation checked by computing the driving-point impedance and voltage gain for all 18 cases. An appendix gives the matrix expressions corresponding to the transmission equivalents of three basic networks."

621.392(083.71) **1322**

Standards on Circuits: Definitions of Terms in Network Topology, 1950.—(*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 27–29.) Reprints of this Standard, 50 IRE 4.S1, may be obtained, while available, from I.R.E. at $0.50 per copy.

621.392.5 **1323**

Theory of the Negative-Impedance Converter.—J. L. Merrill, Jr. (*Bell Syst. tech. J.*, Jan. 1951, Vol. 30, No. 1, pp. 88–109.) A relatively new approach to the solution of negative-impedance problems relating to valve circuits consists in reducing the circuit of a device for producing negative impedance to an electrically equivalent four-terminal network, from which the stability and operation of the device can be predicted accurately. A negative-impedance repeater, such as the recently developed Type E1, can be connected in series with a voice-frequency telephone line to provide a transmission gain which is ample for many purposes.

621.392.5 : 621.3.012 **1324**

New Conductance Diagrams for Passive Linear Quadripoles.—H. Kafka. (*Arch. elekt. Übertragung*, Nov. 1950, Vol. 4, No. 11, pp. 446–454.) All currents and powers are referred to either the input or the output voltage; the corresponding admittance determines the current and the apparent power on the side of the network referred to. A 'calculation' admittance is introduced and the current and apparent power in the other side of the network are derived by a geometrical construction. All the usual transmission quantities, including currents, active and reactive power, phase angle, efficiency and voltage ratio, can be obtained in a simple manner from the conductance diagram.

621.392.52 **1325**

Design of High-Pass, Low-Pass and Band-Pass Filters using RC Networks and Direct-Current Amplifiers with Feedback.—C. C. Shumard. (*RCA Rev.*, Dec. 1950, Vol. 11, No. 4, pp. 534–564.) Operation of a d.c. amplifier near the (1,0) point of the Nyquist diagram results in controlled regeneration without oscillation. When such an amplifier is used with an external RC filter network, the combination gives pass bands comparable with those of LC filters at higher frequencies. Cut-off frequencies down to 0·005 c/s can be obtained.

621.392.52 **1326**

Design of Reactance Filters with Only One Finite Terminal Resistance by Use of Zobel X-Terminations.—J. M. Linke. (*Arch. elekt. Übertragung*, Nov. 1950, Vol. 4, No. 11, pp. 465–474.) Analysis shows the close connection between this type of filter (e.g., one having effectively zero source or output impedance) and the separator-type filter for the design of which the Zobel method is useful. This makes use of divided circuits, the impedance of the input branch being suitably modified by added reactors (X-terminations). The general construction of an unloaded filter by this method is described, and its behaviour in the pass band and the stop band is investigated. In the pass band mismatches have a much greater effect on the attenuation curve than is the case for normal filters with finite terminations at both ends; but for given attenuation requirements in the stop band fewer circuit elements are required. The practical design of a no-load low-pass filter is outlined.

621.392.52.018.8 **1327**

The Effect of Circuit Capacitances on Filter Attenuation Curves, and its Elimination.—W. Herzog. (*Arch. elekt. Übertragung*, Nov. 1950, Vol. 4, No. 11, pp. 462–464.) The effects of capacitance in a bridge-type filter are analysed; they can be minimized by use of trimmers and completely eliminated by balancing the input and output circuit capacitances.

621.396.4 : 621.396.82 **1328**

Theoretical Study of Cross-Modulation resulting from the Simultaneous Excitation of an Aerial by Two Transmitters.—Familier. (See 1507.)

621.396.6 : 665.3 **1329**

Printed-Circuit Production and Assembly Techniques.—R. G. Peters. (*TV Engng, N.Y.*, Nov. 1950, Vol. 1, No. 11, pp. 20–23, 44.) A detailed description of the techniques developed at the Bureau of Standards for the mass production of printed circuits. The main limitations are imposed by the difficulty of printing satisfactory resistors. These difficulties are overcome by using resistors stamped out of coated asbestos-paper tape, which are cemented to the printed-circuit assemblies.

621.396.611.1 **1330**

Sinusoidal Variation of Inductance in a Linear Series RLC Circuit.—E. I. Hawthorne. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 78–81.) A comprehensive theoretical treatment. The solution is simply related to that for capacitance variation, and damping is taken into account. Typical differential-analyser solutions are presented.

621.396.611.1 : 517.942.932 **1331**

Forced Oscillations in Nonlinear Systems.—Cartwright. (See 1417.)

621.396.615.029.53/.55 **1332**

A 300–4 000-kc/s Electrically Tuned Oscillator.—A. I. Pressman & J. P. Blewett. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 74–77.) Tuning is accomplished by varying the degree of saturation of a toroidal ferroxcube core in the inductor of an LC circuit. The output frequency is stable to within 0·1% when the temperature of the inductor is controlled to within 0·01°C; the amplitude is constant to within 4%. A greater frequency range (100–9 500 kc/s) can be obtained by using the saturable inductor in an LR Wien-bridge circuit.

621.396.645 : 621.396.822 **1333**

Background Noise in Amplifiers.—G. Lehmann. (*Rev. gén. Élect.*, Dec. 1950, Vol. 59, No. 12, pp. 543–553.) Classical and modern theoretical approaches are combined in studying the origin, nature and transmission of the irregular residual currents observed in amplifier circuits in the absence of applied voltage. The calculation of current and voltage fluctuations due to thermal agitation of electrons is given briefly. Amplifier-valve anode-current fluctuations and the noise they produce in connected transducers are considered. The use of correlation functions enables the transmission of the fluctuations through practical circuits to be investigated; in a well-designed amplifier only the input circuit and first valve contribute significantly to the noise. Experiments carried out on an amplifier with a gain of 170 db are described.

621.396.645.029.3 **1334**

An Amplifier with Very High Fidelity.—N. Mikhnewitch & M. Alixant. (*Radio tech. Dig., Édn franç.*, 1950, Vol. 4, No. 6, pp. 337–350.) Complete circuit details of the French version of Williamson's design (see 335 of 1950 and back references).

621.396.645.029.42 **1335**

Amplifiers for Slowly Varying Very Low Voltages.—H. Doizelet. (*Radio tech. Dig., Édn franç.*, 1950, Vol. 4, No. 6, pp. 353–358.) Circuits and brief description of two amplifiers for 12- and 24-c/s input, based on the design of Aiken & Welz (381 of 1948).

621.396.645.211 **1336**

Resistance-Coupled Amplifier Bandwidth.—B. A. Lippmann. (*Electronics*, Jan. 1951, Vol. 24, No. 1, pp. 192 . . 200.) The gain characteristic of the coupling network of a RC amplifier is shown to be equivalent to that of a single-tuned circuit.

621.314.2 **1337**

Transformers. [Book Review]—F. C. Connelly. Publishers: Pitman & Sons, London, 490 pp., 35s. (*Wireless Engr*, Feb. 1951, Vol. 28, No. 329, p. 68.) "Although the major part of it is devoted to the 'mains transformer', audio-frequency types, both output and intervalve, instrument transformers and even television scanning transformers are covered although rather less thoroughly. . . An extremely good book which should be of the greatest assistance to everyone concerned with small transformers."

GENERAL PHYSICS

534.01 **1338**

Parametric Excitation.—N. Minorsky. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 49–54.) "This paper outlines a theory of excitation of oscillations under the rather slow variations of a parameter on which a system depends. The basic equation is a Mathieu equation. The basic method consists in reducing the system to polar coordinates and applying perturbations."

534.01 : 621.3.015.3 **1339**

Transients in Multiply Periodic Nonlinear Systems.—F. E. Bothwell. (*Quart. appl. Math.*, Oct. 1950, Vol. 8, No. 3, pp. 247–254.) Analysis of transient oscillations in the general dynamical system with n degrees of freedom.

535.3 : 539.23 **1340**

Research on the Propagation of Sinusoidal Electromagnetic Waves in Stratified Media: Application to Thin Layers: Part 2.—F. Abelès. (*Ann. Phys., Paris*, Nov./Dec. 1950, Vol. 5, pp. 706–782.) Detailed study of the characteristics of single and multiple homogeneous thin layers on a transparent or absorbent support. New formulae relative to an absorbent layer above a transparent medium are derived for the case of total reflection. Phase displacement in an absorbent layer is considered and the necessary conditions for phase constancy with varying amplitude are derived. Optical methods of examination of transparent layers are described and experimental results quoted. The method of calculation outlined in part 1 (857 of April) is applied to determine the transmission coefficient for a system of alternate thin layers with different refractive indices n_1, n_2.

535.37 : 621.32 **1341**

Electroluminescence — A New Light Source.—E. C. Payne, E. L. Mager & C. W. Jerome. (*Sylvania Technologist*, Jan. 1951, Vol. 4, No. 1, pp. 2–5.) Theory is given of the production of light by the direct transfer of energy from a fluctuating electric field to a suitable phosphor embedded in the dielectric material of a capacitor. The intensity of illumination of such a source increases rapidly with voltage at any given frequency, and with frequency at any given voltage. The relation between light output and power consumption is linear over a range of frequencies. Possible applications as low-level large-area light sources are mentioned.

537.311.1 **1342**

The Electron and Electrical Conduction in Solids.—J. Malsch. (*Elektron Wiss. Tech.*, Oct./Nov. 1950, Vol. 4, Nos. 10/11, pp. 348–355.) Non-mathematical treatment of the theory of the electron gas and the modern theory of conduction. The latter is examined by considering (*a*) interaction between lattice ions and electrons; (*b*) wave motion of electrons. Examples are given of the energy-level representation of atomic structure, and its application in explaining the characteristic properties of conductors, semiconductors and insulators is discussed.

537.311.33 **1343**

Graphical Determination of the Fermi Level in a Simple Impurity Semiconductor.—K. Lehovec & H. Kedesdy. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 65–67.) The position of the Fermi level is determined for the case of zero space charge, and the resulting graph is applied to determine the effective electron mass in SiC. Measurements by Busch & Labhart (1820 of 1947) indicate that the effective masses of electrons and holes in SiC crystals are of the order of mass of a free electron.

537.523/.527].4 **1344**

Recent Research on Spark Discharges in Gases.—J. D. Craggs & J. M. Meek. (*Research, Lond.*, Jan. 1951, Vol. 4, No. 1, pp. 4–10.) A review dealing with breakdown in gaps subjected to unidirectional or h.f. voltages.

537.525 **1345**

On the Theory of Double Layers in Low-Pressure Gas Discharges.—T. Wasserrab. (*Z. Phys.*, 7th Dec. 1950, Vol. 128, No. 5, pp. 575–585.)

537.533/.534 : 538.122 **1346**

Consequences of the Radiation from Very Fast Particles in a Magnetic Field.—B. Kwal. (*J. Phys. Radium*, Dec. 1950, Vol. 11, No. 12, pp. 685–690.) The emission of photons by charged particles moving in a magnetic field is discussed on the basis of work done by Arzimovich and Pomeranchuk. The formulae derived are applied to simple cases of motion of electrons, mesons and protons in the magnetic fields of the earth and of the sun.

537.533.8 **1347**

A Pulse Method of Determining the Energy Distribution of Secondary Electrons from Insulators.—K. G. McKay. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 89–94.) Description of a method based on analysis of the transient resulting from pulse bombardment. The analysis is simplest when leakage through the target is negligible, but the effect of such leakage is considered. Space-charge limitation of the emission is assumed to be negligible.

538.122 : 537.525.8 **1348**

Improvements in Visual Depiction of Magnetic Lines of Force by Means of a Gas Discharge.—F. Blaha & J. A. Schedling. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 11–13.) Description of a method basically similar to that described by Lutz & Tetenbaum (2375 of 1949). The use of perforated screens of dielectric material covering the polepieces enables the starting points of the lines of force displayed to be predetermined.

538.311 : 621.318.423 : 513.647.1 **1349**

The Electromagnetic Field Produced by a Helix.—R. S. Phillips. (*Quart. appl. Math.*, Oct. 1950, Vol. 8, No. 3, pp. 229–246.) It is shown that the phase velocity of a monochromatic field is the same as that which would be obtained if the wave travelled along the helix with the free-space velocity. The radiation of energy from the helix is discussed.

538.311 : 621.318.423 : 513.647.1 **1350**

Calculation of the Field of a [travelling-wave] **Helix.**—É. Roubine. (*C. R. Acad. Sci., Paris*, 15th Jan. 1951, Vol. 232, No. 3, pp. 221–222.) The method previously used (see 3036 of 1947) to calculate the E_z component of the electric field at a point on the axis of an endless helix traversed by a progressive current wave Ie^{-jks} is applied to determine the components of the $\vec{E}$ and $\vec{H}$ fields, at any point of the axis, in a finite form involving only known transcendental functions.

538.56 : 530.12 **1351**

On the Relativistic Electromagneto-ionic Theory of Wave Propagation.—V. A. Bailey. (*Phys. Rev.*, 1st Feb. 1950, Vol. 77, No. 3, pp. 418–419.) The equation of dispersion is modified to allow for the occurrence of electron velocities comparable with that of light. The omission of the relativistic terms from the equation previously given (see 3406 of 1949) is in general unimportant, but leads to erroneous conclusions in certain special cases.

538.56 : 535.13 **1352**

The Reflection of an Electromagnetic Plane Wave by an Infinite Set of Plates: Part 3.—A. E. Heins. (*Quart. appl. Math.*, Oct. 1950, Vol. 8, No. 3, pp. 281–291.) Complete results are presented for the cases in which (*a*) the magnetic vector is parallel to the edges of the plates, (*b*) there is one transmitted mode and two reflected waves. More complicated cases are discussed very briefly. Parts 1 & 2: 2756 (Carlson & Heins) and 3504 (Heins & Carlson) of 1947.

538.561 : 621.315.612 **1353**

Free Oscillations of Dielectric Rings.—H. Wigge. (*Arch. elekt. Übertragung*, Nov. 1950, Vol. 4, No. 11, pp. 455–461.) Theoretical analysis of the quasi-stationary condition in an oscillating ring of high-permittivity material. Maxwell's equations are expressed in toroidal coordinates and integrated; from the limiting conditions the free oscillations can be calculated. The distribution of the electric field over the cross-section of the ring is determined. The results obtained indicate that the ring may be regarded as a ring-shaped series arrangement of an infinite number of elementary capacitors possessing a self-inductance which can be calculated from the formulae given. The combination of two rings, one of dielectric and the other of magnetic material, constituting a simple electrical oscillatory system, is briefly considered. Experimental results for rings made from Condensa-C (permittivity 76–80) are noted. Oscillations in the wavelength range 50–100 cm were obtained.

538.561.029.65† : 535.42 **1354**

Evanescent Microwaves Generated by Diffraction.—M. Schaffner & G. Toraldo di Francia. (*Nuovo Cim.*, 12th March 1949, Vol. 6, No. 2, pp. 125–130.) Experiments demonstrating the existence of these waves are described, the wavelength being 32 mm. A diffraction grating made of metal strips was used. One of the first-order waves was transformed into an ordinary plane wave by passing it through a paraffin prism. On plotting the logarithm of the wave power against the distance between prism and grating, a straight line is obtained, whose slope gives the attenuation constant of the surface wave, as predicted by theory.

538.569.4 : 061.3 **1355**

International Congress on Spectroscopy at Radio Frequencies, Amsterdam, September 1950.—M. Soutif. (*J. Phys. Radium*, Dec. 1950, Vol. 11, No. 12, pp. 90S–92S.) A brief report in which the subjects discussed are grouped under five headings:—absorption spectra at centimetre wavelengths, the method of atomic jets, electronic and nuclear paramagnetic resonances, and ferromagnetic resonance. A practical application of resonance absorption mentioned is an 'ammonia clock' constructed by H. R. L. Lamont in the G.E.C. laboratories, Wembley. This operates as follows:—a f.m. oscillator produces two pulses, one as it passes through the resonance frequency corresponding to a spectral line of ammonia, the other when it produces a given beat with the fixed oscillator to be stabilized; the time difference between the two pulses controls the system regulating the fixed oscillator. See also 1983 of 1949.

538.569.4 : 532 **1356**

On the Absorption of U.H.F. Radio Waves in Organic Liquids at Different Temperatures.—S. N. Sen. (*Indian J. Phys.*, Nov. 1949, Vol. 23, No. 11, pp. 495–502.) Absorption maxima were found in the frequency range 250–500 Mc/s for acetone, ether and methyl ethyl ketone at temperatures above 0°C. The maxima shift to lower frequencies at lower temperatures.

538.632 : 621.315.592† **1357**

The Hall Coefficient of Semiconductors.—H. Jones. (*Phys. Rev.*, 1st Jan. 1951, Vol. 81, No. 1, p. 149.) An inconsistency is noted in the theory of Johnson & Lark-Horowitz (2491 of 1950) which takes into account both thermal and impurity scattering of the electrons. The mobilities quoted by these authors (662 of March) should, as a consequence, be reduced. The variation in Hall coefficient is shown as a function of the ratio of the resistance due to impurity scattering to total resistance.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.72 : 621.396.822 **1358**

Study of Low-Intensity Solar Radio Storms.—É. J. Blum, J. F. Denisse & J. L. Steinberg. (*C. R. Acad. Sci., Paris*, 29th Jan. 1951, Vol. 232, No. 5, pp. 387–389.) A report of observations (at frequencies near 164 Mc/s) obtained with recording equipment of small time-constant allowing rapid fluctuations of solar r.f. radiation to be followed easily. On days of low activity, intensity jumps occur, generally well separated from one another and with durations of 0·1–0·4 sec. When the activity is greater (variability I on the U.R.S.I. scale), the radiation level may fluctuate for many hours, returning from time to time to the level for calm periods. The results indicate that this type of disturbance is due to the superposition of a large number of the intensity jumps observed on calmer days. See also 627 of March (Blum & Denisse).

523.72 : 621.396.822 **1359**

The Interpretation of Solar-Noise Jumps.—É. J. Blum, J. F. Denisse & J. L. Steinberg. (*C. R. Acad. Sci., Paris*, 5th Feb. 1951, Vol. 232, No. 6, pp. 483–485.) The jumps in the intensity level of solar r.f. radiation previously reported (1358 above) are only observed on relatively low frequencies, below about 500 Mc/s. The energy is confined to a narrow frequency band, at most a few Mc/s wide. The radiation is almost completely circularly polarized. The jumps last, on the average, about 0·2 sec, and the power radiated during a jump is of the order of 5×10^{-22} W/m² per c/s at a frequency of 164 Mc/s. Possible solar phenomena which could account for the existence of such jumps are considered. The plasma theory of Bohm & Gross (88 and 89 of 1950) can provide a basis for a satisfactory explanation of the observed effects. A mechanism is proposed which can also explain the radio storms which often accompany chromospheric eruptions.

523.72 : 621.396.822 **1360**

A Mechanism of Coronal R.F. Emission.—Y. Rocard. (*C. R. Acad. Sci., Paris*, 12th Feb. 1951, Vol. 232, No. 7, pp. 598–600.) A mechanism is described which could possibly explain the origin of the jumps in the level of solar r.f. radiation recently described by Blum, Denisse & Steinberg (1358 and 1359 above).

523.746"1949.10/.12" **1361**

Provisional Sunspot-Numbers for October to December 1949.—M. Waldmeier. (*J. geophys. Res.*, March 1950, Vol. 55, No. 1, p. 93.)

523.75 : 537.591 **1362**

On the Influence of Solar Activity on the Intensity of Cosmic Rays.—I. L. Chakraborty & S. D. Chatterjee. (*Indian J. Phys.*, Dec. 1949, Vol. 23, No. 12, pp. 525–534.) One theory of the origin of cosmic rays assumes that they are generated on or near the sun and are kept near the solar system by the action of magnetic fields. The validity of this theory is examined in the light of measurements of cosmic-ray intensity and magnetic activity made during the week following the solar flare on 25th January 1949, at Calcutta. An initial increase of cosmic-ray intensity unexpected for the low geomagnetic latitude of 12° was observed. These and other results mentioned support the view that the paths by which the rays can arrive at the earth depend on the combination of magnetic fields prevailing on the sun and the earth.

523.854/.855 : 621.396.822] + 523.5 **1363**

The New Science of Radio Astronomy.—A. C. B. Lovell. (*Nature, Lond.*, 20th Jan. 1951, Vol. 167, No. 4238, pp. 94–97.) Radio 'telescopes' have resulted in important advances in astronomical knowledge. The following aspects of these advances are briefly discussed, with references: (*a*) the measurement of meteor velocities and the conclusion that the interstellar origin of meteors is unlikely; (*b*) the discovery of day-time meteor streams; (*c*) the possible existence of stars which can only be detected on radio frequencies; (*d*) structure of the galaxy; (*e*) radio emissions from extragalactic nebulae; (*f*) the effect of the ionosphere on extraterrestrial radiation.

523.854 : 621.396.822] + 537.591 **1364**

Origin of the Radio-Frequency Emission and Cosmic Radiation in the Milky Way.—A. Unsöld. (*Z. Astrophys.*, 14th Dec. 1949, Vol. 26, Nos. 2/3, pp. 176–199.) A survey with 72 references. See also 2217 of 1949.

523.854 : 621.396.822 **1365**

Origin of the Fluctuations in the Intensity of Radio Waves from Galactic Sources.—F. G. Smith. (*Nature, Lond.*, 18th March 1950, Vol. 165, No. 4194, pp. 422–423.) A report of observations by Cambridge workers on a wavelength of 6·7 m, using receivers with spacings up to 170 km. The two types of fluctuation observed are described, one involving variations of intensity both above and below the mean value, the other having the appearance of individual 'bursts' of large amplitude and of duration 10–20 sec. It seems likely that two separate mechanisms are responsible for the observed fluctuations; one appears to be related to variations of the emission from the sources, the brief duration of the bursts suggesting sources of stellar dimensions, while the other appears to be due to diffraction in a comparatively local region.

523.854 : 621.396.822 **1366**

Origin of the Fluctuations in the Intensity of Radio Waves from Galactic Sources.—C. G. Little & A. C. B.

Lovell. (*Nature, Lond.*, 18th March 1950, Vol. 165, No. 4194, pp. 423–424.) An account of observations at Jodrell Bank, Cheshire, in collaboration with F.G. Smith at Cambridge, 210 km away. Simultaneous observations were made of the radiation from the sources in Cygnus and Cassiopeia on a wavelength of 3·7 m. The results show that the radiation is generally either steady at both sites or fluctuating at both sites on a given night. There are about 10% significant exceptions when fluctuations were observed at one site and not at the other. When fluctuations occurred at both sites, there was no correlation between the disturbances. Further simultaneous observations at sites near Jodrell Bank show that there is complete correlation between the observed fluctuations for a site separation of 100 m. For a separation of 3·9 km the correlation is not complete but remains high, with a correlation factor ranging from 0·5 to 0·95. This indicates that the origin of the fluctuations must be fairly local, and probably lies in the earth's atmosphere or ionosphere rather than in the interstellar medium. Considerations of the Fresnel zone theory indicate that the reversal of the phase of an appreciable fraction of a zone, due to localized changes in the refractive index of the ionosphere, could cause fluctuations of the type observed. If such a mechanism is responsible for the fluctuations, the effect may be expected to increase in prominence with increasing angle of incidence and to show some correlation with abnormal ionospheric effects.

523.854 : 621.396.822 **1367**

Microwave Sky Noise.—A. E. Covington. (*J. geophys. Res.*, March 1950, Vol. 55, No. 1, pp. 33–37.) Observations made during the period April 1946–June 1947 and reported in 721 of 1948 are examined further for correlation between microwave-noise storms on the one hand and magnetic disturbances and auroral displays on the other. The correlation is concluded to be not so close as implied in the earlier communication. The absence of correlation with auroral displays is probably due to the phenomena occurring outside the acceptance cone of the fixed aerial used for the observations.

537.533/.534 : 538.122 **1368**

Consequences of the Radiation from Very Fast Particles in a Magnetic Field.—Kwal. (See 1346.)

550.38 : 551.52 **1369**

On the Relation between Variations of the Earth's Magnetic Field and Variations of the Large-Scale Atmospheric Circulation.—O. R. Wulf & M. W. Hodge. (*J. geophys. Res.*, March 1950, Vol. 55, No. 1, pp. 1–20.) Comparison of geomagnetic data with observations of circulation in the lower atmosphere confirms the view that large-scale movements in the electrically conducting region of the atmosphere affect the value of the earth's magnetic field.

550.38"1949.07/.09" **1370**

International Data on Magnetic Disturbances, Third Quarter, 1949.—J. Bartels & J. Veldkamp. (*J. geophys. Res.*, March 1950, Vol. 55, No. 1, pp. 91–92.)

550.38"1949.10/.12" **1371**

Cheltenham Three-Hour-Range Indices *K* for October to December, 1949.—R. R. Bodle. (*J. geophys. Res.*, March 1950, Vol. 55, No. 1, p. 93.)

550.384 **1372**

'Sudden Commencements' in Geomagnetic Field Variations.—S. K. Chakrabarty. (*Nature, Lond.*, 6th Jan. 1951, Vol. 167, No. 4236, p. 31.) The records of Alibag observatory over the period 1905–1944 have been analysed. The results provide data additional to those recently given by Newton (2235 of 1948) and by Ferraro & Parkinson (1142 of 1950). The first type of sudden commencement, characterized by a rise in H and a fall in V, is very prominent in the Alibag records, but the second type described by Ferraro & Parkinson, in which the increase in H is preceded by a small decrease, is absent. The 'inverted' third type occurs relatively infrequently. Curves for the diurnal variation of sudden-commencement incidence indicate minima at 0400–0700 and about 1700 local mean time, with a more pronounced maximum at 0900–1300. Prominent sudden commencements noted at Alibag but not at Abinger, and vice versa, are tabulated.

550.384.3(68) **1373**

Secular Variation of the Magnetic Elements in South Africa, 1939–1948.—A. M. van Wijk & J. A. N. Burger. (*J. geophys. Res.*, March 1950, Vol. 55, No. 1, pp. 57–64.)

550.385 + 551.594.5 **1374**

The Theory of Magnetic Storms and Auroras.—D. F. Martyn. (*Nature, Lond.*, 20th Jan. 1951, Vol. 167, No. 4238, pp. 92–94.) The Chapman-Ferraro theory postulates a neutral stream of ionized particles of solar origin which envelops the earth during a magnetic storm. Analytical difficulties prevent full use being made of this theory in the quantitative explanation of observed storm phenomena. The formal analogy between familiar hydrodynamical problems and that of a tenuous ionized gas moving in a magnetic field is here applied to the estimation of the dimensions of the hollow formed by the particle stream round the earth, the width and latitude of the auroral zones, the currents flowing in these zones, the formation and stability of the equatorial ring current, and F_2-region disturbances.

550.385 **1375**

Principal Magnetic Storms [April–Dec. 1949].—(*J. geophys. Res.*, March 1950, Vol. 55, No. 1, pp. 94–95.)

551.510.4 **1376**

Further Determinations of the Vertical Distribution of Ozone.—E. Regener, H. K. Paetzold & G. Pfotzer. (*Naturwissenschaften*, Dec. 1950, Vol. 37, No. 24, pp. 559–560.)

551.510.535 **1377**

Statistics of the Night-Time Abnormal E Layer.—E. A. Lauter. (*Z. Met.*, July/Aug. 1950, Vol. 4, Nos. 7/8, pp. 234–240.) Statistical presentation of results of night observations on a wavelength of 1 250 m and of the occurrence of magnetic disturbances between November 1947 and May 1950 shows a marked correlation between times of strong absorption and cosmic bursts. Conditions specially favourable for electrically charged corpuscular radiation evidently exist 3–4 days after a magnetic disturbance, at which time the night-time ionization below the normal E layer is observed to reach a maximum.

551.510.535 **1378**

Observations of the Ionosphere in the Arctic Region.—O. Burkard. (*Arch. Met. Geoph. Bioklimatol. A*, 30th June 1948, Vol. 1, No. 1, pp. 93–99.) Observations on the F layer obtained at Tromsö during the period June 1944–April 1945 are reported and discussed. The region is traversed by many radiocommunication lines. During the summer f_0F_2 was almost constant; during the winter it varied with the sun's height. Magnetic disturbances cause a reduction of f_0F_2; when they are very powerful the reflected wave from the F layer disappears altogether. This is only partly due to the screening effect of the lower absorbing layers; the other factor is a reduction of ionization which is particularly marked during morning hours after magnetic disturbances. Even on magnetically undisturbed days communication lines using the F layer can be relied on only during the daytime. Reference is made to the appearance of the sporadic F layer (see also 390 of 1949).

551.510.535 **1379**

The Approximate World Distribution of F_2-Layer Ionization.—K. Rawer. (*C. R. Acad. Sci., Paris*, 3rd Jan. 1951, Vol. 232, No. 1, pp. 98–100.) The ionization distribution may be represented sufficiently closely by the results of observations in two regions, an eastern and a western [see 2794 of 1949 (Oboril & Rawer)], a linear interpolation being made for the two intermediate regions. The eastern zone corresponds roughly with the land mass of Europe, Africa and Asia, and the wsetern zone with America. The apparent influence on the F_2-layer ionization of the disposition of the continents is attributed to a probable relation between the latter and the magnetic inclination.

551.510.535 : 522.1(481) **1380**

The Ionospheric and Radio Wave Propagation Observatory at Kiruna, 67° 50′ N, 20° 14·5′ E.—O. E. H. Rydbeck. (*Tellus*, Nov. 1949, Vol. 1, No. 4, pp. 61–64.) A short account of the lay-out and equipment of the station.

551.510.535 : 523.75 : 621.396.11 **1381**

Ionospheric Effects of Solar Flares.—R. Lindquist. (*Acta polyt., Stockholm, Elect. Engng Series*, 1950, Vol. 2, No. 9; *Chalmers tekn. Högsk. Handl.*, 1950, No. 95, 11 pp. In English.) Presentation of fade-out observations recorded during the period July 1948–June 1949 at Gothenburg. See also 619 of 1950 (Rydbeck & Stranz).

551.510.535 : 621.3.087.4 **1382**

The Panoramic Ionospheric Recorder.—Lindquist. (See 1425.)

551.510.535 : 621.396.11 **1383**

Longitudinal and Transverse Propagation in Canada.—Scott. (See 1471.)

551.510.535 : 621.396.11.029.51 : 535.312 **1384**

Ionospheric Reflection of Very Long Radio Waves.—Stanley. (See 1474.)

551.578.1 : 621.396.9 **1385**

The Scattering of Ten-Centimetre Radio Waves by Rain.—R. C. Langille. (*J. geophys. Res.*, March 1950, Vol. 55, No. 1, pp. 51–52.) Rain distribution in showers has been determined from observations of reflected 10-cm radio waves, using modified height-finding radar equipment.

551.593.9 **1386**

Study of the Emission Spectrum of the Night Sky from 6800 to 9000 Å.—J. Dufay & M. Dufay. (*C. R. Acad. Sci., Paris*, 29th Jan. 1951, Vol. 232, No. 5, pp. 426–428.) All the spectrum lines observed in this region belong to the vibration-rotation bands of OH and to the (0,1) band of O_2. In agreement with Meinel's measurements, the rotation temperature is found to be 255–270°K for OH and about 130°K for O_2. The intensity of the bands probably has a seasonal variation.

551.594.6 **1387**

Variation of Intensity of Distant Atmospherics with Frequency Channels.—S. R. Khastgir & A. Sen. (*Indian J. Phys.*, Nov. 1949, Vol. 23, No. 11, pp. 483–494.) A c.r. tube direction finder was used to investigate the intensity E of distant atmospherics in the frequency (f) range 170–204 kc/s. During the day and occasionally at night, $E \propto 1/f^3$. Generally at night $E \propto e^{-mf}$, where m is a constant. Sometimes, during the day or night, the variation of E suggested a combination of the inverse and exponential types. The inverse type apparently occurs when the source of atmospherics is not very distant and the pulse travels by the ground path. The exponential type is associated only with sky waves.

LOCATION AND AIDS TO NAVIGATION

621.396.9 **1388**

Sunderland Shore-Based Radar Station.—(*Electronic Engng*, Jan. 1951, Vol. 23, No. 275, p. 29.) A short account of the facilities available, which include Kelvin Hughes Type-1A Series-2 Marine Radar, with ranges of 1–5, 10, 15 and 25 miles, a 2-frequency simplex a.m. system for communication with pilots on frequencies of 163·1 and 158·6 Mc/s, and single-frequency simplex equipment for communication on the international marine frequency of 156·8 Mc/s. See also *Wireless World*, Jan. 1951, Vol. 57, No. 1, p. 34.

621.396.9 **1389**

Angular Jitter in Conventional Conical-Scanning Automatic-Tracking Radar Systems.—C. E. Brockner. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 51–55.) Four sources of jitter are discussed and each is expressed in terms of range and the system parameters. The existence of a range interval of optimum tracking is pointed out and the importance of beamwidth in determining the magnitude of angular jitter is stressed.

621.396.9 : 519.2 **1390**

The Statistical Properties of Noise Applied to Radar Range Performance.—S. M. Kaplan & R. W. McFall. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 56–60.) The relations between detection probability, the clipping level, the pulses per element, the false-alarm time, and other factors are presented both in equation form and graphically. From the graphs the detection range for any desired detection probability and also the probability of false target echoes can be calculated. The influence of various system parameters on the radar performance is also indicated.

621.396.932.1 **1391**

New Developments in Radar for Merchant Marine Service.—C. E. Moore. (*RCA Rev.*, Dec. 1950, Vol. 11, No. 4, pp. 465–481.) The general features of 3-cm radar equipment specifically designed for small vessels are described. Technical factors in design and details of the complete installation are illustrated with diagrams and photographs. General trends in commercial marine radar are considered.

621.396.933.2 **1392**

Distance-Measuring Equipment for Civil Aircraft.—D. G. Lindsay, J. P. Blom & J. D. Gilchrist. (*Proc. Instn Radio Engrs, Aust.*, Dec. 1950, Vol. 11, No. 12, pp. 307–315.) A description of the development of a ground-beacon interrogator-responder system. Requirements and circuitry are outlined. Beacon reply pulses are delayed by 12·4 μs and actuate a locking system in the aircraft which requires 3 to 5 successive correct pulses to operate. Range is displayed by meter.

621.396.933.2 **1393**

Hyperbolic [aerial navigation] **Systems.**—W. Stanner & H. C. Freiesleben. (*Elektron Wiss. Tech.*, Dec. 1950, Vol. 4, No. 12, pp. 417–426.) The principles of pulse-displacement and phase-displacement measurement are illustrated in a review and description of American and British systems. The location and service area of stations in Europe are indicated.

621.396.9 **1394**

Radar Simply Explained. [Book Review]—R. W. Hallows. Publishers: Chapman & Hall, London, 2nd edn, 190 pp., 10s. 6d. (*Elect. Radio Trading*, Jan. 1951, Vol. 23, No. 254, p. 141.) Includes information previously withheld. "It has been translated into six European languages and, it is claimed, is recognized as the best available introduction to radar."

MATERIALS AND SUBSIDIARY TECHNIQUES

533.5 **1395**

An Ionization Pump.—R. Champeix. (*Le Vide*, Nov. 1950, Vol. 5, No. 30, pp. 912–913.) Description of the principle of an apparatus for obtaining very low pressures. A 1-kV discharge takes place between two nickel-mesh electrodes sealed inside a tube connected to a backing pump. The gas molecules are ionized, the ions travelling to the electrodes, where they are subjected to the action of the backing pump and are evacuated. The discharge is interrupted after some 30 sec and the process repeated. For another account see *C. R. Acad. Sci., Paris*, 3rd July 1950, Vol. 231, No. 1, pp. 40–42.

535.37 **1396**

Luminescence Efficiency of Organic Solutions and Crystals.—P. D. Johnson & F. E. Williams. (*Phys. Rev.*, 1st Jan. 1951, Vol. 81, No. 1, p. 146.)

537.311.3 : 539.234 **1397**

The Release of Electrons on Transition from Metal Atoms to the Compact Metal.—H. Mayer. (*Elektron Wiss. Tech.*, Oct./Nov. 1950, Vol. 4, Nos. 10/11, pp. 341–347.) Evaporation processes for producing very thin layers of different metals are outlined; experimental curves showing variation of resistivity with layer thickness are analysed and discussed with reference to Herzfeld's criterion for the free-electron state, viz. $R > M/s$, where R is the molecular refractive power for the gaseous state, M the molecular weight and s the layer thickness.

537.311.33 : 546.289 **1398**

Mobilities of Electrons in High Electric Fields.—E. J. Ryder & W. Shockley. (*Phys. Rev.*, 1st Jan. 1951, Vol. 81, No. 1, pp. 139–140.) An investigation of the current-density/electric-field characteristic for n-type Ge samples, using a pulse technique. The resistivity is constant for fields up to about 6×10^2 V/cm, corresponding to a region of constant mobility. For higher fields, the mobility $\propto E^{-1}$ in a region of constant drift velocity and almost constant current. Hole injection or generation is thought to occur for values of $E > 2 \times 10^4$ V/cm. The predicted drift velocity depends on 'acoustical' and 'optical' scattering, the former predominating at low temperatures.

537.533.8 **1399**

Secondary Emission of Nickel-Barium Mixtures and Rhenium when Bombarded by Electrons with Energies from 50 to 8 000 Electron-Volts.—H. E. Farnsworth & M. J. Lun. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 77–79.) For a cast alloy of Ni containing 1·5% Ba, the secondary-emission ratio (δ) has a maximum value of 2·8 for electrons of 800–900 eV. δ_{max} depends on the previous heat treatment; this is illustrated graphically. For Rh, δ_{max} is 1·3 at 900 eV and the most probable energy of low-speed secondary electrons is 5 eV.

537.58 : 621.385.032.213 **1400**

Certain Refractory Compounds as Thermionic Emitters.—D. L. Goldwater & R. E. Haddad. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 70–73.) Several carbides, nitrides, and borides of Zr, Th, Ti, and Ta were tested after aging in vacuo. The results are shown graphically and discussed. Only ZrC has practical possibilities. Its emissivity is less than 40% of that expected from thoria, but there is no decay of emission when high-density emission currents are continuously drawn. Two ZrC cathodes were operated for several hours at 1 500°C with a continuous space-charge-limited emission current of 0·7 A/cm².

538.221 **1401**

Magnetic Properties of Zinc Ferrite ($Fe_2O_3.ZnO$) in Relation to its Structure.—C. Guillaud & M. Sage. (*J. Phys. Radium*, Dec. 1950, Vol. 11, No. 12, p. 4E.)

538.221 : 621.3.011.5 **1402**

Relation between Dielectric Constant and Loss Angle of Ferroelectric Materials.—M. Kornetzki. (*Z. angew. Phys.*, 10th Nov. 1950, Vol. 2, No. 11, pp. 446–448.) Measurements show that the Rayleigh relation for ferromagnetic materials is equally applicable to ferroelectric materials.

538.632 + 537.311] : 546.87 : 539.23 **1403**

Hall Coefficient and Resistivity of Evaporated Bismuth Layers.—W. F. Leverton & A. J. Dekker. (*Phys. Rev.*, 1st Jan. 1951, Vol. 81, No. 1, pp. 156–157.)

546.431.82 : 537.226.2 **1404**

The Dielectric Constant of Barium Titanate.—M. Kornetzki. (*Z. Phys.*, 7th Dec. 1950, Vol. 128, No. 5, pp. 605–613.) A formula for calculating the permeability of ferromagnetic materials, based on displacements of the Bloch wall, is used to estimate the dielectric constant of polycrystalline $BaTiO_3$ at room temperature.

621.315.61 **1405**

Research Developments in Dielectrics.—A. E. Javitz. (*Elect. Mfg, N.Y.*, Jan. 1950, Vol. 45, No. 1, pp. 80–85 . . 184.) Report of the 1949 Annual Conference on Electrical Insulation. Prepared papers were grouped under the headings: electrical properties of matter; insulating materials; dielectric and related measurements; insulated wire and cable. At informal sessions the most widely discussed subjects were: service performance and trends in the use of insulation; high-temperature organic and organo-inorganic insulation; ferroelectric materials. The recently developed tetrafluoroethylene suspensoids are expected to find wide application. The production of 'bonded' and 'integrated' mica was described. Semiconductor synthesis and the rectifying properties of metal/semiconductor interfaces were also discussed.

621.315.61 **1406**

The Interpretation of Dielectric Measurements using the Cole-Cole Plot.—J. G. Powles. (*Proc. phys. Soc.*, 1st Jan. 1951, Vol. 64, No. 373B, pp. 81–82.) Plots of the imaginary part against the real part of the dielectric constant, using frequency and temperature respectively as parameters, are of practical (though limited) use for estimating dielectric properties under conditions for which measurements are not available. See also 3022 of 1950 (Stark).

621.315.613.1 **1407**

'Samica' Mica Paper.—H. George & L. Metzger. (*Rev. gén. Élect.*, Dec. 1950, Vol. 59, No. 12, pp. 519–524.) A brief account is given of the invention of 'mica paper' by the French chemist J. Bardet; thermal and chemical treatments are involved. A method of manufacturing the material in continuous sheet form from mica pulp has been developed, using modified paper-making machinery. The product has a density about half that of natural mica; the thickness is from some thousandths to some hundredths of a millimetre, and is very uniform. The pulp can be dried, ground and moulded into required shapes, but the sheet form is of most importance in the electrical industry and can be used as an economical substitute for mica splittings in insulation. Results of measurements of dielectric and mechanical properties are reported and compared with figures for corresponding products made from splittings.

621.316.8 : 621.396.822 **1408**

Noise in Unidirectional Conductors.—W. Kroebel. (*Fernmeldetech. Z.*, Dec. 1950, Vol. 3, No. 12, pp. 466–470.) An account is given of experiments on semiconductor rectifiers (galena, carborundum and Ge point types and a 'Sirutor' disk type). The values found for d.c., h.f. and equivalent noise resistances as functions of applied d.c. voltage are shown in curves. An explanation of the variation of equivalent noise resistance is based on Schottky's theory of variation of barrier-layer thickness with applied d.c. voltage, and on the assumption that discharges take place within the barrier layer on account of the high field strengths present. The difference in the course of the equivalent-noise-voltage curve for point rectifiers for forward and backward voltages is due partly to the difference of operative volume in the two cases. The measurement arrangements are described briefly.

621.317.3 : 538.569.4.029.64 + 621.317.335.3† **1409**

Microwave Measurements of the Dielectric Properties of Gases.—Birnbaum, Kryder & Lyons. (See 1426.)

666.3.056.5 : 621.791.3 **1410**

Metal/Ceramic Sealing with Manganese.—H. J. Nolte & R. F. Spurck. (*TV Engng, N.Y.*, Nov. 1950, Vol. 1, No. 11, pp. 14–18, 39.) The use of a metallizing mixture of 20% Mn and 80% Mo for forming a bonding layer on ceramic materials enables reproducible vacuum-tight ceramic/metal seals to be made efficiently. Details are given of techniques used in various industrial applications of the process.

669.27 : 621-42 : 548.53 **1411**

On the Recrystallization and Grain Growth in Tungsten Wire.—H. A. DeVincentis & J. H. Dedrick. (*Sylvania Technologist*, Jan. 1951, Vol. 4, No. 1, pp. 6–8.) A brief survey is made of the important factors affecting recrystallization and grain growth in tungsten, with emphasis on the manufacturing problems in the valve and incandescent-lamp industries. Methods of controlling these two phenomena are discussed.

669.27 : 621-42 : 621.385.032.213 **1412**

Preliminary Treatment of Tungsten Wire for Electronic Valves.—G. Mesnard & R. Uzan. (*Le Vide*, Nov. 1950, Vol. 5, No. 30, pp. 896–904.) Discussion of the preparation of valve filament wire of diameter < 1 mm. Microphotographs reproduced indicate that, for decarbonizing, the soda treatment is generally the most effective; the concentration and temperature of the solution should be as high as possible. Other methods considered are heat treatment in a hydrogen atmosphere, and electrolysis. Details are given of an electrolytic method of polishing and of pyrometric determination of the operating temperature of the wire.

533.5 **1413**

Le Vide et ses Applications. [Book Review]—L. Dunoyer. Publishers: Presses universitaires de France, Paris, 1950, 114 pp., 90 fr. (*Proc. phys. Soc.*, 1st Jan. 1951, Vol. 64, No. 373B, p. 93.) "A book particularly suitable for the physics student, or for the layman with some mathematical knowledge and an intelligent interest in science."

621.315.211 : 614.841 **1414**

A Comparison of the Flame-Retardant Properties of Plastics-Insulated and Rubber-Insulated Electric Cable. [Book Review]—Publishers: British Plastics Federation, 47–48 Piccadilly, London, W.1, 1950, 2s. 6d. (*Electrician*, 29th Dec. 1950, Vol. 145, No. 26, p. 1603.) The comparison is made for the two cases of heating due to an external source and heating due to overload current, respectively. The plastics used were polythene and p.v.c.

MATHEMATICS

517.942.72 : 621.396.11 **1415**

Associated Legendre Polynomial Approximations.—R. Landauer. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 87–89.) "Approximations for the associated Legendre Polynomials are derived by a phase-integral method. The method is an extension of the WBK method, applicable to separable multidimensional wave propagation problems."

517.942.9 : 519.21 **1416**

Random Walks and the Eigenvalues of Elliptic Difference Equations.—W. Wasow. (*Bur. Stand. J. Res.*, Jan. 1951, Vol. 46, No. 1, pp. 65–73.) Discussion of the application of random-walk procedure to the solution of differential equations of the form $\nabla^2 u + g(x, y)u = 0$. It is shown that under suitable conditions the Monte Carlo solution converges and gives the solution of the difference analogue of the above equation.

517.942.932 : 621.396.611.1 **1417**

Forced Oscillations in Nonlinear Systems.—M. L. Cartwright. (*Bur. Stand. J. Res.*, Dec. 1950, Vol. 45, No. 6, pp. 514–518.) Shows how the approximate form of the solutions of a certain nonlinear differential equation may be obtained from certain general results which are proved in detail. The method could be applied to any equation of the form

$$\ddot{x} + kf(x)\dot{x} + g(x) = kp(t)$$

where the period of $p(t)$ is $2\pi/\lambda$, and $\int_0^t p(t)dt$ is bounded for all values of t, $f(x) \geqslant 1$ for $|x| \geqslant a$, and $g(x)/x \geqslant 1$ for $|x| \geqslant a$. See also 2740 of 1948.

517.948 **1418**

An Iteration Method for the Solution of the Eigenvalue Problem of Linear Differential and Integral Operators.—C. Lanczos. (*Bur. Stand. J. Res.*, Oct. 1950, Vol. 45, No. 4, pp. 255–282.) A systematic method is described for finding the latent roots and the principal axes of a matrix without reducing its order. The method has wide applicability and great accuracy, since the accumulation of rounding errors is avoided by use of a method of 'minimized iterations'. The method leads to a rapidly convergent analytical iteration procedure by which the solution of integral equations of the Fredholm type and of the eigenvalue problems of linear differential and integral operators can be obtained.

681.142 **1419**

An Analogue Multiplier.—B. O. Marshall, Jr. (*Nature, Lond.*, 6th Jan. 1951, Vol. 167, No. 4236, pp. 29–30.) Short description of a method based on the relation $xy = [(x + y)^2 - (x - y)^2]/4$. The equipment required is relatively simple and gives results to an accuracy well within 1%.

681.142 **1420**

Automatic Computing Equipment at the N.P.L.—(*Engineering, Lond.*, 5th Jan. 1951, Vol. 171, No. 4432, pp. 6–8.) A general description, with illustrations, of the pilot model electronic computer known as ACE. It employs the binary system for the coding of data and instructions, the information being fed into standard Hollerith punched-card equipment. Calculating circuits are not described, but an account is given of the data-storage system, employing acoustic delay lines to circulate pulses continuously until required. Results are produced as punched cards or printed numerals. The equipment can deal with 900 million binary digits in a quarter of an hour. Programming and coding are relatively slow, but when these procedures have been carried out, extended computations may thereafter be performed with great rapidity. Equipment failure is usually readily recognizable, and servicing is facilitated by assembly in replaceable units.

681.142 : 511.2.004.4 **1421**

Digital Information Storage in Three Dimensions using Magnetic Cores.—J. W. Forrester. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 44–48.) An operating mode is suggested which depends on the ability of the magnetic material to discriminate between two magnetizing forces having a ratio of 2 : 1. Existing metallic magnetic materials have switching times of 20–10 000 μs and are too slow, but non-metallic magnetic materials of the ferrite type, with switching times $< 1\ \mu$s, are promising. See also 1422 below.

681.142 : 511.2.004.4 **1422**

Static Magnetic Memory for Low-Cost Computers.—M. Kincaid, J. M. Alden & R. B. Hanna. (*Electronics*, Jan. 1951, Vol. 24, No. 1, pp. 108–111.) A new principle in storage systems is described, employing a magnetic material, Deltamax. The hysteresis loop of this material is flat at top and bottom, giving two stable states suitable for the storage of information in binary form. A method is described by which binary digits may be fed serially into a set of Deltamax solenoid cores. No power is required during storage, nor is reshaping of pulses necessary. The method is also useful for transferring pulses between systems operating at different speeds, for use in pulse-counting systems, and for interconversion of parallel and serial sets of pulses.

518.3 **1423**

The Nomogram. [Book Review]—H. J. Allcock & J. R. Jones. Publishers: Pitman & Sons, London, 4th edn 1950, 238 pp., 18s. (*Wireless Engr*, Feb. 1951, Vol. 28, No. 329, p. 68.) "Little change has been made from the third edition published in 1941, except for the addition of a new chapter showing the connection between intersection and alignment nomograms. . . Strongly recommended to engineers, designers and research workers."

MEASUREMENTS AND TEST GEAR

389.2(94) : 621.396.91 **1424**

Time Signals for Scientific and Industrial Use.—(*Proc. Instn Radio Engrs, Aust.*, Dec. 1950, Vol. 11, No. 12, p. 316.) Commonwealth Observatory time signals, broadcast by Belconnen Naval Wireless Station, are now available by day and by night. Mean Time signals, of the American type, are emitted and measured during the Australian daytime, at 0025 to 0030 UT. They consist of a dot for every second of mean time. Modified rhythmic-type time signals are emitted during the Australian night, at 1025 to 1030, 1455 to 1500 and 1855 to 1900 UT. They give equally spaced intervals of 60/61 parts of one second of mean time and are comparable in accuracy with the Mean Time signal except that they are usually unattended during the transmission. Estimates of errors are given.

621.3.087.4 : 551.510.535 **1425**

The Panoramic Ionospheric Recorder.—R. Lindquist. (*Tellus*, Nov. 1949, Vol. 1, No. 4, pp. 37–43.) Description of a recorder covering the frequency range 1–20 Mc/s in 30 sec, with an output pulse power varying from 16 kW on the lowest frequency to 6 kW on the highest frequency. The results are presented on the screen of a 12-in. c.r. tube and recorded on 16-mm film. The short sweep time is particularly suitable for investigations in the polar regions, where ionospheric conditions often change rapidly. Only a single variable capacitor is used in the frequency sweep. Automatic tracking between receiver and transmitter is secured by means of a heterodyne system. Details are given of the different units of the equipment, with sample records obtained at Kiruna since the beginning of observations in July 1948.

621.317.3 : 538.569.4.029.64+621.317.335.3† **1426**

Microwave Measurements of the Dielectric Properties of Gases.—G. Birnbaum, S. J. Kryder & H. Lyons. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 95–102.) The resonance curves of two identical cavities were observed simultaneously on a c.r.o. The change in resonance frequency caused by the admission of a gas into one of the resonators was measured directly by superposing frequence markers on the resonance curves. The r.m.s. error in measuring $\epsilon' - 1$ for a lossless gas is estimated as 0·4%. The loss factor was measured by observing either the bandwidth of the cavity or the change in peak amplitude. Results obtained on O_2, N_2, CO_2, Ar, He, air, and NH_3 at 9 kMc/s are given.

621.317.329 **1427**

Plotting Electric Fields with the aid of Semiconducting Films.—W. Claussnitzer & H. Heumann. (*Z. angew. Phys.*, 10th Nov. 1950, Vol. 2, No. 11, pp. 443–446.) Discussion of a method using semiconducting sheets of graphite-impregnated paper on which copper electrodes are deposited by spraying through a suitable mask. Equipotential points are marked directly with a probe. Experimental results for a parallel-plate capacitor with plates of different sizes are in good agreement with theory.

621.317.329 : 538.311 **1428**

A Method for the Mapping of Vector-Potential Distributions in Axially Symmetrical Systems.—G. Liebmann. (*Phil. Mag.*, Nov. 1950, Vol. 41, No. 322, pp. 1143–1151.) Measurements in two electrolyte tanks, one with inclined bottom, can be used for the experimental determination of the magnetic field in a rotationally symmetrical system containing iron. From the basic equations of the sy tem, the form of the resistance networks required to set up the appropriate fields is derived. The networks are then used to determine the vector-potential distribution. The correctness of the method has been confirmed by experiments with a linear resistance strip. The method should have applications in the design of betatron and synchrotron magnets and in problems of machine design. See also 1988 of 1949 (Peierls & Skyrme).

621.317.335.3.029.6.083.4† **1429**

Principles of a Null Method for the Determination of Dielectric Constants at U.H.F.—M. Bruma. (*C. R. Acad. Sci., Paris*, 3rd Jan. 1951, Vol. 232, No. 1, pp. 42–44.) Theory of the method depending on the change of the resonance frequency of a cavity resonator when the test sample is introduced, the initial resonance frequency being restored by deformation of the resonator wall.

621.317.335.3.029.6.083.4† **1430**

Equipment for the Determination of Dielectric Constants at U.H.F. by a Null Method.—M. Bruma. (*C. R. Acad. Sci., Paris*, 15th Jan. 1951, Vol. 232, No. 3, pp. 219–221.) The general formula previously given (1429 above) can be simplified considerably in certain cases. A formula giving results accurate to within 1% is derived for the case in which the cavity is cylindrical, vibrating in the E_{010} mode, and the sample of dielectric, also cylindrical, is introduced along the axis. The initial resonance frequency before insertion of the dielectric is restored by displacement of a small metal cylinder projecting through the cavity wall either axially or in a direction normal to the axis.

621.317.42 **1431**

A Simple Means of Measuring Large Magnetic Fields.—G. K. T. Conn & B. Donovan. (*J. sci. Instrum.*, Jan. 1951, Vol. 28, No. 1, pp. 7–9.) Difficulties in applying the magnetoresistance effect in Bi to the measurement of magnetic fields have been overcome by using thin fibres of Bi drawn down in soda glass. The anisotropy of the Bi fibres limits the accuracy obtainable, but by etching the fibres and winding in tight coils the anisotropy is largely eliminated.

621.317.7.001.4 : 621.385.3 : 546.289 **1432**

Transistor Measurement Technique.—Mataré. (See 1533.)

621.317.733 **1433**

A Method of Decreasing the Effect of Earth Admittances in A.C. Bridges.—C. G. Mayo: G. H. Rayner. (*J. sci. Instrum.*, Jan. 1951, Vol. 28, No. 1, p. 24.) Comment on 1973 of 1950 (Rayner & Willmer) and author's reply.

621.317.755.029.5/.6 **1434**

An Experimental 'Stroboscopic' Oscilloscope for Frequencies up to about 50 Mc/s: Part 1—Fundamentals.—J. M. L. Janssen. (*Philips tech. Rev.*, Aug. 1950, Vol. 12, No. 2, pp. 52–59.) Describes the principle of stroboscopic examination of a h.f. voltage by mixing with phase-modulated pulses whose central repetition frequency is a submultiple of the frequency of the voltage to be examined. The pulses of anode current of the mixer valve produce 'snapshots' of the examined voltage; the low-frequency components of the anode current are filtered out and used for vertical trace deflection in a c.r. tube. The phase modulation scans the voltage over an adjustable region, and a stationary picture with linear time scale is obtained by using the same time function for the horizontal deflection as for the phase modulation, preferably a sinusoidal function at mains frequency. The effects of the gaps between pulses and of the finite pulse duration are considered.

621.317.755.029.5/.6 **1435**

An Experimental 'Stroboscopic' Oscilloscope for Frequencies up to about 50 Mc/s: Part 2—Electrical Build-Up.—J. M. L. Janssen & A. J. Michels. (*Philips tech. Rev.*, Sept. 1950, Vol. 12, No. 3, pp. 73–82.) Part 1: 1434 above. See also 949 of April (Janssen).

621.317.755 : 621.385.012 **1436**

Electronic Tracing of Tube Characteristics.—J. Arnold. (*Sylvania Technologist*, Jan. 1951, Vol. 4, No. 1, pp. 14–17.) Description, with block diagrams, of equipment for displaying in a few seconds on a c.r.o. complete families of valve characteristics.

621.396.615.001.4 : 621.396.611.21 **1437**

Progress in Development of Test Oscillators for Crystal Units.—L. F. Koerner. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 16–26.) Early test oscillators were principally duplicates of the actual equipment in which the crystals were to be used, but it is now recognized that a knowledge of the equivalent electrical elements of the crystal unit is essential. Modern test oscillators, with frequency and capacitance measuring apparatus as auxiliary equipment, which are used to determine the magnitudes of these elements and also the frequency characteristics are described. The transmission measuring circuit is proposed as a standard reference circuit for comparison with the test oscillator.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

531.787.6 : 621.38 **1438**

Diaphragm-Type Micromanometer for Use on a Mass Spectrometer.—V. H. Dibeler & F. Cordero. (*Bur. Stand. J. Res.*, Jan. 1951, Vol. 46, No. 1, pp. 1–4.) A detailed description, with full circuit details, of the instrument noted in 952 of April.

531.787.6 : 621.38 **1439**

An Electronic Circuit for Measuring the Displacement of Pressure-Sensitive Diaphragms.—M. L. Greenough & W. E. Williams. (*Bur. Stand. J. Res.*, Jan. 1951, Vol. 46, No. 1, pp. 5–10.) Description of apparatus depending on the change in the mutual inductance of a pair of coils due to a displacement of the diaphragm near which the coils are mounted. See also 1438 above.

534.321.9 : 534.232 **1440**

Ultrasonic Energy.—Crawford. (See 1291.)

534.321.9 : 620.179.16 **1441**

Supersonic Examination of Boiler Plate and Welded Seams.—(*Engineering, Lond.*, 5th Jan. 1951, Vol. 171, No. 4432, pp. 29–30.) Description of technique under investigation for routine testing in the works of Babcock & Wilcox, Renfrew. Ultrasonic pulses of frequency 2·25 Mc/s are sent through the plate under test and flaws are revealed by the existence of echo pips on the c.r. tube trace in addition to that corresponding to the echo from the back face. During the development stage of the technique, radiographic tests have also been carried out. The relative merits of the two methods are discussed briefly.

538.71 **1442**

Airborne Equipment for Geomagnetic Measurements.—L. H. Rumbaugh & L. R. Alldredge. (*Trans. Amer. geophys. Union*, Dec. 1949, Vol. 30, No. 6, pp. 836–848.) The equipment described is an AN/ASQ-3A magnetometer modified to permit mapping the contours of the total magnetic field over wide areas. The main features of the instrument system are: (*a*) a self-oriented magnetometer using the output of a system of saturable inductors to provide a d.c. signal whose noise level and drift rate are low; (*b*) instruments for helping the pilot to follow predetermined lines of a grid covering the area to be explored; (*c*) an interlocked group of recorders for automatically correlating a continuous magnetometer record with aeroplane position and altitude. The system has been used extensively by U.S. Government services. A shorter account was noted in 697 of 1950 (Schonstedt & Irons).

621.317.083.7 : 629.13.00.141 **1443**

A Multichannel P.A.M.-F.M. Radio Telemetering System.—J. P. Chisholm, E. F. Buckley & G. W. Farnell. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 36–43.) 1950 I.R.E. National Convention paper. The system, designed primarily for flight testing of pilotless aircraft, can provide up to 64 channels with a bandwidth per channel $>$ 800 c/s, or fewer channels with a correspondingly increased bandwidth. Frequency modulation of the transmitter is effected by a reactance switching technique and an overall linearity to within $\pm 1\%$ is obtained.

621.38+534.321.9].001.8 **1444**

Electronic Guiding Aids for Blind People.—R. L. Beurle. (*Electronic Engng*, Jan. 1951, Vol. 23, No. 275, pp. 2–7.) Desirable characteristics of guiding aids are discussed and various experimental aids are described, all of which provide aural indication. The instruments fall into three classes:—(*a*) operating by light pulses, distances of obstacles being derived by simple scanning of the transmitted beam, the receiver 'looking' in a fixed direction; (*b*) operating by ultrasonic waves of frequency 17–150 kc/s; binaural reception for direction indication was tried; (*c*) operating by sound-waves, an audible click being transmitted and the unaided ears used to detect the echoes. The results of the tests carried out indicate that no device which can be envisaged at present is likely to become popular with blind people.

621.38.001.8 : 786.6 **1445**

Gas-Diode Electronic Organ.—R. M. Strassner. (*Electronics*, Jan. 1951, Vol. 24, No. 1, pp. 70–74.) Details are given of the construction of an organ which uses Type-NE2 neon tubes in chains of sawtooth-wave generators whose frequencies are stabilized by twelve separately tuned master oscillators. Good tone quality is obtained by filtering out undesired harmonics.

621.384.6† **1446**

The Importance of Gas Scattering in Particle Accelerators.—L. Riddiford. (*Proc. phys. Soc.*, 1st Jan. 1951, Vol. 64, No. 373A, pp. 10–12.)

621.384.6† **1447**

Questions of Direction and Phase in Recently Developed Particle Accelerators.—R. Kollath. (*Elektron Wiss. Tech.*, Oct./Nov. 1950, Vol. 4, Nos. 10/11, pp. 383–392.)

621.384.611.1/.2† **1448**

A Note on Resonance Damping, at Injection, in Betatrons and Synchrotrons.—S. E. Barden. (*Proc. phys. Soc.*, 1st Jan. 1951, Vol. 64, No. 373B, pp. 85–86.)

621.384.612.1/.2† **1449**

Cyclotron and Synchrocyclotron.—W. de Groot. (*Philips tech. Rev.*, Sept. 1950, Vol. 12, No. 3, pp. 65–72.) A general account, introductory to a series of articles on the Amsterdam synchrocyclotron.

621.385.83 : 621.386.1 **1450**

An Electrostatic Focusing System and its Application to a Fine-Focus X-Ray Tube.—W. Ehrenberg & W. E. Spear. (*Proc. phys. Soc.*, 1st Jan. 1951, Vol. 64, No. 373B, pp. 67–75.)

621.385.833 **1451**

Schlieren Optics in the Electron Microscope.—H. König. (*Naturwissenschaften*, Nov. 1950, Vol. 37, No. 21, pp. 486–490.) An account of techniques particularly suitable for investigating crystal structure and magnetic-field patterns, including the methods developed by Marton & Lachenbruch (199, 967 and 1211 of 1950).

621.385.833 **1452**

Spider-Thread Grids for Electron Microscopy.—H. Dessens & C. Fert. (*C. R. Acad. Sci., Paris*, 12th Feb. 1951, Vol. 232, No. 7, pp. 606–608.) A description is given of the technique used in the preparation of a spider-thread grid supported on a small capsule with a central hole of diameter 0·5–1·0 mm for the passage of the electron beam. The diameter of the threads is sometimes < 100 Å; the use of these grids facilitates the detection and examination of very small particles.

621.385.833 **1453**

A Condenser Aperture Device for Electron Microscopes.—J. D. Boadway. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 104–105.) Description of a device for reducing spherical aberration without causing electron bombardment of large areas of the specimen under examination.

621.385.833 **1454**

Calculation of Optical Parameters of Magnetic Electron Lenses from the Dimensions of the Pole-Pieces and the Operating Characteristics.—F. Lenz. (*Z. angew. Phys.*, 10th Nov. 1950, Vol. 2, No. 11, pp. 448–453.) See also 705 of March.

621.385.833 **1455**

Theory of the Independent Electrostatic [electron] **Lens with Thick Central Electrode.**—É. Regenstreif. (*C. R. Acad. Sci., Paris*, 12th Feb. 1951, Vol. 232, No. 7, pp. 604–606.) Extension of theory given previously (1213 and 1743 of 1950).

621.385.833 **1456**

Potential and Field of a Particular Type of Cylindrical [electron] **Lens.**—É. Durand. (*C. R. Acad. Sci., Paris*, 22nd Jan. 1951, Vol. 232, No. 4, pp. 314–316.) A series of conformal transformations is used to calculate the potential and field of an e.s. lens formed by two parallel half-planes located between two infinite planes parallel to the first two but maintained at a different potential.

621.385.833 **1457**

Permanent-Magnet Electron Microscope.—J. H. Reisner & S. M. Zollers. (*Electronics*, Jan. 1951, Vol. 24, No. 1, pp. 86–91.) A simple and reliable instrument in which the magnetic fields required for focusing the electron beam are provided by permanent magnets of alnico V. Changeable pole-pieces enable magnifications of 1 500, 3 000 or 6 000 to be used. A resolution of 100 Å is obtained using an accelerating voltage of 50 kV, stabilized to one part in 10^4. The construction of the microscope is described in detail, with circuit and photographs.

621.385.833 **1458**

The Philips 100-kV Electron Microscope.—A. C. van Dorsten, H. Nieuwdorp & A. Verhoeff. (*Philips tech. Rev.*, Aug. 1950, Vol. 12, No. 2, pp. 33–51.) Describes in detail the construction and operation. The tube (20-cm screen) is mounted at an angle on a desk containing all the auxiliary equipment. Five water-cooled magnetic lenses, supplied with maximum currents of 100 mA in some cases and 400 mA in others, include a diffraction and an intermediate lens providing magnification variable from 1 000 to 60 000 times and quick change from a normal image to a diffraction diagram. The object plane lies in the gap between the pole pieces, thus permitting simple adjustment of the specimen. Forty photographs on 35-mm film are obtainable; a wobbling beam facilitates focusing. Accelerating voltage is 40, 60, 80, or 100 kV and is derived from a stabilized valve oscillator. Various attachments simplify the operation of the instrument.

621.385.833 : [537.212+538.122 **1459**

Experimental Determination of Fields by Marton's Electronic Method.—F. Bertein. (*C. R. Acad. Sci., Paris*, 5th Feb. 1951, Vol. 232, No. 6, pp. 491–493.) An explanation of Marton's method (199 and 967 of 1950) is given, based on the convergence properties of low-power thin lenses.

621.387.4† **1460**

Oversize Pulses in Vapour-Filled Counter Tubes.—E. Fünfer & H. Neuert. (*Z. Phys.*, 16th Nov. 1950, Vol. 128, No. 4, pp. 530–537.) See also 3121 of 1950.

621.387.4† **1461**

The Properties of Spark Counters of the Rosenblum Type.—R. D. Connor. (*Proc. phys. Soc.*, 1st Jan. 1951, Vol. 64, No. 373B, pp. 30–44.)

621.387.4† : 621.3.089.6 **1462**

Current Integration Circuits for Counter Tubes.—K. H. Lauterjung. (*Z. angew. Phys.*, 10th Nov. 1950, Vol. 2, No. 11, pp. 433–437.) Discussion of calibration methods for the thyratron- and the multivibrator-driven integrator.

621.398 **1463**

A New Inductance Method for Remote Indication of Tank Level.—J. M. Marzolf. (*Instruments*, June 1950, Vol. 23, No. 6, pp. 562–563.) Apparatus developed at the U.S. Naval Research Laboratory is described. The tank unit comprises a set of 48 coils wound in series on a vertically mounted plastics tube, the squares of the numbers of turns on successive coils forming an arithmetic progression. The inductance of the system varies linearly with the position of a cylindrical steel float which moves inside the tube. The measuring circuit is described and illustrated. Application is particularly for use on board ship.

PROPAGATION OF WAVES

538.566 : 535.51 **1464**

A Note on Ionospheric Radio Wave Polarization.—A. L. Aden, J. T. deBettencourt & A. T. Waterman, Jr. (*J. geophys. Res.*, March 1950, Vol. 55, No. 1, pp. 53–56.) Early papers on the magneto-ionic theory are cited as giving the impression that the major axis of the polarization ellipse for the ordinary ray is perpendicular to that for the extraordinary ray; this is not necessarily the case unless the effect of collisional friction is neglected. Analysis is presented to clarify the point.

538.566.2 **1465**

Theory of the Propagation of Electromagnetic Waves in an Atmospheric Duct.—T. Kahan & G. Eckart. (*Ann. Phys., Paris*, Vol. 5, Nov./Dec. 1950, pp. 641–705.) Complete analysis, with mathematical theory in two appendices (pp. 656–705). The principal results have been published previously (see 1466 and 1467 of 1949). The region above the duct is also considered. Here, for large angles of elevation, the field varies as $1/R$, where R is the distance from the dipole source, and tends linearly towards zero as $z \to h$, h being the height of the duct. In the region immediately above the dividing plane the field decreases exponentially with height. These two phenomena account for the existence of zones of silence.

538.566.2 : 551.52 **1466**

Some Meteorological Aspects of Radio-Duct Formation.—E. Knighting. (*Proc. phys. Soc.*, 1st Jan. 1951, Vol. 64, No. 373B, pp. 21–30.) Three problems of meteorological interest concerning the formation of radio ducts are treated. The first concerns the rate of growth of ducts, with special reference to ducts over the sea; ducts form quickly at first and then more slowly as the maximum duct width is approached. The second problem concerns the formation of ducts under conditions of nocturnal cooling; there is a limit to the height which the duct may attain. The third problem concerns the width of a radio duct necessary to enclose the track width of a mode associated with a propagated signal of wavelength λ, assuming a power law of modified refractive index with height; the necessary width is proportional to $\lambda^{2/3}$, and the factor of proportionality, which depends upon the index in the assumed power law, is calculated.

The three problems have a common meteorological basis, for each is concerned with turbulent motion near the earth's surface. The law of turbulent diffusion assumed here is that the coefficient of eddy diffusion is proportional to a power of the height, following the theory developed by O. G. Sutton and others.

621.396.11 **1467**

Asymmetry in Wave Propagation: Study of Non-reciprocity observed on the Two-Way Paris/Algiers Link.—P. Niguet. (*Onde élect.*, Dec. 1950, Vol. 30, No. 285, pp. 533–541.) Curves of the received field strength throughout the day at the two ends of the link, for nearly equal operating wavelengths (12·105 Mc/s in the southward and 12·12 Mc/s in the northward direction), show marked differences, which vary in magnitude with the season, being large in September and decreasing with the approach of winter. The discrepancy is investigated theoretically; formulae are developed for determining the paths of the refracted and reflected beams in an ionosphere of complex structure, taking into account that the ionization gradient has a horizontal as well as a vertical component. In the vertical plane the lines of equal ionization are deformed parabolas on a circular axis, the arms extending southward and approaching asymptotically the limit circles of the ionized region; this is shown to cause the asymmetry in propagation.

621.396.11 : 517.942.72 **1468**

Associated Legendre Polynomial Approximations.—Landauer. (See 1415.)

621.396.11 : 523.75 : 551.510.535 **1469**

Ionospheric Effects of Solar Flares.—R. Lindquist. (*Acta polyt., Stockholm, Elect. Engng Series*, 1950, Vol. 2, No. 9; *Chalmers tekn. Högsk. Handl.*, 1950, No. 95, 11 pp. In English.) Presentation of fade-out observations recorded during the period July 1948–June 1949 at Gothenburg. See also 619 of 1950 (Rydbeck & Stranz).

621.396.11 : 551.510.535 **1470**

Ionospheric Storms and Radio-Circuit Disturbances.—C. M. Minnis. (*Wireless Engr*, Feb. 1951, Vol. 28, No. 329, pp. 43–51.) "The importance of distinguishing between forecasts of radio-circuit disturbances and ionospheric or magnetic storms is emphasized. Varying amounts of advance warning are given by different precursors of storms and the consequent logical division of storm warnings into the long- and short-range and immediate-warning categories is explained. The more important storm precursors are discussed, but it is concluded that none of them alone can be used as a reliable basis for making forecasts. The problem of forecasting reduces to a statistical one which cannot immediately be solved because the necessary data do not exist. Empirical methods must therefore be used; these would become more reliable if more were known of the physical processes in the sun responsible for the emission of storm-causing radiation and of the subsequent development of the storm effects both in time and over the earth's surface."

621.396.11 : 551.510.535 **1471**

Longitudinal and Transverse Propagation in Canada.—J. C. W. Scott. (*J. geophys. Res.*, March 1950, Vol. 55, No. 1, pp. 65–84.) The Canadian ionosphere is complicated by the presence of the geomagnetic pole and the auroral zone. The apparent terrestrial magnetic field in the ionosphere, as calculated from measured critical-frequency differences for the extraordinary and ordinary modes, shows large diurnal and seasonal variations. The longitudinal mode, which is often observed in high magnetic latitudes, gives a field consistently different from that of the transverse mode. These results are explained as due to deflections of the energy path from the vertical in conjunction with variations of the horizontal ionization gradients. The direction of the complex Poynting vector is calculated for the different modes. The westward component of the deflection of the longitudinal ordinary mode is shown to be as large as the north-south deflection.

621.396.11 : 621.317.353.3† **1472**

Some Further Investigations of Ionospheric Cross-Modulation.—I. J. Shaw. (*Proc. phys. Soc.*, 1st Jan. 1951, Vol. 64, No. 373B, pp. 1–20.) Measurements of the phase and percentage depth of the modulation transferred to an unmodulated wanted wave by a modulated disturbing wave, together with simultaneous measurements of the height of reflection of the wanted wave, lead to a value of $1{\cdot}4 \times 10^6$ per sec for the collision frequency of electrons with gas molecules at a height of 92 km. Calculations of the percentage depth of transferred modulation to be expected with given pairs of transmitters, using formulae derived theoretically, are in most cases in good agreement with experimental values, both for vertical and for oblique incidence. No increase in cross-modulation is observed when the disturbing transmitter operates on the local gyro-magnetic frequency. At sunrise the percentage depth of transferred modulation is observed to decrease in all cases. These facts are discussed with reference to a modification of the theory previously given [3219 of 1948 (Ratcliffe & Shaw)].

621.396.11.029.45/.51 : 551.594.6 **1473**

The Use of Atmospherics to Study the Propagation of Very Long Radio Waves.—F. F. Gardner. (*Phil. Mag.*, Dec. 1950, Vol. 41, No. 323, pp. 1259–1269.) The mean level (integrated over one minute) of atmospherics received on narrow-band receivers tuned to frequencies between 3·5 and 50 kc/s was recorded at Cambridge during 1948 and 1949. The results are analysed so as to eliminate the unknown spectral distribution of energy at the source. The attenuation suffered by radio waves from a distant source is deduced; this is large for frequencies below 10 kc/s and is greater during daylight than at night for all frequencies. The quasi-sinusoidal waveform often assumed by atmospherics is related to the frequency cut-off at 10 kc/s.

The level of atmospherics on frequencies below 10 kc/s decreases during sudden ionospheric disturbances. This contrasts with the known increase on frequencies above about 20 kc/s.

621.396.11.029.51 : 535.312 : 551.510.535 **1474**

Ionospheric Reflection of Very Long Radio Waves.—J. P. Stanley. (*Canad. J. Res.*, Nov. 1950, Vol. 28, Sec. A, No. 6, pp. 549–557.) The simplified model of the long-wave-reflecting region of the ionosphere previously considered (974 of April) is used to calculate the theoretical variation of the sky-wave reflection coefficient with angle of incidence and with the angle of dip of the earth's magnetic field. The curves obtained are in good agreement with experimental results. The assumption of a vertical magnetic field should not lead to errors in estimates of the vertical-incidence sky-wave reflection coefficient greater than about 10%, even though the field is actually inclined to the vertical at an angle of as much as 23°.

621.396.11.029.62 **1475**

Effective Earth's Radius for Radiowave Propagation beyond the Horizon.—W. Miller. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 55–62.) The ideas of geometrical optics, on which calculations of the equivalent radius of the earth for radio-wave propagation are based, are extended to non-horizontal rays. The appropriate wave equation for a nonuniform, but spherically symmetrical, region is derived and a solution obtained in terms of a Green's function. The formal solution includes the known solutions for a uniform medium. For the non-uniform case, the solutions of the radial equation are found by a technique due to Langer. The functions involved account for the variation of refractive index near the surface of the earth without making unwarranted assumptions about the variation at greater heights. The formal series obtained is summed by the Watson technique. The first term in this series (lowest mode) alone determines the field at large distances and indicates that standard atmospheric refraction may be accounted for by assuming an effective radius for the earth.

621.396.81 : 621.3.018.41(083.74) **1476**

Reception of WWV Standard-Frequency Transmissions.—W. Ebert. (*Tech. Mitt. schweiz. Telegr.-TelephVerw.*, 1st Dec. 1950, Vol. 28, No. 12, pp. 457–482. In German and French.) Observations were made at Châtonnaye, Switzerland, of the reception of WWV standard-frequency transmissions over the period 15th February 1946–8th July 1949 for 2·5, 5, 10 and 15 Mc/s, and 22nd December 1946–8th July 1949 for 20, 25, 30 and 35 Mc/s. The receiving site and equipment are described. Signal strengths were measured at every even hour on all the frequencies; results are presented in charts. Short-wave propagation conditions are discussed with reference to the structure of the ionosphere. Maximum usable and optimum working frequencies are determined for distances > 4 000 km, and observed and predicted values are compared.

621.396.812.5 **1477**

Investigation of Phenomena connected with Mögel-Dellinger Effects.—F. Schindelhauer & E. A. Lauter. (*Z. Met.*, July/Aug. 1950, Vol. 4, Nos. 7/8, pp. 243–245.) Analysis of observation of sudden s.w. fade-outs and associated geomagnetic disturbances, particularly those of 28th June and 13th September 1949, indicates that (*a*) in most cases long-wave reflection occurs only a few minutes after the onset of s.w. fading; (*b*) some of the effects observed [see 716 of 1950 (Lauter)] are not connected with s.w. fade-outs but are rather traceable to reflection of long waves and slight increases in the limiting frequency for the D layer.

RECEPTION

621.396.11.029.45/.51 : 551.594.6 **1478**

The Use of Atmospherics to Study the Propagation of Very Long Radio Waves.—Gardner. (See 1473.)

621.396.621 : 621.396.619.13 **1479**

Detector Circuits for Frequency-Modulation Receivers: Part 2.—C. J. Boers. (*Fernmeldetech. Z.*, Dec. 1950, Vol. 3, No. 12, pp. 458–465.) Particular types of discriminator circuit are described. Part 1: 2880 of 1950.

621.396.621 : 621.396.931 **1480**

Adjacent-Channel-Rejection Receiver.—H. Magnuski. (*Electronics*, Jan. 1951, Vol. 24, No. 1, pp. 100–104.) Flat-topped selectivity curves for adjacent-channel rejection may be obtained by the use of a passive band-pass filter between a low-gain input and mixer unit and a nonselective high-gain amplifier. Advantages include high stability of gain and selectivity for a wide range of input signal amplitudes, freedom from intermodulation and image interference, and good signal/noise ratio.

621.396.621.54 **1481**

Gain-Doubling Frequency Converters.—V. H. Aske. (*Electronics*, Jan. 1951, Vol. 24, No. 1, pp. 92–96.) Approximately twice the normal conversion transconductance can be obtained from a pentode mixer by applying the signal to the control grid and the local oscillation to the suppressor, with the tuned i.f. circuit between the anode and screen grid. Performance figures verifying this are given for push-pull and single-valve mixer circuits. The method also gives more effective rejection of i.f. signals and a smaller equivalent noise resistance. The principle can be applied in a converter valve combining the functions of mixer and local oscillator. The design of such a stage for the broadcast band is described and its performance characteristics are compared with those of a conventional circuit.

621.396.621.54 **1482**

Comments on Interelectrode Feedback in Frequency Changers: Part 1.—B. G. Dammers & J. Otte. (*Philips tech. Commun., Aust.*, 1950, No. 5, pp. 13–19.) Discussion of the general formulae for frequency changers and also of the influence of anode/grid capacitance of the modulator section on amplification and selectivity.

621.396.82 : 621.315.1 **1483**

A New Locator of Sources of R.F. Interference affecting Overhead Electrical Lines.—J. Meyer de Stadelhofen. (*Tech. Mitt. schweiz. Telegr.-TelephVerw.*, 1st Dec. 1950, Vol. 28, No. 12, pp. 482–485. In French.) A locating device which indicates the direction of propagation of interfering energy is based on determination of the sign of the vector expression $|\vec{U} + \vec{I}| - |\vec{U} - \vec{I}|$, where $\vec{U}$ is the interfering h.f. voltage between earth and the group of conductors considered, and $\vec{I}$ is the current produced in a section of the line by $\vec{U}$. Voltages proportional to $\vec{U}$ and $\vec{I}$ are obtained by means of a CR potential divider and a loop pickup respectively. The arrangement can be used also as a reflection-coefficient indicator. A laboratory prototype is described; this has given excellent service over several months under varied conditions.

STATIONS AND COMMUNICATION SYSTEMS

621.39.001.11 **1484**

Communication Theory and Physics.—D. Gabor. (*Phil. Mag.*, Nov. 1950, Vol. 41, No. 322, pp. 1161–1187.) Full paper. Abridged version abstracted in 208 of January.

621.394/.395 : 621.396.619.13 **1485**

Frequency Modulation for Line Transmission.—G. Hässler. (*Fernmeldetech. Z.*, Dec. 1950, Vol. 3, No. 12, pp. 445–454.) Two important applications are: (*a*) telephony via h.v. lines; (*b*) a.c. telegraphy. Interference and distortion in these systems are investigated quantitatively. The advantages obtainable from the use of f.m. within the restricted frequency band available are discussed.

621.395.813 : 621.39.001.11 **1486**

Application [to signal and information theory] **of Means Used for Assessing the Quality of Telephone Transmission.**—P. Chavasse. (*Ann. Télécommun.*, Dec. 1950, Vol. 5, No. 12, pp. 427–440.) Paper included in the symposium on Signal and Information Theory held in Paris, April–May 1950. The transmission of ideas is discussed to some extent subjectively. On the basis of established phonetic theory it is possible to predict the quality of a transmission from a knowledge of the characteristics of the telecommunication system used and of the properties of the human voice and ear. The C.C.I.F. is experimenting with methods for designating by a single number the effect of a complex of factors on the ease with which a telephone conversation can be carried on. The intelligibility of different languages is considered.

621.396.619.16 : 519.283 **1487**

An Application of Autocorrelation Analysis.—E. R. Kretzmer. (*J. Math. Phys.*, Oct. 1950, Vol. 29, No. 3, pp. 179–190.) Analysis of the spectrum of the interference produced in pulse-time modulation systems (e.g. pulse-duration and pulse-position modulation) by random disturbances. The relation between the autocorrelation function and power-density spectrum is established and applied to a pulse sequence in which one or both edges of each pulse undergo random time shifts, or in which pulses are randomly missing. Besides giving the power and spectral distribution of the noise, the analysis also throws some light on the nature of random time modulation. For example, it shows that the time-shift noise is generated at the expense of the h.f. components of the pulse-train spectrum and permits exact calculation of this exchange of power. The autocorrelation method used should prove very useful in the increasing applications of statistical theory to communications.

621.396.619.16 : 621.3.018.078† **1488**

Quantization Distortion in Pulse-Count Modulation with Nonuniform Spacing of Levels.—P. F. Panter & W. Dite. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 44–48.) 1949 I.R.E. National Convention paper. The distortion introduced in a pulse-count-modulation system due to quantization can be minimized by nonuniform spacing of levels. Equations are derived for an arrangement of levels resulting in minimum distortion. When the crest factor of the signal is > 4, minimum distortion is significantly less than distortion resulting from uniform quantization.

621.396.65 : 621.396.619.13 : 621.3.018.78† **1489**

Distortion in Multichannel Frequency-Modulation Relay Systems.—L. E. Thompson. (*RCA Rev.*, Dec. 1950, Vol. 11, No. 4, pp. 453–464.) Design formulae are given relating intermodulation to the harmonic distortions produced by the modulator and discriminator and by phase nonlinearity in tuned circuits, with experimental confirmation and an example of their application.

621.396.712.006 **1490**

Optimum Spacing of Broadcast Transmitters.—D. C. Espley. (*Wireless Engr*, Feb. 1951, Vol. 28, No. 329, pp. 37–39.) "It is known that the interference range of a radio transmitter extends, to some extent, beyond the limits of the effective service area. This note gives the unique solution of the geometrical problem in which it is desired to know the number of different stations necessary to cover an unlimited territory for a given ratio of service range to interference range. The shape and extent of a finite territory have some effect on this number."

621.396.97 : 621.396.66 **1491**

The Broad Principles in the Design of Automatic Monitors.—H. B. Rantzen, F. A. Peachey & C. Gunn-Russell. (*Electronic Engng*, Jan. 1951, Vol. 23, No. 275, pp. 19–27.) The purpose of an automatic monitor is to call attention to a transmission imperfection of such magnitude that a normal listener would be disturbed by it, while neglecting minor defects which are normally corrected by routine maintenance tests. Two types of equipment are described. The simpler type, the Minor, is used on programme links where both the reference programme and the programme to be monitored are available at one point. The Major type is designed for use on long-distance circuits where the reference and monitored programmes are only available at opposite ends of the system. The operation of the two types is described with the aid of block diagrams. The installation of these monitors has already resulted in a considerable economy in skilled personnel; they have particular advantages for unattended stations. Some experiments on the application of automatic monitoring to recording processes are briefly described.

SUBSIDIARY APPARATUS

621.316.722.078.3 **1492**

A Low-Power Alternating-Voltage Stabilizer.— D. J. R. Martin & A. J. Maddock. (*J. sci. Instrum.*, Jan. 1951, Vol. 28, No. 1, pp. 1–3.) "A unit is described providing an a.c. output at 15 V (pre-set within the range 12–18 V) and possible current drain of 2 mA; its main use would be as a source of stable reference voltage, for the efficiency of the system is inherently low and the output voltage is sensitive to load variations. A change of alternating input voltage between 190 and 270 V (i.e. 230 ± 17%) produces ± 0·015 V (± 0·1%) change in output voltage. Temperature compensation is provided and the frequency coefficient and waveform distortion are both small."

621.355.2+621.355.8 **1493**

Accumulators for Very Low Temperatures.—H. Mandel. (*Elektron Wiss. Tech.*, Dec. 1950, Vol. 4, No. 12, pp. 412–416.) German version of 2904 of 1950.

TELEVISION AND PHOTOTELEGRAPHY

621.397.335 **1494**

Improved Vertical Synchronizing System.—R. C. Moses. (*Electronics*, Jan. 1951, Vol. 24, No. 1, pp. 114–118.) The conventional integration method for segregation of frame synchronizing pulses does not achieve accurately timed triggering of the line-deflection oscillator. A new method described uses a RC differentiating network. The relatively long frame-synchronizing pulses undershoot the pulse base-line after differentiation. Subsequent rectification and amplification provide a train of sharply rising pulses which can be used for frame synchronization at a rigidly controlled instant.

621.397.5+778.5 **1495**

Some Comparative Factors of Picture Resolution in Television and Film Industries.—H. J. Schlafly. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 6–10.) Discussion of the meaning given to the term 'resolution' in the television and film industries. Limiting values of resolution, however defined, should not be regarded as the sole measure of picture quality.

621.397.5 : 621.396.619.16 **1496**

Television by Pulse Code Modulation.—W. M. Goodall. (*Bell Syst. tech. J.*, Jan. 1951, Vol. 30, No. 1, pp. 33–49.) 1949 I.R.E. National Convention paper. In a p.c.m. system, the information signal is periodically sampled and its instantaneous amplitude described by a group of pulses according to a pre-set code. These pulse groups occur at the sampling rate and constitute the transmitted signal. In this process an operation known as amplitude quantization is required. Time sampling, amplitude quantization, binary coding and decoding of a television signal, and the operation of the equipment used to perform these functions, are described. The results obtained with an experimental system for different numbers of digits (i.e. maximum number of pulses per group) from one to five are illustrated by photographs. The television signal used in these tests was obtained from a special low-noise film scanner. As was expected, the number of digits required depends upon the amount of noise in the test signal.

621.397.5 : 621.396.68(083.74) **1497**

Standards on Television: Methods of Measurement of Electronically Regulated Power Supplies, 1950.—(*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 29–35.) Reprints of this Standard, 50 IRE 23.S3, may be obtained, while available, from I.R.E. at $0.75 per copy.

621.397.611.2 **1498**

The Formation of the Signal in Pickup Tubes. The Conductron.—W. Veith. (*Le Vide*, Nov. 1950, Vol. 5, No. 30, pp. 887–895.) In the conductron a magnetically deflected scanning beam is passed through a focusing and retarding electric field on to a semiconducting target of CdS backed by a thin transparent metal plate which receives the light. The semiconducting layer is photosensitive, its resistance increasing with brightness. Optimum layer thickness and operating conditions are discussed. Sensitivity and storage capacity are compared with those of the supericonoscope, the image orthicon and the vidicon [2040 of 1950 (Weimer et al.)].

621.397.611.2 : 537.533.8 **1499**

Secondary Emission and Application to the Design of a Television Analyser.—R. Barthélemy. (*Onde élect.*, Dec. 1950, Vol. 30, No. 285, pp. 499–509.) Methods are described for the measurement of secondary emission from conducting and from insulating targets, and the distribution of secondary-emission velocities is investigated. An analytical expression is derived for the variation with time of the potential of the target in a capacitive signal-plate assembly. The processes by which the signal voltage is produced in a supericonoscope are examined and the operating conditions under which space charge becomes effective are discussed. The reasons for the relatively recent introduction of thin insulating targets are explained; beyond certain limits further reduction of thickness produces no advantage. An expression is derived from which the sensitivity can be stated in μA/lumen; sensitivity depends on the mean voltage at which the target is maintained.

621.397.611.21 : 537.533.8 **1500**

Measurement of the Secondary Emission from Insulators.—Barthélemy. (See 1511.)

621.397.621.2 **1501**

Low-Reflection Picture Tubes.—G. S. Szegho, M. E. Amdursky & W. O. Reed. (*Electronics*, Jan. 1951, Vol. 24, No. 1, pp. 97–99.) A process is described by which unwanted reflections from the face plates of metal-cone c.r. tubes can be much reduced. The plate surface is first etched, either chemically or by spraying with a liquid in which abrasive material is suspended. It is then treated with hydrofluoric acid to restore satisfactory transmission characteristics. Results are given of comparative tests of the reflection of treated and untreated surfaces.

621.397.621.2 **1502**

The Optimum Use of Picture Tubes.—W. B. Whalley. (*Sylvania Technologist*, Jan. 1951, Vol. 4, No. 1, pp. 9–13.) The principal circuit factors affecting the performance of c.r. television tubes are discussed and methods of investigation are outlined which assist in attaining optimum performance.

621.397.8 : 535.371.07 **1503**

Flicker in Television Pictures.—J. Haantjes & F. W. de Vrijer. (*Wireless Engr*, Feb. 1951, Vol. 28, No. 329, pp. 40–42.) The effects of (*a*) distance from picture to observer (measured in frame-height units), (*b*) frame frequency, (*c*) phosphor decay time, on critical high-light brightness for flicker to be observable are shown in curves.

About 10 different observers were used. With normal pictures at 50 frames/sec on a sulphide screen with 0·1-ms decay time, critical brightness was about 12 foot-lamberts at 6 frame-heights, and 30 at 14, about five times higher than with blank raster. With a screen of willemite (decay time 13 ms) with admixture of a short-persistence blue phosphor, these values were improved to about 56 and 136 respectively. At 60 frames/sec on a sulphide screen, critical brightness was about four times higher than at 50 frames/sec, and about 5·5 times higher for a silicate screen with decay time 5 ms. Ambient illumination had little influence on the results.

621.397.828 **1504**

Interference Suppression Circuits.—W. I. Flack. (*Elect. Radio Trading*, Jan. 1951, Vol. 23, No. 254, pp. 75–78.) Reviews basic and popular ignition-interference suppression circuits used in the vision and sound channels of television receivers. Sound-channel interference suppression is considered most important. Various circuits used in Murphy receivers are discussed.

621.397.9 **1505**

Industrial Television.—V. K. Zworykin. (*Electronic Engng*, Jan. 1951, Vol. 23, No. 275, pp. 8–11.) A general article indicating the broad scope of television applications within industry. The design of standardized equipment suitable for many applications is outlined. It comprises a highly sensitive and compact camera, connected by 500 ft of cable to a receiver-monitor which includes controls and power supplies for the camera. The possibilities of stereoscopic and colour television for industrial purposes are briefly mentioned.

TRANSMISSION

621.396.4 **1506**

Simultaneous Feeding of an Aerial from Two Transmitters of 100 and 20 kW [respectively] **at the Toulouse-Muret Station.**—M. Merlet. (*Onde élect.*, Dec. 1950, Vol. 30, No. 285, pp. 522–527.) The reconstruction of the French transmitting-station network to provide alternative programmes has been proceeding since 1944, and in view of the high cost of aerial installations (e.g., 25 million francs in 1950 for a 220-m pylon) a single aerial is being used for two or more transmitters where possible. A trial was made at the Muret station, where a 100-kW transmitter was already operating on 913 kc/s with a 120-m mast; a new 20-kW transmitter on 1·339 Mc/s was added. The feeder arrangements are described in detail; measurements indicate that they satisfy the conditions (*a*) that the impedance presented by the aerial to one of the transmitters at its operating frequency must not vary by more than 2% when the other transmitter is connected, and (*b*) that the voltage induced by one transmitter in the oscillating circuit of the other must not exceed a thousandth of the carrier voltage of the latter. Difficulties encountered in the actual installation are described. The cabins provided for the matching and filter networks should be spacious to reduce undesired capacitances. An appendix gives a simple graphical method for determining the impedance of two elements connected in parallel.

621.396.4 : 621.396.82 **1507**

Theoretical Study of Cross-Modulation resulting from the Simultaneous Excitation of an Aerial by Two Transmitters.—V. Familier. (*Onde élect.*, Dec. 1950, Vol. 30, No. 285, pp. 528–532.) The cross-modulation is calculated by the following steps:—(*a*) derivation of an expression for the composite voltage e_c applied to the class-C power valve of the disturbed transmitter; (*b*) simulating the valve characteristic by a broken straight line, part of which coincides with the voltage axis; (*c*) representation of this characteristic by a finite power series of e_c, (*d*) determination of the coefficients of this series from a set of linear equations. From the general formula thus established, the cross-modulation is shown to vary approximately as the square of the ratio of undesired to desired voltage; this is fairly well confirmed by experiment.

VALVES AND THERMIONICS

537.533.8 **1508**

A Pulse Method of Determining the Energy Distribution of Secondary Electrons from Insulators.—McKay. (See 1347.)

537.533.8 **1509**

Secondary Emission of Nickel-Barium Mixtures and Rhenium when Bombarded by Electrons with Energies from 50 to 8 000 Electron-Volts.—Farnsworth & Lun. (See 1399.)

537.533.8 : 621.397.611.2 **1510**

Secondary Emission and Application to the Design of a Television Analyser.—Barthélemy. (See 1499.)

537.533.8 : 621.397.611.21 **1511**

Measurement of the Secondary Emission from Insulators.—R. Barthélemy. (*C. R. Acad. Sci., Paris*, 3rd Jan. 1951, Vol. 232, No. 1, pp. 20–22.) A method is described which has been used for determining the distribution of initial velocities of secondary electrons emitted by the target of a television pickup tube.

537.58 : 621.385.032.213 **1512**

Certain Refractory Components as Thermionic Emitters.—Goldwater & Haddad. (See 1400.)

621.383.42 **1513**

Characteristics of Selenium Photocells.—P. T. Landsberg. (*Proc. phys. Soc.*, 1st Jan. 1951, Vol. 64, No. 373B, pp. 82–83.) Preston's (3199 of 1950) experimental reverse-current characteristics for Se with a sputtered layer of ZnO are in excellent agreement with those obtained when Landsberg's theory (465 of 1950) is applied to a Schottky barrier. Analysis of Preston's results shows that the mobility of current carriers decreases with increasing thickness of the ZnO layer.

621.385 : 537.525.92 **1514**

The Distribution of Space Charge in Thermionic Valves.—M. Matricon & S. Trouvé. (*Onde élect.*, Dec. 1950, Vol. 30, No. 285, pp. 510–521.) Langmuir's rigorous derivation of formulae expressing cathode current as a function of anode voltage for simple electrode systems is summarized; the current at the cathode surface can be expressed in a form common to parallel-plane, cylindrical and spherical arrangements by introducing a term λ which depends on the proportions rather than the absolute dimensions of the electrodes. The formulae derived may be applied to systems with any configuration by adjusting the value of λ. The case of a filamentary cathode parallel to but not coaxial with the anode is examined, making the simplifying assumption that the shapes of the equipotentials are the same in the absence and presence of space charge, though the levels differ; simple conformal transformations are used to determine these shapes. Experimental results are reported for this case; they are in satisfactory agreement with the approximate formulae. Other commonly used cathode arrangements are also investigated theoretically.

621.385 : 621.318.572.004.6 **1515**

Electrode Deterioration in Transmit-Receive Tubes.—J. C. French. (*Bur. Stand. J. Res.*, Oct. 1950, Vol. 45, No. 4, pp. 310–315.) The glow discharge maintained in a Type-1B24 t.r. tube develops momentary arcs which disintegrate the cathode, so that deposits of cathode material short-circuit cathode and anode. This effect was studied with actual tubes and experimental diodes. Recommendations are: to reduce distributed capacitance, to avoid pulsed operation when permissible, to use low cathode-current density, to avoid water vapour or active gas, and to use 18-8 stainless steel in place of kovar as cathode material.

621.385.012 : 621.317.755 **1516**

Electronic Tracing of Tube Characteristics.—Arnold. (See 1436.)

621.385.012.6 **1517**

Electron Tube Performance with Large Applied Voltages.—A. E. S. Mostafa. (*Proc. Inst. Radio Engrs*, Jan. 1951, Vol. 39, No. 1, pp. 70–73.) An analytical treatment based on the transconductance characteristic instead of on the anode-current/grid-voltage characteristic. By choosing a certain function and its Fourier expansions over a suitable interval of the characteristic, the analysis of valves with large applied voltages is simplified. Experimental verification is carried out for a triode.

621.385.029.63/.64 **1518**

Theory of the Travelling-Wave Valve.—W. Frey & F. Lüdi. (*Z. angew. Math. Phys.*, 15th July 1950, Vol. 1, No. 4, pp. 237–247.) An equivalent circuit is used to deduce the characteristic impedance of the helix, for purposes of comparison with the klystron and the triode. With the klystron and the travelling-wave valve a shot effect is induced in the amplifier input, but not with the triode, so that increase of their transconductance does not result in a reduction of the noise factor as in the case of the triode. For the same beam current the noise factor is about the same for the klystron and the travelling-wave valve, but the latter has the advantage that for the same beam length the gain is greater, as it increases exponentially with the beam length, while in the klystron it increases linearly. It should be possible to improve considerably the signal/noise ratio of the klystron type of amplifier by increasing the beam length, e.g. by magnetic means. A resulting advantage would be the decoupling of input and output; in the case of the travelling-wave valve this leads to oscillation if the helix is not matched so as to avoid reflections.

621.385.029.64/.65 **1519**

Medium-Power Traveling-Wave Tube Type 5929.—J. H. Bryant. (*Elect. Commun.*, Dec. 1950, Vol. 27, No. 4, pp. 277–279.) A helix type of valve for operation in the band 4·4–5·0 kMc/s, with a gain of 20 db and power rating of 10 W. Waveguide input and output systems are used.

621.385.029.64 **1520**

A Survey of Modern Radio Valves: Part 6—Valves for use at Frequencies above 3 000 Mc/s.—W. J. Bray. (*P.O. elect. Engrs' J.*, Oct. 1950 & Jan. 1951, Vol. 43, Parts 3 & 4, pp. 148–153 & 187–191.) The principles of operation, methods of construction and characteristics of u.h.f. low-power oscillator and amplifier valves are described, including klystron oscillators and amplifiers, travelling-wave and electron-wave amplifiers, grounded-grid triode amplifiers and c.w. magnetrons. The suitability of the oscillators for a.m., f.m. or p.m. is considered. Part 5: 3201 of 1950 (White).

621.385.029.64/.65 **1521**

Amplification at 6-Millimeter Wavelength.—J. B. Little. (*Bell Lab. Rec.*, Jan. 1951, Vol. 29, No. 1, pp. 14–17.) Describes a travelling-wave valve amplifier with a gain of about 4 db near 6-mm wavelength, designed by scaling down a 4-kMc/s valve. Axial spacing rods were eliminated, input and output waveguides made part of the valve envelope, and a special matching method was used. The helix was wound with 0·003-in. wire on a 0·030-in. mandril and stretched to 0·0065-in. pitch. Preliminary tests are briefly described and a gain/wavelength curve is shown.

621.385.032.21 : 539.16 **1522**

The Use of Radioactive Elements in the Study of Oxide Cathodes.—J. Debiesse, J. Challansonnet & G. Neyret. (*C. R. Acad. Sci., Paris*, 12th Feb. 1951, Vol. 232, No. 7, pp. 602–604.) Experiment shows that it is possible to prepare cathodes emitting β and γ radiation (period 5·3 years) by subjecting Ni electrodes containing a small proportion of Co to neutron irradiation. The resultant activity affords an extremely sensitive quantitative method of estimating the amount of Co in Ni alloys.

621.385.032.213 **1523**

Emissivity Changes of Thoria Cathodes.—O. A. Weinreich. (*J. appl. Phys.*, Dec. 1950, Vol. 21, No. 12, pp. 1272–1275.) The variations with time of thermionic emission and spectral emission of a thoria-coated tungsten filament are dependent on its previous heat treatment and on the electron current which is being drawn from it. Experimental results are presented in a series of curves. The relation between emissivity and thermal activation is discussed in terms of impurities produced during the heat treatment, such as free thorium and possibly a thorium sub-oxide.

621.385.032.213 : 669.27 : 621-42 **1524**

Preliminary Treatment of Tungsten Wire for Electronic Valves.—Mesnard & Uzan. (See 1412.)

621.385.032.216 **1525**

Optical Pyrometry of Oxide Cathodes: Measurement of Spectral Emissive Power.—R. Champeix. (*Le Vide*, July/Sept. 1948, Vol. 3, Nos. 16/17, pp. 469–479.) A reflectometer method is described. See also 2973 of 1948.

621.385.032.216 **1526**

Deterioration of Oxide-Coated Cathodes under Low-Duty-Factor Operation.—J. F. Waymouth, Jr. (*J. appl. Phys.*, Jan. 1951, Vol. 22, No. 1, pp. 80–86.) The oxide coatings were deposited on a Ni alloy containing about 0·1% Si. At zero duty-factor the operation of these cathodes favoured the development of high resistance in a layer of Ba_2SiO_4 located at the interface between the oxide and the core. This layer was present in cathodes aged without or with electron emission. A possible explanation of the observations is suggested. Evidence is presented which indicates that an 'active' Ni alloy may exist which does not lead to the development of undue interface resistance.

621.385.032.216 **1527**

Oxide-Cathode Base-Metal Studies.—R. Forman & G. F. Rouse. (*Bur. Stand. J. Res.*, Jan. 1951, Vol. 46, No. 1, pp. 30–37.) The effect of small traces of Mg in the Ni base metal of an oxide-coated cathode was investigated experimentally. Experimental double-diode valves are described having two plane cathodes with a common heater, one cathode having a pure Ni base and the other a base of Ni with a trace of Mg. The cathodes were processed under identical conditions before insertion in the envelope. The Mg-Ni cathode was found to have the greater emission decay in d.c. life tests, and an earlier departure from the space-charge voltage/current curve in pulse tests. The phenomenon of pulse-current decay, for pulses lasting about 250 μs, is discussed. Experiments indicate that this effect does not occur if the cathode and anode are correctly processed and aged, and it may thus provide a test of the initial quality of a valve.

621.385.2 : 546.289 **1528**

A Note on the Decay of Current in Germanium Diodes.—J. R. Tillman & H. Yemm. (*Phil. Mag.*, Dec. 1950, Vol. 41, No. 323, pp. 1281–1283.) From measurements of crosstalk voltages in time-division multiplex systems it is found that the current in a Ge diode decays with a time constant of the order of 1 μs. The time constant varies considerably for different diodes; no correlation of the observed crosstalk with 'turnover' voltage or with reverse resistance could be found.

621.385.2 : 546.289 **1529**

Reverse Current of Germanium Diodes at High Voltages.—P. Aigrain. (*C. R. Acad. Sci., Paris*, 13th Nov. 1950, Vol. 231, No. 20, pp. 1047–1048.) By assuming that a strong normal electric field [see 3198 of 1950 (Stuetzer)] modifies the surface conductance, the characteristics of Ge diodes can be explained quantitatively. In particular the increase of reverse current at high voltages is explained without recourse to a field emission theory. Experimental results support the theory.

621.385.2 : 546.289 **1530**

The Inverse-Voltage Characteristic of a Point Contact on *n*-Type Germanium.—L. P. Hunter. (*Phys. Rev.*, 1st Jan. 1951, Vol. 81, No. 1, pp. 151–152.) A qualitative explanation of the effect of self-heating on the inverse-voltage characteristic. A method is shown of deriving a thermal-equilibrium curve resembling the measured characteristic. The theory of Aigrain (1305 and 1306 of 1950) is discussed in relation to the relatively large currents found at low voltages with some point contacts.

621.385.2 : 546.289 **1531**

Pulse Measurement of the Inverse-Voltage Characteristic of Germanium Point Contacts.—A. I. Bennett & L. P. Hunter. (*Phys. Rev.*, 1st Jan. 1951, Vol. 81, No. 1, p. 152.) The isothermal pulse characteristics are almost linear up to voltages of more than twice the d.c. inverse breakdown voltage. Some experimental details are shown graphically and the linear results are discussed in terms of Aigrain's theory (1305 and 1306 of 1950). A qualitative relation apparently exists between the thermal-equilibrium d.c. characteristic and the isothermal pulse characteristic, back-voltage breakdown being really a self-heating effect.

621.385.2 : 621.314.632 **1532**

The Impedance of Crystal Rectifiers with Heavy D.C. Bias in the Blocking Direction.—E. Spenke. (*Z. Phys.*, 7th Dec. 1950, Vol. 128, No. 5, pp. 586–604.) The diffusion theory of crystal rectifiers with a.c. loading was previously limited to frequencies lower than the relaxation frequency of the high-resistance boundary layer of the semiconductor (see 532 of 1942). The theory is extended to high frequencies, small compared with the relaxation frequency of the low-resistance interior of the semiconductor. For 'exhausted' boundary layers, the equivalent circuit of resistance with parallel capacitance is strictly applicable. For 'reserve' layers the approximate validity of the so-called 'fixed-layer' hypothesis is established, at least for high frequencies. See also 349 of 1950 (Bardeen) and 2917 of 1949.

621.385.3 : 546.289 : 621.317.7.001.4 **1533**

Transistor Measurement Technique.—H. F. Mataré. (*Elektron Wiss. Tech.*, Oct./Nov. 1950, Vol. 4, Nos. 10/11, pp. 368–379.) An account of the present state of development of the transistor based on information given at the Reading conference on semiconductors, July 1950. Forms and types of transistor are classified and the best method of specification is outlined. Test equipment discussed includes: (*a*) a c.r.o. circuit for displaying the characteristic modulation waveform obtained by modulating collector and emitter currents at different frequencies, the width of the wave envelope indicating transistor quality; (*b*) an arrangement for connecting the transistor as an amplifier for measuring amplification factors; (*c*) a saturated-pentode circuit for loading the transistor without altering the working point, to determine the characteristic cross-resistances of the transistor; (*d*) an a.c. bridge operating at 5 kc/s to determine the interaction coefficient γ. Examples of measured values and typical characteristics are shown.

621.385.3.012.8 **1534**

Triode Transmission Networks under Linear Negative-Grid Conditions.—Keen. (See 1321.)

621.396.822 **1535**

A Note on Induced Grid Noise and Noise Factor.—I. A. Harris. (*J. Brit. Instn Radio Engrs*, Dec. 1950, Vol. 10, No. 12, pp. 396–400.) A theoretical expression is given for induced grid noise which gives better agreement with experimental data than previous theoretical formulae. The noise factor of a common-cathode triode circuit is calculated by a novel method which ensures that account is taken of transit-time effects. The results confirm the possibility of reducing the noise factor by detuning the input circuit, with or without neutralization.

621.385.832 **1536**

New Developments in Storage Tubes.—H. Klemperer. (*Arch. Elektrotech.*, 1950, Vol. 40, No. 1, pp. 45–48.) The operation of signal-storage c.r. tubes is described on the basis of the secondary-emission processes involved. When operated with appropriate voltage relations between cathode, target and collector, such tubes are capable of distinguishing between irregular signals and periodically repeated signals, and hence can be used as filters for transmitting the former while suppressing the latter. With tubes at present available a separation of 40 db can be effected, i.e., a variable input signal is amplified up to the level of a steady input signal 100 times as large.

669.27 : 621-42 : 548.53 **1537**

On the Recrystallization and Grain Growth in Tungsten Wire.—DeVincentis & Dedrick. (See 1411.)

MISCELLANEOUS

551.510.535 : 522.1(481) **1538**

The Ionospheric and Radio Wave Propagation Observatory at Kiruna, 67° 50′ N, 20° 14·5′ E.—Rydbeck. (See 1380.)

621.396.6.002.2.004.13.004.5/.6 **1539**

The Relation between Production, Operation and Maintenance of Service Radio Equipment.—(*Proc. Instn elect. Engrs*, Part III, Jan. 1951, Vol. 98, No. 51, p. 68.) Report of an I.E.E. Radio Section discussion, 24th April 1950.

621.396.029.63/.64 **1540**

Microwave Electronics. [Book Review]—J. C. Slater. Publishers: D. Van Nostrand Co., New York, 1950, 406 pp., $6.00. (*Rev. sci. Instrum.*, Oct. 1950, Vol. 21, No. 10, p. 877.) ". . . a logical, thorough, basic and easy-to-understand development . . . a reader familiar with Maxwell's theory and equipped with the mathematical background of a graduate student of physics or engineering will find himself well prepared for its study."