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# Editorial

## Natural and Resonant Frequencies of Coupled Circuits

IT is many years since we first showed that the two natural frequencies of two similar oscillatory circuits coupled, say, as shown in Fig. 1, by the condenser $K$, can be determined very simply by assuming the circuits to be opened and the condensers $CC$ equally charged.* On simultaneously closing the circuits there will be a simple damped oscillatory current; if the condensers are charged so that they both tend to discharge in the same direction around the circuit $LCCL$, the condenser $K$ plays no part and $\omega^2LC = 1$, neglecting the effect of $R$; if, however, the condensers are charged in opposite directions, they will both discharge simultaneously through $K$, which may be regarded as two condensers of half the capacitance connected in parallel, and $\omega^2LC' = 1$, where $C'$ is the capacitance of $C$ and $K/2$ in series. If only the left-hand condenser is charged, then on discharge, beats will occur due to the simple superposition of the two symmetrical cases.

If one were asked how many resonant frequencies the arrangement shown in Fig. 1 possessed, one would naturally, in the light of the above, reply two. Even if the resistances were so great that the discharges became non-oscillatory, and there was consequently no natural frequency, one would feel tempted to maintain that the two resonant frequencies would be unaffected. This would only be justified, however, if the exciting electromotive forces were operative on both circuits in a symmetrical manner, one frequency corresponding to the case in which the electromotive forces induced in the coils were in phase and the other to that in which they were in opposition.

If the exciting e.m.f. $E$ is only induced in the left-hand circuit, which we may regard as the primary, conditions are not nearly so simple. If the resistances $RR$ are small, there are three resonant frequencies, that is, three frequencies at which the current $I_1$ is in phase with $E$. Two of them are the frequencies discussed above, and they correspond to maximum values of the current $I_1$; the other is a frequency that could not arise from consideration of the natural frequencies, since it corresponds to a minimum value of $I_1$, that is, it is a case of rejector resonance or, as it is sometimes called, anti-resonance. If now the resistances $RR$ are gradually increased, this latter resonant frequency is unchanged,

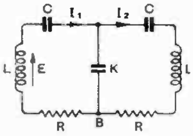

Fig. 1.

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* "A new method of determining the frequencies and coupling coefficients in coupled oscillatory circuits." *Elect. World*, N.Y. 68, p. 368, 1916.

whereas the two former frequencies approach one another until at a certain value of $R$ they coalesce, only to vanish, for on any further increase of $R$, resonance of this type becomes impossible. This can be shown as follows. If an electromotive force $E$ be induced in the left-hand coil, the impedance $Z = Z_1 + \frac{Z_1 Z_2}{Z_1 + Z_2}$ where $Z_1 = R + j\left(\omega L - \frac{1}{\omega C}\right)$ and $Z_2 = 1/j\omega K$.

For the admittance we have

$$Y = \frac{1}{Z} = \frac{Z_1 + Z_2}{{Z_1}^2 + 2\,Z_1 Z_2}$$

If we put $R = a$, $\omega L - \frac{1}{\omega C} = b$, and $\frac{1}{\omega K} = d$ so that $Z_1 = a + jb$ and $Z_2 = -jd$

$$\text{then } Y = \frac{a + j(b - d)}{a^2 - b^2 + 2bd + j2a\,(b - d)}$$

$$= \frac{\{a + j(b - d)\}\,\{a^2 - b^2 + 2bd - j2a\,(b - d)\}}{(a^2 - b^2 + 2bd)^2 + 4a^2(b - d)^2}$$

Now $I_1 = EY$ and for $I_1$ to be in phase with $E$ the imaginary component of $Y$ must vanish, that is $(a^2 - b^2 + 2bd)(b - d) - 2a^2(b - d) = 0$.

Hence for resonance either $b - d = 0$ or $a^2 + b^2 - 2bd = 0$. If $b - d = 0$, that is $\omega L - \frac{1}{\omega C} - \frac{1}{\omega K} = 0$, then

$$\omega^2 L \frac{CK}{C + K} = 1 \text{ or } \omega^2 LC = 1 + \frac{C}{K}.$$

which gives also the resonant frequency of either $LCK$ circuit with the other one open.

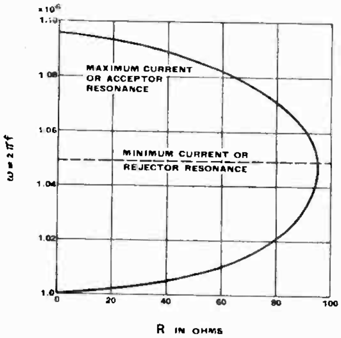

Fig. 2.

It is interesting to note that this frequency is independent of the resistance of the circuits (see Fig. 2). At this frequency the expression for the admittance reduces to

$$Y = \frac{a}{a^2 + d^2} = \frac{R}{R^2 + (1/\omega K)^2}$$

$$\text{and } Z = R + \frac{1}{\omega^2 K^2 R} = R + \frac{CL}{K(C + K)} \cdot \frac{1}{R}$$

This is obviously a case of rejector resonance and as $R$ is increased from zero $Z$ falls from infinity as shown in Fig. 3; it reaches a minimum value of $2R$ when $R = \sqrt{\frac{CL}{K(C + K)}}$ and then increases continually with increasing $R$.

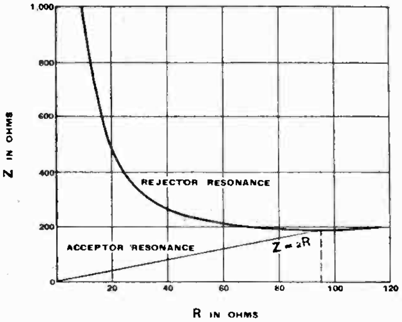

Fig. 3.

The other condition for resonance, viz., $a^2 + b^2 - 2bd = 0$ that is

$$R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2 - \frac{2}{\omega K}\left(\omega L - \frac{1}{\omega C}\right) = 0$$

gives

$$\omega^2 = \frac{C + K}{LCK} - \frac{R^2}{2L^2}$$

$$\pm \sqrt{\left(\frac{C + K}{LCK} - \frac{R^2}{2L^2}\right)^2 - \frac{1}{L^2 C^2}\left(1 + \frac{2C}{K}\right)}$$

For this to have real values, that is, for the existence of such resonant frequencies, the quantity under the root must be positive, that is

$$\left(\frac{C + K}{LCK} - \frac{R^2}{2L^2}\right)^2 > \frac{1}{L^2 C^2}\left(1 + \frac{2C}{K}\right)$$

$$\text{and } \frac{C + K}{CK} - \frac{R^2}{2L} > \frac{1}{C}\sqrt{1 + \frac{2C}{K}}$$

Hence $\dfrac{R^2}{2L}$ must not exceed

$$\frac{1}{K}+\frac{1}{C}\left(1-\sqrt{1+2C/K}\right)$$

For smaller values of $R^2/2L$ the root will be real and there will be two values of $\omega$. If $R = 0$

$$\omega^2 = \frac{C+K}{LCK}$$

$$\pm\sqrt{\left(\frac{C+K}{LCK}\right)^2-\frac{1}{L^2C^2}\left(1+\frac{2C}{K}\right)}$$

$$=\frac{C+K\pm C}{LCK}$$

$$=\frac{1}{LC}\text{ or }\frac{1}{L\dfrac{CK/2}{C+K/2}}$$

which correspond to the two natural frequencies referred to in our opening paragraph.

These could be obtained directly by putting $a = 0$ in the condition $a^2 + b^2 - 2bd = 0$.

If $R$ has a value less than the critical value determined above, we have for the resonant admittance, putting $a^2 + b^2 - 2bd = 0$, i.e. $a^2 - b^2 + 2\,bd = 2a^2$

$$Y = \frac{\{a+j(b-d)\}\{2a^2-j2a(b-d)\}}{4a^2(a^2+b^2+d^2-2\,bd)}$$

$$=\frac{2a^3+2a(b-d)^2}{4a^2d^2}=\frac{2ad^2}{4a^2d^2}=\frac{1}{2a}=\frac{1}{2R}$$

Hence the impedance is simply $2R$ for both the resonant frequencies, as shown in Fig. 3.

As $R$ is increased from zero the two frequencies approach until, when $R$ has the critical value, they coalesce. This frequency is given by the formula

$$\omega^2 = \frac{C+K}{LCK}-\frac{R^2}{2L^2}$$

since the quantity under the root vanishes. Putting $\dfrac{R^2}{2L}=\dfrac{1}{K}+\dfrac{1}{C}\left(1-\sqrt{1+2C/K}\right)$ this becomes

$$\omega^2LC = \sqrt{1+2C/K}.$$

If the coupling is made very weak by increasing the value of $K$, so that $2C/K$ is small compared with unity, this will approximate to

$$\omega^2LC = 1 + C/K$$

which is the formula found above for the rejector resonant frequency.

Figs. 2 and 3 refer to an example in which

$L = 1$ mH
$C = 1$ m$\mu$F
$K = 10$ m$\mu$F

If $R = 0$ the three values of $\omega$ are $10^6$, $1.049 \times 10^6$ and $1.096 \times 10^6$. As $R$ is increased, the acceptor resonance frequencies, which correspond to the humps in the resonance curve, approach each other, until when $R = 95.45$ ohms, they coalesce at a value of $\omega$ of $1.047 \times 10^6$ with an impedance $Z$ of 190.9 ohms. As $R$ is increased, the rejector resonant $\omega$ remains unchanged at $1.049 \times 10^6$ whilst the impedance falls to a minimum of 190.7 ohms at a value of $R$ of 95.35 ohms. The small differences between some of these figures are not errors of calculation but become more pronounced the tighter the coupling. A vertical line on Fig. 2 gives the values of $\omega$ for the two humps and the trough of the resonance curve for any value of $R$; their heights will be inversely proportional to ordinates of Fig. 3. Practically speaking, when $R$ reaches 95.4 ohms, the humps vanish and the impedance is then 190.8 ohms. With any further increase of $R$ there is only one resonant frequency, the single hump now replacing the trough, and we are no longer justified in calling it rejector resonance, for its rejector characteristics have been replaced by those of acceptor resonance. We have idealised the problem to some extent by assuming the effective resistance of each circuit to be exactly the same. In practice this will rarely be the case, but the assumption simplifies the problem and is the most reasonable one to make. It should also be noted that we have confined our attention entirely to the primary current $I_1$, whereas when considering resonance curves it is more often the secondary current $I_2$ that is plotted.

G. W. O. H.

# Inductance Linearized Time Base*

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**PART I**

## PART I

## 1. Introduction

THE purpose of a time base is the repeated provision of a voltage which increases sensibly linearly with time throughout a certain time interval whose length can be varied over a wide range. Usually, this voltage is produced by the comparatively slow charging of a condenser, the charging epoch being terminated at some specified condenser voltage, and the initial voltage conditions reinstated, by the quasi-instantaneous discharge of the condenser via some kind of discharge tube. For exact repetition to ensue, the charging current must also repeat its initial value at the instant when the discharge tube flashes, but it is quite immaterial whether or not it does so as a result of the flash, in a similar manner to the condenser voltage, or acquires that value independently.

Thus, four distinct modes of operation present themselves, depending on the behaviour of the charging current whilst the condenser voltage increases. The current may :

(*a*) remain constant throughout,
(*b*) return to its initial value immediately before the discharge, and remain constant during the discharge,
(*c*) be reset by a separate device in a manner analogous to the resetting of the voltage by the discharge tube,
(*d*) be reset by the same device which resets the voltage.

The pentode or saturated-diode charging circuits are examples of type (*a*) : the simple resistance charging circuit, in which the early part of the exponential rise of condenser voltage is utilised, is an example of type (*d*). These devices are already well known and merit no further discussion : it is the object of this paper to discuss type (*b*), type (*c*) being thought too complicated to be of practical value.

An important distinction between type (*b*) and (*d*) operation is at once apparent. For a range of time limited to the charging period, type (*d*) occurs if the voltage is a single valued function of the current, which would be the case if the current decreased (or increased) smoothly. But type (*b*) requires that the voltage be a double valued function of the current, a condition which would be satisfied if the current increased at first, reached a maximum, and decreased thereafter (or conversely if it first decreased, reached a minimum, and increased thereafter). A current curve of the shape required in type (*d*) may be obtained if the circuit associated with the condenser is non-inductive. This is fortunate, since, on short circuiting the condenser, the current immediately resumes its initial value, a transition which would be impossible if inductance were present. But a current curve of the shape required by type (*b*) may be obtained by the use of inductance, and this again is fortunate, since it enables the current to be kept sensibly constant during the discharge period. It is with this type of circuit that this paper is concerned : in particular, to ascertain

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* MS. accepted by the Editor, November, 1940.

whether or not it possesses any advantage, either in better linearity or greater output, over the usual one.

It is of interest to note that the problem is very reminiscent of the familiar one of signal shaping in cable telegraphy. Attention has been given to this topic by others (*Bib.* 1, Chap. 16, p. 479; and later workers), and more complicated networks are possible.

## 2. Theory

### 2.1. Circuit Operation

The circuit under consideration is shown in Fig. 1. The condenser $C$ charges through $R$ and $L$ in series, and, when $V$ reaches $V_2$, the thyratron trips and discharges $C$ down to $V_1$, the minimum ionisation potential of the thyratron. This discharge is performed very rapidly indeed, and may be regarded as instantaneous to a fair degree of approximation: it follows that the current $I$ will be the same at the beginning of the new charging epoch as it was at the end of the preceding one. Thus, if time is reckoned from the beginning of a charging epoch of duration $T$, $I = I_0$ at $t = 0$ and $t = T$, and also $V = V_1$ at $t = 0$ and $V_2$ at $t = T$.

With these boundary conditions fixed, the problem reduces to a consideration of a simple series $RLC$ circuit: the thyratron can be omitted since it operates only infinitesimally before and infinitesimally after the epoch defined above. Since the operation of the time base does not extend beyond the first peak of the voltage wave, it is instructive to consider first the manner in which the shape and size of this voltage " wave front " vary with the circuit constants and initial conditions.

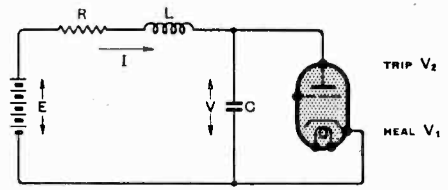

Fig. 1.

### 2.2. Effect of Circuit Constants and Initial Conditions

The general solutions of the equations for the simple $RLC$ circuit with various initial conditions of circuit current and condenser voltage are well known: they are available elsewhere (*Bib.* 2, Chap. 5, p. 47), and will not be repeated here. Instead, the results of a numerical study of a particular case will be given: these are shown in Figs. 2, 3 and 4. Figs. 2 and 3 are designed to illustrate the effect upon the voltage wavefront as the circuit is arranged to be successively highly damped, critically damped, oscillatory and damped, and oscillatory and undamped. The curves have been drawn for two particular initial conditions, when the initial current $I_0$ is zero and when it is 50 mA, the initial condenser voltage being zero in each case. Curves for various initial condenser voltages have not been given since, within the range of interest, the solution is comparatively insensitive to the initial condenser voltage. The voltage range over which the potential-time characteristic is sensibly linear is obviously greatest in the oscillatory case and, accordingly, Fig. 3 has been drawn to illustrate in more detail the effect of the initial current: the time scale has been halved so as to show the effect of damping more clearly, and to give a more complete picture of the oscillation.

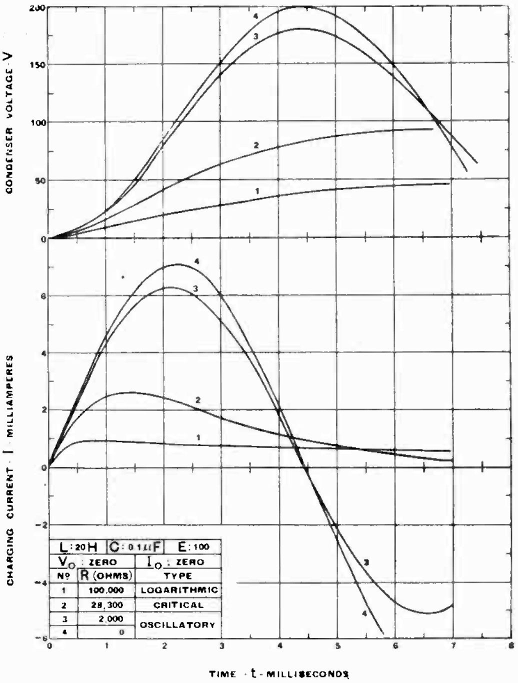

Fig. 2.

### 2.3. Detailed Analysis

Examination of Curves 2 and 3 of Fig. 4 shows that, during the first rise of voltage, there is a time, $T$ say, at which the current repeats its initial value. If at that instant the voltage could be reset to its initial value, without changing the current, the voltage and current curves would repeat between $T$ and $2T$ their values between $O$ and $T$: and if the resetting occurred at $2T$, $3T$ . . . etc., the process would be repeated indefinitely, yielding voltage and current curves as shown in Fig. 5. Such a device would be a time base of type (*d*), and could be realised by arranging the thyratron of Fig. 1 to trip and heal at the potentials $V_1$ and $V_2$ relevant to Fig. 5.

It is apparent that the condition of interest is the oscillatory one where $R^2 \ll \frac{4L}{C}$: as a first approximation to this, the condition with $R = 0$ will be discussed.

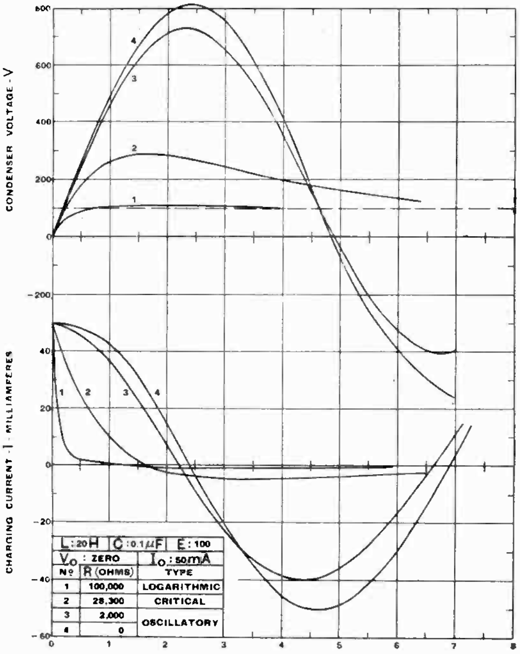

Fig. 3.

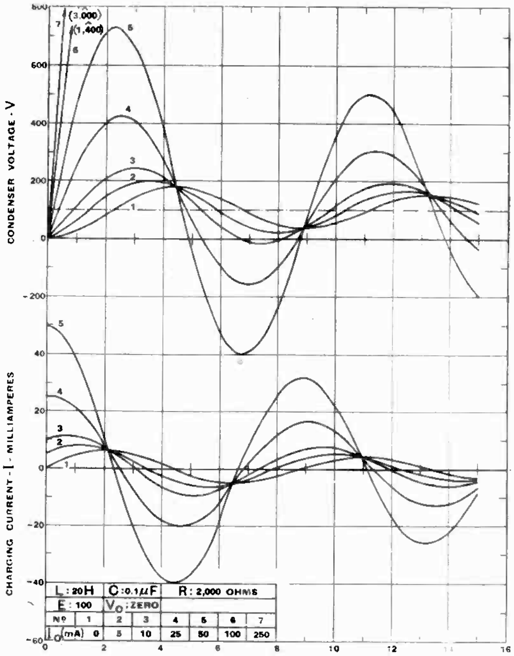

Fig. 4.

#### 2.31. *General Equations*

Adopting the usual symbol convention, the circuit equation is:

$$L\frac{d^2Q}{dt^2} + \frac{Q}{C} = E \qquad \ldots \qquad \ldots \qquad (1)$$

or, since:

$$V = \frac{Q}{C}$$

$$C\,L\frac{d^2V}{dt^2} + V = E \qquad \ldots \qquad \ldots \qquad (2)$$

of which the solution has the form:

$$V = E + A\sin(\omega t - \phi) \quad \ldots \qquad (3)$$

and hence, since:

$$I = C\frac{dV}{dt}$$

$$I = CA\omega\cos(\omega t - \phi) \qquad \ldots \qquad (4)$$

where: $$\omega = \frac{1}{\sqrt{LC}} \qquad \ldots \qquad \ldots \qquad \ldots \qquad (5)$$

and $A$ and $\phi$ have yet to be determined from the initial conditions.

$I = I_0$ at $t = 0$ and also at $t = T$ so:

$$\left.\begin{array}{lll}(t = 0) & I_0 = CA\omega\cos(-\phi) & \text{(a)} \\ (t = T) & I_0 = CA\omega\cos(\omega T - \phi) & \text{(b)}\end{array}\right\} \quad (6)$$

whence:

$$\cos(-\phi) = \cos(\omega T - \phi)$$

or: $$-\phi = \mp(\omega T - \phi) \mp 2\pi$$

Of these solutions the only one of interest is the first :

$$-\phi = -(\omega T - \phi)$$

or :
$$\phi = \frac{\omega T}{2} \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

and, from (6) :

$$A = \frac{I_0}{C\omega \cos \omega T/2} \quad \ldots \quad \ldots \quad (8)$$

Thus, substituting from (7) and (8) into (4) it follows that :

$$I = \frac{I_0 \cos (\omega t - \omega T/2)}{\cos \omega T/2} \quad \ldots \quad (9)$$

Similarly, on substituting in (3) :

$$V = E + \frac{I_0 \sin (\omega t - \omega T/2)}{C\omega \cos \omega T/2} \quad (10)$$

But $V = V_1$ at $t = 0$, and $V = V_2$ at $t = T$ so:

$$\left.\begin{array}{lll} (t = 0) & V_1 = E - \dfrac{I_0 \tan \omega T/2}{C\omega} & \text{(a)} \\ (t = T) & V_2 = E + \dfrac{I_0 \tan \omega T/2}{Cw} & \text{(b)} \end{array}\right\} (11)$$

whence :

$$\left.\begin{array}{lll} & (V_2 + V_1) = 2E & \text{(a)} \\ \text{or :} & E = \dfrac{(V_2 + V_1)}{2} & \text{(b)} \end{array}\right\} (12)$$

$$\left.\begin{array}{lll} \text{and :} & (V_2 - V_1) = \dfrac{2I_0 \tan \omega T/2}{C\omega} & \text{(a)} \\ \text{or :} & I_0 = \dfrac{(V_2 - V_1)C\omega}{2 \tan \omega T/2} & \text{(b)} \end{array}\right\} (13)$$

and, substituting for $E$ and $I_0$ from (12) and (13) into (10), it follows that :

$$V = \left[\frac{V_2 + V_1}{2}\right] + \left[\frac{V_2 - V_1}{2}\right] \left[\frac{1}{\sin \omega T/2}\right] \left[\sin (\omega t - \omega T/2)\right] \quad (14)$$

a result which is, of course, self-evident from Fig. 5. Equations (9) to (14) specify the operation of the circuit.

### 2.32. *Condition for Maintenance of Steady State*

From (12) it is necessary that $V_1$ and $V_2$ be displaced equally above and below $E$. At first sight this result appears somewhat surprising for, although $V_1$ is fixed by the ionisation potential of the thyratron, $V_2$ is variable at will by varying the grid bias. It would seem, therefore, that $V_2$ might have any value not necessarily that defined by (12). In fact it cannot, for the existence of a steady state has been postulated, and this can only hold if (12) is satisfied : attempts to use the circuit with $V_2 <$ or $> (2E - V_1)$ would end in failure. Thus, deriving the same result from energy considerations for one epoch :

Energy supplied by battery
= Energy withdrawn from condenser

$$\text{i.e.,} \quad EC(V_2 - V_1) = \frac{C(V_2^2 - V_1^2)}{2} \quad \ldots \quad (15)$$

$$\text{and hence :} \quad 2E = (V_2 + V_1) \quad \ldots \quad (16)$$

If $2E > (V_2 + V_1)$, the energy supplied would exceed that withdrawn, and the energy in the circuit would increase continually towards infinity : conversely, if $2E < (V_2 + V_1)$, the stored energy would decrease to zero. In neither case could a steady state exist. It may be noted that in the latter case since $V_2 > V_1$, $V_2 > E$, and the condenser potential assumes the steady value $E$ which is insufficient to trip the thyratron.

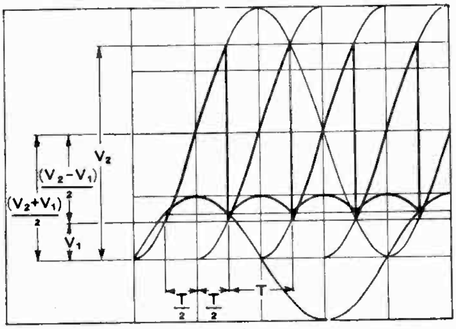

Fig. 5.

### 2.33. *Frequency*

From (13) it is not possible to evaluate $T$ immediately, for the equation contains $I_0$ which depends on the circuit conditions at the instant of switching on. This state of affairs has arisen as a result of considering a non-dissipative circuit for, in such a circuit, the initial conditions govern the behaviour for all time. But in a dissipative circuit, the initial conditions control only the early transient régime, and play no part in the steady state performance of the circuit. The procedure to be adopted is, therefore, immediately apparent : a resistance $R$ must be introduced, and it must be supposed so small that it does not appreciably influence the wave form in any one cycle, and does not invalidate (13)*. Thus, whatever the initial conditions, once the steady state has been reached, the current in the circuit will assume a steady mean value $I_m$ which is quite independent of $I_0$.

Now $Q = CV$

or : $I = C\dfrac{dV}{dt}$

so :
$$I_m = \frac{C}{T}\int_0^T \frac{dV}{dt}\,dt \quad \dots \quad \dots \quad (17)$$

and therefore :
$$I_m = \frac{C\,(V_2 - V_1)}{T} \quad \dots \quad (a)$$

or :
$$T = \frac{C\,(V_2 - V_1)}{I_m} \quad \dots \quad (b)$$

or, since the frequency $f = \dfrac{1}{T}$ (and does not, it should be noted, generally require to exceed $0.5.10^6$ cycles/sec.) :
$$f = \frac{I_m}{C(V_2 - V_1)} \quad \dots \quad (c) \qquad (18)$$

and if $V_1 \ll V_2$, (18) ($a$), ($b$) and ($c$) become :
$$\left.\begin{aligned} I_m &= \frac{CV_2}{T} \quad \dots \quad \dots \quad (a)\\ \text{or : } T &= \frac{CV_2}{I_m} \quad \dots \quad \dots \quad (b)\\ \text{and : } f &= \frac{I_m}{CV_2} \quad \dots \quad \dots \quad (c) \end{aligned}\right\} \quad (19)$$

(18) ($a$) is, of course, physically obvious since it is merely the charge gained by the condenser in the given time interval $T$, divided by that time. It should be noted that it is quite independent of the manner of variation of $V$ between the two limiting values $V_1$ and $V_2$, at $t = 0$ and $t = T$ : it depends only on the mean value of $\dfrac{dV}{dt}$ throughout this interval and, therefore, only on $V_1$ and $V_2$.

It is now necessary to evaluate $I_m$ in terms of the known circuit parameters : this is most readily done from energy considerations. If the form factor of $I$ be denoted by $F$, the effective value of $I$ is $FI_m$, and since :

Energy supplied by battery
= Energy withdrawn from condenser
+ Energy dissipated

it follows that :
$$EI_mT = \frac{C(V_2^2 - V_1^2)}{2} + RF^2I_m^2T \quad \dots \quad \dots \quad \dots \quad \dots \quad (20)$$

and, on substituting for $I_m$ from (18) ($a$) :
$$\frac{EC(V_2 - V_1)}{T} = \frac{C(V_2^2 - V_1^2)}{2T} + \frac{RF^2C^2(V_2 - V_1)^2}{T^2}.$$

or :
$$E = \frac{(V_2 + V_1)}{2} + \frac{RF^2C(V_2 - V_1)}{T}$$

$$\left.\begin{aligned} \text{and so : } T &= \frac{RF^2C(V_2 - V_1)}{E - (V_2 + V_1)/2} \quad (a)\\ \text{or : } f &= \frac{E - (V_2 + V_1)/2}{RF^2C(V_2 - V_1)} \quad (b) \end{aligned}\right\} \quad (21)$$

If the current fluctuations are small, negligible error will be introduced by assuming $F = 1$ : (21) ($a$) and ($b$) become :
$$\left.\begin{aligned} T &= \frac{RC(V_2 - V_1)}{E - (V_2 + V_1)/2} \quad (a)\\ f &= \frac{E - (V_2 + V_1)/2}{RC(V_2 - V_1)} \quad (b) \end{aligned}\right\} \quad (22)$$

and if $V_1 \ll V_2$, (22) ($a$) and ($b$) may be still further reduced to :
$$\left.\begin{aligned} T &= \frac{RCV_2}{(E - V_2/2)} \quad (a)\\ f &= \frac{(E - V_2/2)}{RCV_2} \quad (b) \end{aligned}\right\} \quad (23)$$

Since operation is confined to that portion of the voltage wave bounded by peaks of opposite sense, it is apparent from physical considerations that $\omega T \not> \pi$, and, therefore, that $T \not> \dfrac{\pi}{\omega}$. The analytical necessity for this restriction will emerge later (see Subsection 2.35 Equation (39) *et seq.*)

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* *Cf.* Fig. 3, Curve 3.

Further, (23) (b) may be written:

$$R = \frac{E - V_2/2}{fCV_2} \quad \ldots \quad \ldots \quad (24)$$

and it is obvious that $V_2 \not> 2E$ for, otherwise, it would be necessary for $R$ to assume negative values. The ratio $V_2/E$ thus acquires a particular significance, and may be termed the "voltage utilisation factor" of the circuit.

From (18) ($a$) and (21 ($a$) it follows that:

$$I_m = \frac{E - (V_2 + V_1)/2}{F^2 R} \quad (a)$$

and if it be assumed that $F = 1$:

$$I_m = \frac{E - (V_2 + V_1)/2}{R} \quad (b) \qquad (25)$$

and if $V_1 \ll V_2$:

$$I_m = \frac{E - V_2/2}{R} \quad \ldots \quad (c)$$

It should be noted from (25) ($c$) that, if $R$ is very small, as is assumed in the theory, appreciable reduction of $V_2$ below $2E$ in the course of adjustments would lead to dangerously high values of $I_m$. A method of overcoming this difficulty will be described later (see Subsection 2.36).

(25) ($b$) may be written:

$$R = \left[1 - \frac{(V_2 + V_1)}{2E}\right]\left[\frac{E}{I_m}\right] \quad (a)$$

and if $V_1 \ll V_2$:

$$R = \left[1 - \frac{V_2}{2E}\right]\left[\frac{E}{I_m}\right] \quad \ldots \quad (b) \qquad (26)$$

the quantity $\frac{E}{I_m}$ may thus be regarded as a second significant quantity* denoting the "mean resistance" of the circuit. From (26) ($b$)

$$\frac{R}{E/I_m} = \left[1 - \frac{V_2}{2E}\right] \quad \ldots \quad \ldots \quad (27)$$

If $\frac{V_2}{2E} = 1$, $\frac{R}{E/I_m} = 0$ and either $R = 0$, or $\frac{E}{I_m} = \infty$; thus

$I_m = 0$ and, therefore, no current flows.

If $\frac{V_2}{2E} = 0$, $\frac{R}{E/I_m} = 1$ and $\frac{E}{I_m} = R$, the thyratron remaining tripped.

### 2.34. *Maximum Output Voltage*

From (14) the output voltage is $(V_2 - V_1)$ and from (13) ($a$) this may be seen to have a maximum when:

$$\frac{\omega T}{2} = \frac{\pi}{2} \quad \ldots \quad \ldots \quad \ldots \quad (28)$$

Substituting for $T$ from (28) in (22) ($a$) there results:

$$(V_2 - V_1) = \left[\frac{\pi}{RC\omega}\right]\left[E - \frac{V_2 + V_1}{2}\right] \quad (29)$$

and if $V_1 \ll V_2$ this reduces to:

$$V_2 = \left[\frac{\pi}{RC\omega}\right]\left[E - \frac{V_2}{2}\right] \quad (a)$$

$$\text{or} \qquad V_2\left(RC\omega + \frac{\pi}{2}\right) = \pi E \quad \ldots \quad (b) \qquad (30)$$

It may be noted that, with $R = 0$, $V_2 = 2E$, a result which is in agreement with (12) for $V_1 = 0$.

But: $RC\omega = \frac{R}{L\omega} = \frac{1}{Q}$

and it may be concluded that, provided $Q > 4$, the maximum possible value of $V_2$ will not be seriously affected by the presence of $R$.

### 2.35. *Linearity*

The fractional linearity may be defined as follows:

$$\delta = 1 - \left\{\frac{\left[\frac{dV}{dt}\right]\text{min.}}{\left[\frac{dV}{dt}\right]\text{max.}}\right\}_0^T \quad \ldots \quad (31)$$

or since $I = C\frac{dV}{dt}$

$$\text{as:} \quad \delta = 1 - \left[\frac{I \text{ min.}}{I \text{ max.}}\right]_0^T \quad \ldots \quad (32)$$

From (14):

$$\frac{dV}{dt} = \left[\frac{(V_2 - V_1)}{2}\right]\left[\frac{\omega\cos(\omega t - \omega T/2)}{\sin \omega T/2}\right] \quad \ldots \quad \ldots \quad \ldots \quad (33)$$

This has a maximum when $t = T/2$ given by:

$$\left\{\left[\frac{dV}{dt}\right]\text{max.}\right\}_0^T = \left[\frac{(V_2 - V_1)\omega}{2\sin\omega T/2}\right] \quad \ldots \quad (34)$$

and minima when $t = 0$ and $t = T$ given by:

$$\left\{\left[\frac{dV}{dt}\right]\text{min.}\right\}_0^T = \left[\frac{(V_2 - V_1)\omega}{2\sin\omega T/2}\right]\cos\frac{\omega T}{2} \quad \ldots \quad \ldots \quad \ldots \quad (35)$$

---

* See equation (24) *et seq.*

From (31), (34) and (35) it follows that :

$$\left.\begin{aligned} \delta &= 1 - \cos\frac{\omega T}{2} \qquad (a) \\ &= 1 - \sqrt{1 - \sin^2\frac{\omega T}{2}} \\ \text{and if } \frac{\omega T}{2} \ll \frac{\pi}{2}: & \\ \delta &= 1 - \left(1 - \frac{1}{2}\sin^2\frac{\omega T}{2}\right) \\ \text{or : } \quad &= \frac{1}{2}\sin^2\frac{\omega T}{2} \qquad (b) \end{aligned}\right\} \quad (36)$$

which may be still further reduced to :

$$\delta = \frac{1}{2}\left(\frac{\omega T}{2}\right)^2$$

$$\text{or : } \quad \delta = \frac{1}{8}\left(\omega T\right)^2 \quad \ldots \quad \ldots \quad (37)$$

On substituting for $\omega$ and $T$ from (5) and (18) in (36) $(a)$ :

$$\left.\begin{aligned} \delta &= 1 - \cos\left[\frac{1}{2\sqrt{LC}}\right]\left[\frac{C(V_2 - V_1)}{I_m}\right] \quad (a) \\ &\text{which, if } V_1 \ll V_2 \text{ gives :} \\ \delta &= 1 - \cos\frac{1}{2}\left[\sqrt{\frac{C}{L}}\,\frac{V_2}{I_m}\right] \quad \ldots \quad (b) \end{aligned}\right\} \quad (38)$$

and similarly, using (37) instead of (36) :

$$\left.\begin{aligned} \delta &= \frac{1}{8}\left[\frac{1}{LC}\right]\left[\frac{C(V_2 - V_1)}{I_m}\right]^2 \quad (a) \\ &\text{and this, if } V_1 \ll V_2, \text{ gives :} \\ \delta &= \frac{1}{8}\left[\sqrt{\frac{C}{L}}\,\frac{V_2}{I_m}\right]^2 \quad \ldots \quad (b) \end{aligned}\right\} \quad (39)$$

From (36) $(a)$ it follows that, since $\delta \ngtr 1$, $\frac{\omega T}{2} \ngtr \frac{\pi}{2}$, and, therefore, that $T \ngtr \pi$ : the physical necessity of this result has already been noted (see Subsection 2.33, equation (23) *et seq.*).

Further, since $\frac{\omega T}{2} \ngtr \frac{\pi}{2}$, it follows from (38) $(b)$ that $\frac{1}{2}\left[\sqrt{\frac{C}{L}}\,\frac{V_2}{I_m}\right] \ngtr \frac{\pi}{2}$.

It may be seen from (37) that, for a given $\delta$ :

$$T \propto \sqrt{LC}$$

and, therefore, large values of $T$ necessitate very large values of $L$ and $C$. Further, for a given $\omega$ :

$$\delta \propto T^2$$

and deterioration of $\delta$ with $T$ is, therefore, very rapid. These findings limit the field of application of the device : the point will be discussed at a later stage (see Section 5).

$\sqrt{\frac{L}{C}}$ here appears as a third significant quantity* : since $L\omega = \frac{1}{C\omega} = \sqrt{\frac{L}{C}}$, it may be termed the " element reactance " of the circuit and cannot readily exceed $10^4$ ohms.

### 2.36. *Improved Circuit Arrangement*

In Subsection 2.33, Equation (25) *et seq.*, it was pointed out that appreciable reduction of $V_2$ below $2E$ might result in dangerously high values of $I_m$. An alternative circuit which eliminates this trouble is shown in Fig. 6. Here the decoupling circuit $R'C'$ supplies the time base with a smooth voltage $E'$ given by :

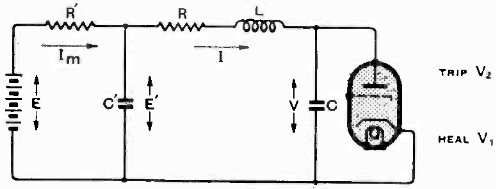

Fig. 6.

$$E' = E - R'I_m \quad \ldots \quad \ldots \quad (40)$$

(25) $(a)$ must be rewritten therefore as :

$$\left.\begin{aligned} I_m &= \frac{E - R'I_m - (V_2 + V_1)/2}{F^2R} \quad (a) \\ \text{or : } \quad I_m &= \frac{E - (V_2 + V_1)/2}{(F^2R + R')} \quad \ldots \quad (b) \end{aligned}\right\} \quad (41)$$

Let :

$$\left.\begin{aligned} R'' &= (F^2R + R') \quad \ldots \quad (a) \\ &\text{or, if } F = 1, \text{ and with } R' > R : \\ R'' &= (R + R') \quad \ldots \quad (b) \end{aligned}\right\} \quad (42)$$

and (41) $(b)$ may be rewritten :

$$\left.\begin{aligned} I_m &= \frac{E - (V_2 + V_1)/2}{R''} \quad \ldots \quad (a) \\ &\text{and if } V_1 \ll V_2 : \\ I_m &= \frac{E - V_2/2}{R''} \quad \ldots \quad (b) \end{aligned}\right\} \quad (43)$$

Thus $I_m \ngtr \frac{E}{R}$: this occurs when $V_2 = 0$,

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* See equations (24) *et seq.*, and (26) *et seq.*

and a safe value can readily be ensured by a suitable choice of $R'$.

From (43) (*b*) :

$$R'' = \frac{E - V_2/2}{I_m} \qquad (a)$$

which, as in (26) (*b*) becomes : (44)

$$R'' = \left[1 - \frac{V_2}{2E}\right]\left[\frac{E}{I_m}\right] \qquad (b)$$

2.37. *Comparison with Simple RC circuit*

2.371. *Output Voltage for a Given Linearity.*—It is required to ascertain $\frac{V_2}{E}$ for a specified $\delta$ and a probable $Q$.

From (23) (*a*) :

$$\frac{V_2}{E} = 1/\left(\frac{1}{2} + \frac{1}{Q\omega T}\right) \quad .. \quad (45)$$

where, from (37) :

$$\omega T = \sqrt{\frac{\delta}{8}} \quad .. \quad .. \quad (46)$$

If $\delta = 0.01$, $\omega T = 0.3$ and with $Q = 6$ :

$$V_2 \ngtr E \quad .. \quad .. \quad .. \quad (47)$$

In the simple RC circuit :

$$V = E(1 - e^{-t/RC}) \quad .. \quad (48)$$

and, as in Subsection 2.35 :

$$\frac{dV}{dt} = \frac{E}{RC}\left(e^{-t/RC}\right) \quad .. \quad (49)$$

so :

$$\left\{\left[\frac{dV}{dt}\right]_{\text{max.}}\right\}_0^T = \left[\frac{dV}{dt}\right]_{t=0}$$

$$= \frac{E}{RC} \quad .. \quad (50)$$

and :

$$\left\{\left[\frac{dV}{dt}\right]_{\text{min.}}\right\}_0^T = \left[\frac{dV}{dt}\right]_{t=T}$$

$$= \frac{E - V_2}{RC} \quad .. \quad (51)$$

so :

$$\delta = \left[1 - \frac{(E - V_2)}{E}\right] \quad .. \quad (52)$$

or :

$$0.99 = \frac{(E - V_2)}{E}$$

and :

$$V_2 = 0.01\,E \quad .. \quad .. \quad (53)$$

From (47) and (53) it appears that the introduction of inductance of low damping permits a 100-fold increase of amplitude without loss of linearity.

But it is to be expected that such improvement could only be obtained by the use of relatively large currents : this possibility will therefore be examined in the following paragraph :

2.372 *Current Required.*—From (25) (*c*) :

$$I_m = \frac{E - V_2/2}{R} \quad .. \quad .. \quad (54)$$

where, for the same value of $\delta$ as before, from (45) :

$$R = \left[0.3\sqrt{\frac{L}{C}}\,\frac{1}{V_2}\right]\left[E - \frac{V_2}{2}\right] \quad .. \quad (55)$$

or :

$$I_m \nless \frac{V_2}{0.3\sqrt{L/C}} \quad .. \quad .. \quad .. \quad (56)$$

And if $\sqrt{\frac{L}{C}} = 5.10^3$ :

$$I_m \nless \frac{V_2}{1.5}10^{-3}$$

So, with $V_2 = 100$ :

$$I_m \nless 70 \text{ mA} \quad .. \quad .. \quad .. \quad (57)$$

which is rather a lot.

(*To be concluded*)

## I.E.E. Wireless Section Committee

THE Committee of the Wireless Section of the Institution of Electrical Engineers has made the following nominations to fill the vacancies which will occur on the Committee on September 30th, 1941 :—Chairman, Mr. H. Bishop, C.B.E., B.Sc. (Eng.), (British Broadcasting Corporation) ; vice-chairman, Mr. A. H. Mumford, B.Sc. (Eng.), (Post Office Engineering Department) ; ordinary members of committee, Mr. H. G. Beer (Post Office Engineering Department), Mr. F. P. Best, M.Sc., B. Eng. (Marconi International Marine Communication Co.), Mr. H. G. Hughes, M.Sc. (H.M. Signal School), Prof. Willis Jackson, D.Sc., D. Phil. (Manchester University), and Dr. H. A. Thomas, D.Sc. (National Physical Laboratory).

Not later than June 7th, any five (but not more than five) members of the Wireless Section may nominate any other duly qualified person as chairman, vice-chairman, or ordinary member by delivering such nomination in writing to the secretary of the Institution, together with the written consent of such person to accept office if elected.

## Book Received

**Understanding Radio.**—By Herbert M. Watson, Herbert E. Welch and George S. Eby. This American book, which is written in a clear, easily readable style, is designed to provide the beginner with an elementary working knowledge of the fundamental principles of wireless and electricity. In addition to the text matter, each of the fourteen chapters contains a list of technical terms used. At the end of each section a list of questions is given on the subjects covered. Pp. 603 + IX, 379 Figs. McGraw-Hill Publishing Co., Ltd., Aldwych House, London, W.C.2. Price £1.

# The Pierce Piezo-Electric Oscillator*

## Analysis for the Design of Crystal and Line-Controlled Apparatus

*By H. Jefferson, B.A.*

*(Research and Development Department, Marconi's Wireless Telegraph Company, Ltd.)*

### Introduction

THE need for a fresh analysis of the Pierce crystal oscillator circuit was felt particularly in designing an oscillator required to have the frequency variable over the maximum range compatible with control by a single crystal. It was desired that the frequency should be varied by a single element, and that the amplitude of oscillation should not vary with the frequency. Little guidance was found in the papers consulted, which, while deriving conditions for oscillation, gave no indication of a method of selecting circuit values for a particular application. The analysis given here provides a means whereby component values may be chosen, and the method is extended in an appendix to an analogous form of line-controlled oscillator.

### Symbols

For ease of reference the symbols used in the analysis are listed below :—

| | |
|---|---|
| $C$ | Feedback condenser (Figs. 1 and 2). |
| $C_m$ | Optimum value of $C$. |
| $C_0$ | Total grid-cathode capacitance. |
| $C_1$ | Crystal series capacitance (Fig. 3.) |
| $C_2$ | Anode tuning capacitance. |
| $C_3$ | Physical capacitance in grid-cathode circuit. Lumped in $C_0$ for analysis. |
| $G_1$ | Grid circuit conductance. |
| $G_2$ | Anode circuit conductance. |
| $I_1$ | Input current to four terminal network. |
| $I_2$ | Output current from four terminal network. |
| $L$ | Equivalent anode circuit inductance. |
| $L_m$ | Optimum value of $L$. |
| $L_1$ | Crystal inductance. |
| $L_2$ | Physical anode circuit inductance. |
| $P$ | Admittance of grid circuit. |
| $Q$ | $1/G_2\omega L$. |
| $r$ | $C_0/C_1$. |
| $V_1$ | Input voltage to four terminal network. |
| $V_2$ | Output voltage from four terminal network. |
| $Y$ | Admittance of anode circuit. |
| $\alpha$ | $(1 + r(1 - \sigma^2))/(1 - \sigma^2)$. |
| $\mu$ | Amplification factor of valve. |
| $\eta$ | Anode voltage/grid voltage. |
| $\rho$ | Impedance of valve. |
| $\sigma$ | $\omega/\omega_0$. |
| $\omega_0$ | $1/(L_1C_1)^{\frac{1}{2}}$ : $2\pi \times$ resonant frequency of crystal. |
| $\omega$ | $2\pi \times$ operating frequency. |

The analysis is confined to the circuit with the crystal connected between grid and cathode. A similar analysis for the grid-anode connection could be performed, but in general the mechanical convenience of having one crystal electrode earthed makes this form of the circuit more popular. The results are expressed in the form of a design basis in the section headed Application of Results.

Finally an example is given applying the results of the analysis to the oscillator referred to above. Curves show the agreement between theory and experimental results.

In the appendix the corresponding line-controlled oscillator is discussed : the crystal is replaced by a line of length $\lambda/4$, short circuited at one end, and with the connections made at an intermediate point on the line. The anode load is formed by another suitable line.

### Analysis

The conventional physical circuit is shown in Fig. 1. A tetrode is used in order that the grid-anode capacitance shall be small compared with the required value, and thus an external element may be used, which will be independent of valve operating conditions.

The valve is biased in the usual way to give class *A* working, and the criterion for oscillations to be maintained is derived. If the amplification factor of the valve is

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* MS. accepted by the Editor, February, 1941.

slightly higher than that required for steady oscillation, oscillations, once started, will grow in amplitude until limited. Any random discontinuity in the circuit currents will suffice to initiate oscillation.

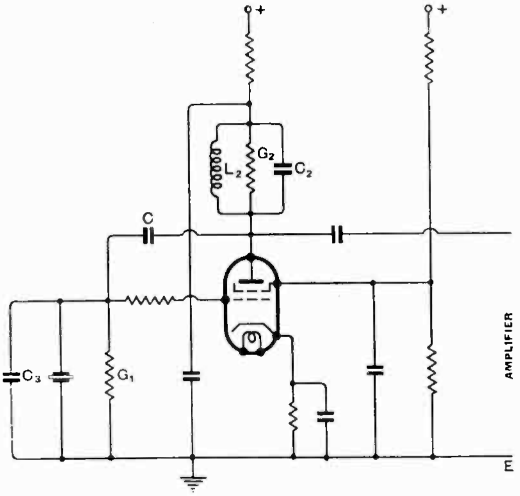

Fig. 1.

To simplify the analysis the tuned anode load is replaced by an equivalent inductance. Normally this inductance may be regarded as constant over the working frequency range of the oscillator.

Rearranging the circuit and taking account only of A.C. paths, the circuit can be drawn as Fig. 2. The valve is drawn as a triode, as the screen circuit provides only a static control of the effective $\mu$ and $\rho$ of the valve.

Assume that the connection between terminals 1 and 3 of Fig. 2 is broken. Then, provided that physical means are provided for maintaining the correct bias conditions, the network becomes an amplifier followed by a load $YCP$. If a voltage $e = e_0 \cos \omega t$ is applied between 1 and 2, the voltage between 3 and 4 will be $e' = e'_0 \cos (\omega t + \theta)$. If now $YCP$ is such that $e_0 = e'_0$ and $\theta = 2\pi n$ ($n$ an integer), terminals 1 and 3 will be at the same potential, and may be connected together without affecting the circuit. Then oscillations once set up will persist. For class $A$ conditions with zero grid current this means

$$I_1 = I_2 = 0$$
$$V_1 = V_2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Hence by applying the circuit laws

$$1 = -\frac{1}{\mu}\Big[(1 + \rho Y)(1 + P/j\omega C) + \rho P\Big] \quad \ldots \quad \ldots \quad (2)$$

$P$ is the admittance of the grid circuit and therefore

$$\begin{aligned} P &= j\omega C_0 + G_1 + j\omega C_1/(1 - \omega^2 L_1 C_1) \\ &= G_1 + j\omega C_1[1 + r(1 - \sigma^2)]/(1 - \sigma^2) \\ &= G_1 + j\omega C_1\,\alpha \quad \ldots \quad \ldots \quad \ldots \quad (3) \end{aligned}$$

where $\alpha = [1 + r(1 - \sigma^2)]/(1 - \sigma^2) \quad \ldots \quad (4)$

$Y$ is the admittance of the anode circuit and therefore

$$Y = G_2 + (1 - \omega^2 L_2 C_2)/j\omega L_2 \quad \ldots \quad (5)$$

If $1 - \omega^2 L_2 C_2$ is not too small, this may be written

$$Y = G_2 + 1/j\omega L \quad \ldots \quad \ldots \quad (6)$$

where $L = L_2/(1 - \omega^2 L_2 C_2) \quad \ldots \quad \ldots \quad (7)$

Substituting from (3) and (4) in (2),

$$\begin{aligned} -(\mu + 1) &= \rho G_1 + \rho G_2 + \frac{C_1}{C}\alpha \\ &\quad + \rho\left(\frac{1}{j\omega L} + G_2\right)\left(\frac{C_1\alpha}{C} + \frac{G_1}{j\omega C}\right) \ldots \quad (8) \\ &\quad + \frac{G_1}{j\omega C} + \frac{\rho}{j\omega L} + j\omega C_1\rho\alpha \end{aligned}$$

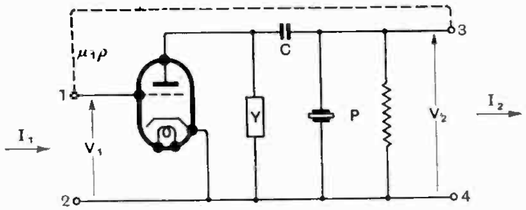

Fig. 2.

Separating real and imaginary parts we have :

$$\begin{aligned} -(\mu + 1) &= \rho(G_1 + G_2) \\ &\quad + (1 + \rho G_2)\frac{C_1\alpha}{C} - \rho\,\frac{G}{\omega^2 LC} \quad \ldots \quad (9) \end{aligned}$$

$$\begin{aligned} 0 &= \left(\rho\frac{C_1}{C} - \rho\omega^2 L C_1\right)\alpha \\ &\quad + \left(\rho G_1 G_2 + G_1\right)\frac{L}{C} + \rho \quad \ldots \quad (10) \end{aligned}$$

From (10)

$$\alpha = \frac{(\rho G_1 G_2 + G_1)\dfrac{L}{C_1} + \rho\,\dfrac{C}{C_1}}{\rho(\omega^2 LC - 1)} \quad \ldots \quad (11)$$

C

On substitution in (9) this gives, after rearrangement,

$$\mu = 1/\left(\frac{1}{\omega^2 LC} - 1\right) + \rho G_2/\left(\frac{1}{\omega^2 LC} - 1\right) \qquad \ldots \quad \ldots \quad (12)$$

$$+ \rho G_1\left[\frac{1}{\omega^2 LC} - 1 + \frac{L}{C\rho^2}\cdot\frac{1}{1 - \omega^2 LC}\right]$$

$$+ (2 + \rho G_2)\frac{L}{C}\,\frac{G_1 G_2}{1 - \omega^2 LC}$$

Reverting to equation (10)

$$\alpha = [1 + r(1 - \sigma^2)]/(1 - \sigma^2)$$

$$= \left[(\rho G_1 G_2 + G_1)\frac{L}{C_1} + \rho\frac{C}{C_1}\right]\Big/\Big(\rho(\omega^2 LC - 1)\Big) \qquad \ldots \quad \ldots \quad (13)$$

Rearranging (4)

$$\sigma^2 = 1 + 1/(r - \alpha) \qquad \ldots \quad \ldots \quad (14)$$

and inserting the value for $\alpha$ and $C_0/C_1$ for $r$

$$\sigma^2 = 1 + \rho C_1\Big/$$

$$\left[\rho C_0 + \frac{L(\rho G_1 G_2 + G_1) + \rho C}{1 - \omega^2 LC}\right] \qquad (15)$$

Equations (12) and (15) give the condition for oscillation and the oscillation frequency. In practice the value of $\mu$ given by equation (12) is lower than that obtained for small grid swings, and the amplitude of the oscillations grows until the curvature of the characteristic results in a mean value of $\mu$ corresponding to that of equation (12). It will be noticed that equation (12) which may be considered as determining the output of the oscillator, is independent of $C_0$, which may therefore be conveniently used to adjust the oscillator frequency as given by equation (15).

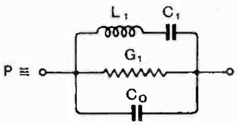

Fig. 3.

It now remains to select some physical condition which will permit the determination of the circuit elements, or will reduce the number of variable elements. One condition selected is approached from two standpoints, but may be taken as a single condition; either that $C_3$ (Fig. 1) should have a variable range effecting the greatest possible shift of oscillation frequency, or that $C_3$ should be sufficiently large to make the oscillation frequency independent of changes of valve input capacitance. Choice of $L_2$ will be left to the physical considerations applicable to any particular oscillator, as will choice of $L_1$ and $C_1$, the crystal constants. Another condition will be that over the range of variation of frequency, the output shall be maintained constant. To obtain this, use will be made of a rule applicable to all oscillators.

## Rule to be Applied

In a valve oscillator where constant output is desired with variation of circuit elements, the output must be taken from that valve electrode where limiting takes place.

Simple examples of this are :—

(1) With a low anode load impedance, and grid limiting taking place before anode limiting, the grid voltage remains constant.

(2) With a high load impedance, and limiting taking place at the anode, the anode voltage remains constant.

(3) With small swings, but an A.V.C. system operated from the anode, the anode swing remains constant.

Applying this rule to our crystal oscillator, if the ratio of the permissible anode swing to the permissible grid swing is $\eta$, we can take as a good class $A$ approximation,

$$\eta = \text{D.C. anode volts/D.C. grid volts} \qquad \ldots \quad \ldots \quad (16)$$

For limiting to take place at the anode we must have

$$\eta \leqslant |\mu/[Y(\rho + 1/Y)]| \qquad \ldots \quad \ldots \quad (17)$$

while for grid limitation

$$\eta \geqslant |\mu/[Y(\rho + 1/Y)]| \qquad \ldots \quad \ldots \quad (18)$$

when $\mu$ is the amplification factor for small grid swings.

For the oscillator under consideration we take the output from the anode, so rearranging (17)

$$\mu/\eta \geqslant |1 + \rho Y|$$

and this inequality certainly holds if

$$\mu/\eta - 1 \geqslant |\rho Y|$$

$$\geqslant \rho(G_2{}^2 + 1/\omega^2 L^2)^{\frac{1}{2}} \qquad \ldots \quad (19)$$

Hence we find that the optimum value of $L$, namely $L_m$, must satisfy the inequality

$$1/\omega L_m \leqslant \left[\left(\frac{\mu - \eta}{\rho\eta}\right)^2 \cdot - G_2{}^2\right]^{\frac{1}{2}} \qquad \ldots \quad (20)$$

If $\mu \gg \eta$ this can be written

$$\omega L_m \geqslant \left[\left(\frac{\mu}{\rho}\cdot\frac{1}{\eta}\right)^2 - G_2{}^2\right]^{-\frac{1}{2}} \quad .. \quad (20a)$$

A further condition which may be imposed is that $C$ should be chosen to make $\mu$ a minimum ; this is the condition for maximum output.

From (12), by rearrangement,

$$\mu = \frac{\omega L}{1 - \omega^2 LC}\left[\omega C(1 + \rho G_2) + \frac{G_1}{\rho\omega C}(1 + \rho G_2)^2\right] + \rho\cdot\frac{G_1}{\omega^2 LC} - \rho G_1$$

Equating the derivative with respect to $C$ to zero, all other elements being assumed constant, since in any case change of $C$ cannot greatly affect $\omega$, we obtain :

$$\frac{\omega^2 L(1 + \rho G_2) - \frac{LG_1}{\rho C^2}(1 - 2\omega^2 LC)(1 + \rho G_2)^2}{(1 - \omega^2 LC)^2} - \frac{\rho G_1}{\omega^2 LC^2} = 0$$

which gives the equation for $C_m$, the optimum value of $C_1$

$$\omega^4 L^2 C^2{}_m(1 + \rho G_2 - \rho G_1) + 2\omega^2 LC_m\left[\frac{\omega^2 L^2 G_1}{\rho}(1 + \rho G_2)^2 + \rho G_1\right] - \left[\frac{\omega^2 L^2 G_1}{\rho}(1 + \rho G_2)^2 + \rho G_1\right] = 0.$$

Writing for convenience

$$A = \left[\frac{\omega^2 L^2}{\rho^2}(1 + \rho G_2)^2 + 1\right]\rho G_1 \quad .. \quad (21)$$

we have

$$\frac{1}{\omega C_m} = \omega L\left[1 + \left(1 + \frac{1 + \rho G_2 - \rho G_1}{A}\right)^{\frac{1}{2}}\right] \quad .. \quad .. \quad (22)$$

which value may be inserted in equations (12) and (15).

Reverting now to equation (15), having fixed $C_m$ and $L_m$, we require for good frequency control by $C_0$ that

$$C_0 \gg [L_m(G_1 G_2 + G_1/\rho) + C_m]/(1 - \omega^2 L_m C_m) \quad .. \quad .. \quad (23)$$

for the smallest value of $C_0$, while for maximum range of control by $C_0$, $C_0/C_1$ must be as small as possible. Since $C_0$ includes $C_3$ and stray capacitances in addition to the crystal capacitance, this means that a low inductance crystal is required.

For frequency stability with supply variation the frequency must not depend on $\rho$. The term containing $\rho$ in (12) should therefore be small, and thus

$$L_m G_1/\rho \ll C_0(1 - \omega^2 L_m C_m) + L_m G_1 G_2 + C_m \quad .. \quad .. \quad (24)$$

Clearly when (23) holds, (24) holds also.

### Summary of Results

Writing $L_m$ in place of $L_2/(1 - \omega^2 L_2 C_2)$ (6) for anode limiting

$$\omega L_m \geqslant \left[\left(\frac{\mu - \eta}{\rho\eta}\right)^2 - G_2{}^2\right]^{-\frac{1}{2}} \quad .. \quad (20)$$

The optimum value of $C$ is given by

$$1/\omega C_m = \omega L_m[1 + \{1 + (1 + \rho G_2 - \rho G_1)/A\}^{\frac{1}{2}}]$$

where $A = \rho C_1[\omega^2 L_m{}^2(1 + \rho G_2)^2/\rho^2 + 1]$ (22)

For frequency control to be by $C_0$ we require

$$C_0 \gg [L_m G_1(1 + \rho G_2)/\rho + C_m]/(1 - \omega^2 L_m C_m) \quad .. \quad .. \quad (23)$$

while for wide range of frequency control the crystal inductance should be low. On the other hand, for rigorous control by the crystal, the crystal inductance should be high and $C_1$ low, so that the right-hand side of equation (15) is effectively unity.

For maximum frequency stability with valve changes

$$L_m G_1/\rho \ll C_0(1 - \omega^2 L_m C_m) + L_m G_1 G_2 + C_m \quad .. \quad .. \quad (24)$$

### Application of Results

The following example illustrates application of the results obtained above to the design of a crystal oscillator. The frequency of the oscillator is required to be variable over the maximum range compatible with crystal control in the region of 79.8 kc/s, control being effected by variation of $C_3$ (Fig. 1), forming part of $C_0$. The output is to be taken from the anode via a buffer stage.

(1) Valve selected ; KTZ.63, giving explicitly $\mu = 1.8 \times 10^3$, $\rho = 1.5 \times 10^6$, $\eta = 100$.

(2) Crystal selected with resonant frequency 79.8 kc/s ($\omega = 0.5 \times 10^6$). For the the specimen chosen $C_1 = 0.165 \times 10^{-12}$, $C_0 = 20.5 \times 10^{-12}$. To allow for valve and stray capacitances take $C_0 = 30 \times 10^{-12}$.

(3) Coil selected : the criterion in this case is that the self-capacitance should not

be greater than about one-tenth of the value of $C_2$ required, and that the coil should have a good $Q$ at the operating frequency. For the coil chosen: conveniently $L_2 = 20 \times 10^{-3}$ with a $Q$ of 100 and a self-capacitance of $4 \times 10^{-12}$ to be lumped in $C_2$.

(4) Grid resistance: conveniently $G_1 = 10^{-6}$.

(5) Anode conductance: from the $Q$ of the coil, $G_2 \nless 10^{-6}$. If we include the grid resistance of the buffer stage, $G_2$ is correspondingly increased. For convenience take $G_2 = 10^{-5}$.

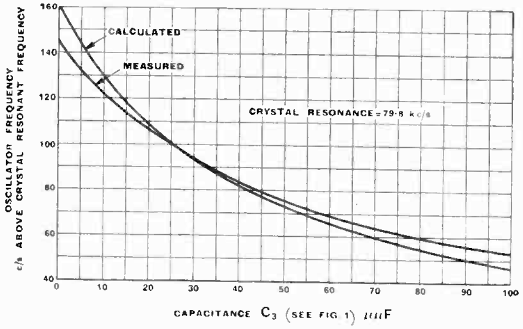

Fig. 4.

(6) Anode condenser, $C_2$: using (20), $\omega L_m \geqslant 188 \times 10^3$; $L_m \geqslant 376 \times 10^{-3}$. Hence taking the lowest value for $L_m$, by (16) $C_2 = 190 \times 10^{-12}$.

(7) Coupling condenser, $C_m$: by (21) $A = 7.53$ and by (22) $\omega C_m = 1.95 \times 10^{-6}$ and $C_m = 3.9 \times 10^{-12}$.

(8) Control by $C_0$: The right-hand side of the inequality (23) is $[L_m G_1(1 + \rho G_2)/\rho + C_m]/(1 - \omega^2 L_m C_m) = 10.8 \times 10^{-12}$. Hence $C_0$ will still exercise reasonable control at its minimum of $30 \times 10^{-12}$.

(9) Frequency Stability: Inequality (24) reduces to $0.125 \times 10^{-6} \leqslant 1.90 \times 10^{-6}$ which may be considered reasonably satisfactory. The component values obtained above are not critical.

Fig. 4 shows the calculated and measured curves of the oscillator frequency plotted against the capacitance of $C_3$, and Fig. 5 shows the measured output plotted against frequency. Departure from the calculated performance in Fig. 4 is due to the difference between the design values and the values of the components actually used.

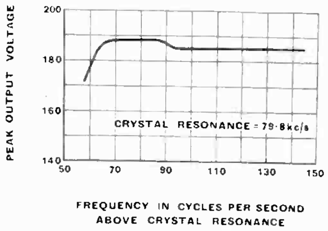

Fig. 5.

## APPENDIX

### *Application of the Theory of the Pierce Oscillator to Line-stabilised Oscillators*

At very high frequencies, the use of quartz crystals to provide stabilisation of an oscillator becomes impracticable, partly for mechanical reasons, and partly because the "$Q$," or reactance/resistance ratio, of the crystal is no longer large. A circuit commonly used is, however, almost identical with the crystal oscillator circuit, with the exception that the controlling crystal is replaced by a quarter-wave line, connection being made to an intermediate point on the line. By expressing the impedance of the line in suitable form, the design principles laid down above can be extended to cover this circuit.

*Analysis.*

Consider a line of characteristic impedance $Z_0 = 1/Y_0$ and of length $l = \lambda/4$, short circuited at one end (Fig. 6.) The admittance measured at a point $l$ from the open end will be $Y = jY_0 \cos(\omega l/v)/[\cos(\omega l_1/v) \sin(\omega(l - l_1)/v)]$.

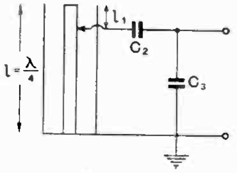

Fig. 6.

Near the first zero, where $\omega l/v = \pi/2$, let $Y = j\omega C_1 + 1/j\omega L_1$ and $\omega^2 L_1 C_1 \doteqdot 1$ (Fig. 7a).

Differentiating, the appropriate values for $C_1$ and $L_1$ are found to be:

$$C_1 = \frac{Y_0}{\omega}\frac{\pi}{4}\sec^2\left(\frac{l_1}{l}\frac{\pi}{2}\right) = \frac{Y_0 l}{2v}\sec^2\left(\frac{l_1}{l}\frac{\pi}{2}\right) = \frac{Kl}{2}\sec^2\left(\frac{l_1}{l}\frac{\pi}{2}\right)$$

$$L_1 = \frac{Z_0}{\omega}\frac{\pi}{4}\cos^2\left(\frac{l_1}{l}\frac{\pi}{2}\right) = \frac{1}{\omega^2}\frac{2v}{Y_0{}^1}\cos^2\left(\frac{l_1}{l}\frac{\pi}{2}\right)$$

$$= \frac{2}{K\omega_1{}^2}\cos^2\left(\frac{l_1}{1}\frac{\pi}{2}\right)$$

where $K$ is the capacitance per unit length of the line.

If the circuit includes a series capacitance $C_2$, the reactance characteristic becomes that of Fig. 7b, and the ratio of anti-resonant frequency to resonant frequency will be

$$\frac{v_a}{v_r} = \left(l + \frac{C_2}{C_1}\right)^{\frac{1}{2}}$$

The addition of a shunt capacitance $C_3$ gives the reactance characteristic of Fig. 7c. Here $v_r$ has not changed, but $v_a$ has been reduced to

$$v_a{}^1 = \tfrac{1}{2\pi} \cdot [L_1 \cdot \{C_1 + C_2C_3/(C_2 + C_3)\}]^{-\frac{1}{2}}$$

It will be seen that this reactance characteristic is identical with that of the crystal elements of the oscillator circuit discussed above. Hence the conclusions derived are applicable to the line oscillator.

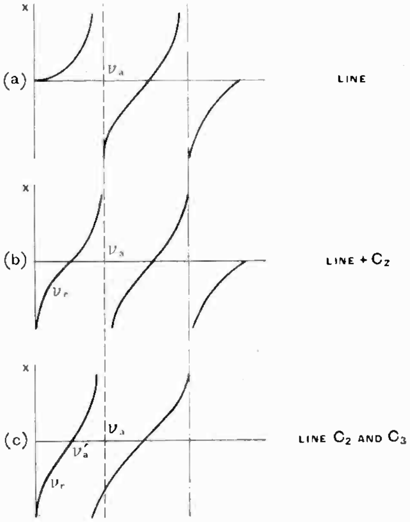

Fig. 7.

With an inductive anode circuit impedance, produced by either a suitable physical coil or a line of length between $\lambda/4$ and $\lambda/2$, the oscillation frequency lies between $v_r$ and $v_a{}^1$. For the maximum stability then, these two frequencies should be as close as possible. This becomes

$$\frac{C_1 + C_2C_3/(C_2 + C_3)}{C_1 + C_2} \sim 1 \qquad \text{giving}$$

$$C_2 \ll (C_1C_3)^{\frac{1}{2}}$$

Furthermore, as $C_3$ has some control of the frequency, it should be stable in value. Hence a physical condenser should be included to minimise the effects of valve capacitance changes. The largest possible value of $C_3$ should be used.

Making use of equations (20) and (21) of the crystal oscillator analysis, the minimum reactance of the anode circuit is found to be :

$$\omega L_m = \eta\rho/\mu \text{ approximately, or}$$

$$\frac{\text{D.C. anode voltage}}{\text{D.C. grid voltage}} \div \text{(mutual conductance of the valve).}$$

The feedback capacitance is approximately given by

$$\omega C_{ag} - 1/\omega L_m$$

This value is somewhat greater than that obtained from the more exact equation (22). If possible this capacitance should also be a physical element.

Unfortunately the writer has no experimental verification of the results here obtained. Such information as has been made available to him has been in a form unsuitable for use in confirming the conclusions reached. The success of the crystal oscillator theory, however, affords some hope that the extension of the theory may be of value.

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# The Crosley Contrast Expander*

## An Analysis of the Circuit

### By S. W. Amos, B.Sc. (Hons.)

THE following is an analysis of that type of contrast expansion circuit, which consists of two similar metal-filament bulbs and two fixed resistances of the same value arranged in the form of a Wheatstone's bridge, as shown in Fig. 1.

Metal filament lamps possess the property that their resistance increases as the P.D. across them is increased. Some experiments carried out on a 2.5 volt torch bulb to determine this variation gave the curve shown in Fig. 2, from which it can be seen that the resistance varies from 1 to 10 ohms. In fact a 10 to 1 variation is nearly always possible with a metal filament lamp, and it is by virtue of this fact that such lamps can be used to achieve contrast expansion.

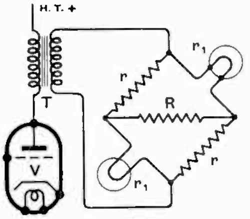

Fig. 1.

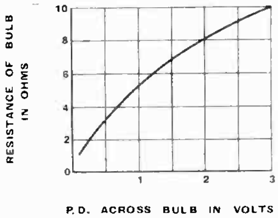

Fig. 2.

In Fig. 1, $V$ is an output valve, $T$ the output transformer, $r$ two similar fixed resistances and $r_1$ two similar lamps. $R$ represents the speech coil of the moving-coil loudspeaker.

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* MS. accepted by the Editor, March, 1941.

Let $r_1$ = resistance of each lamp when cold,

and $r_2$ = resistance of each lamp when hot.

If $r < r_1$ then the directions of the currents in all the resistances are as shown in Fig. 3.

Let $i_1$ = current in $AB$ and $CD$,

$i_2$ = current in $AC$ and $BD$,

and $i_3$ = current in the speech coil $R$.

Equating currents at $B$ :—

$$i_2 = i_1 + i_3.$$

Equating E.M.F.s around the circuit $ABC$ :—

$$r_1 i_1 = r i_2 + R i_3.$$

From these two equations

$$i_2 = i_1 \frac{R + r_1}{R + r}$$

and

$$i_3 = i_1 \frac{r_1 - r}{R + r}.$$

Hence the power in the loudspeaker is given by

$$i_3^2 R = R i_1^2 \frac{(r_1 - r)^2}{(R + r)^2}.$$

Now the total power absorbed by the whole network is given by :—

Total power = P.D. between $A$ and $D$ × Total current flowing into $A$

$$= (i_2 r + i_1 r_1) \times (i_1 + i_2)$$

$$= i_1^2 \left(r_1 + r\frac{R+r_1}{R+r}\right)\left(1 + \frac{R+r_1}{R+r}\right).$$

Hence

$$\frac{\text{Power in speech coil}}{\text{Total power}} = \frac{R(r_1 - r)^2}{(Rr + Rr_1 + 2rr_1)(2R + r + r_1)}.$$

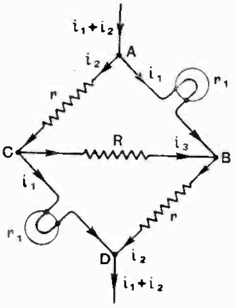

Fig. 3.

This result as it stands applies when the bulb is cold. By substituting $r_2$ for $r_1$ it applies when the bulb is hot. Now if, during the reproduction of loud orchestral passages the bulbs burn brilliantly, and if their resistances during very quiet passages are not appreciably different from the cold value, then it follows from the above that the ratio of increase of contrast given by the expander is given by :—

Ratio of increase of contrast

$$= \frac{[Rr + r_1(R + 2r)][(2R + r) + r_1](r_2 - r)^2}{[Rr + r_2(R + 2r)][(2R + r) + r_2](r_1 - r)^2}.$$

Putting $A = \dfrac{r_1(R + 2r)}{Rr}$; $B = \dfrac{r_1}{2R + r}$ and $r_2 = 10r_1$, and, writing it in the usual decibel notation we obtain for the improvement in contrast

$$10 \operatorname{Log}_{10} \frac{[A + 1][B + 1](10r_1 - r)^2}{[10A + 1][10B + 1](r_1 - r)^2} \text{ decibels.}$$

The behaviour of this expression with variation of $r$ is given in the Table, which also includes the corresponding values of power delivered to the speech coil and total power absorbed. These results have been evaluated for a speech coil of 5 ohms resistance and for bulbs having a rating of 4 volts and 0.1 amps. The curve of Fig. 4 illustrates the dependence of contrast upon the value of $r$. It is seen that the contrast increases with increase of $r$ and it actually reaches a theoretical value of infinity at $r = 4$ ohms, the resistance of the bulbs when cold. An improvement of 12 decibels is generally advocated as being most suited

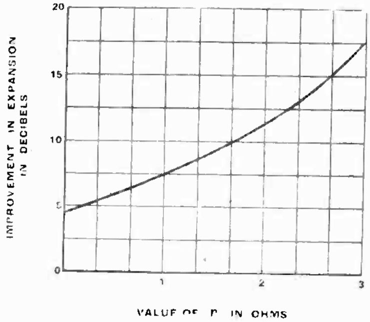

Fig. 4.

| Value of $r$ | Power delivered to speech coil | Total power absorbed by network | Ratio of increase of expansion | Improvement in expansion in decibels |
|---|---|---|---|---|
| 0 | 3.2 watts | 4.0 watts | 2.8 : 1 | 4.5 |
| 1 ohm | 2.11 watts | 4.04 watts | 5.76 : 1 | 7.6 |
| 2 ohms | 1.47 watts | 3.97 watts | 13.8 : 1 | 11.4 |
| 3 ohms | 1.07 watts | 3.77 watts | 56.9 : 1 | 17.6 |

to the reproduction of orchestral music, and it is seen that for the particular values chosen this is achieved with fixed resistors of value just over 2 ohms each.

The law which the increase of contrast obeys depends upon the way the resistance of the bulb varies with the P.D. across it. From Fig. 2 the variation of resistance is seen not to be a linear function of the applied P.D. and hence we can conclude that this expander does not give linear expansion, i.e. the improvement in contrast is not proportional to the original contrast present. Nevertheless, even this kind of expander is well worth including in receivers, owing to its simplicity.

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# Wireless Patents

## A Summary of Recently Accepted Specifications

*The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each*

### ACOUSTICS AND AUDIO-FREQUENCY CIRCUITS AND APPARATUS

531 963.—Means for producing "vibrato" effects in a low-frequency amplifier.

*S. W. Kaye. Application date 10th July, 1939.*

532 302.—Amplifying system in which a combination of positive and negative feed-back is used to stabilise the circuit.

*Standard Telephones and Cables (assignees of F. B. Llewellyn). Convention date (U.S.A.) 7th October, 1938.*

533 255.—Low-frequency amplifier with negative feed-back giving a differential attenuation of the high and low notes in order to improve the timbre of the reproduction.

*Philips Lamps. Convention date (Netherlands) 26th October, 1938.*

### DIRECTIONAL WIRELESS

532 107.—Aeroplane aerial designed to show equal sensitivity, at all points along the gliding path taken by the craft when making a blind landing.

*W. H. A. Thiemann (communicated by Bendix Aviation Corporation). Application date 25th May, 1939.*

532 122.—Keying system for a radio-navigation beacon transmitter of the overlapping-beam type.

*Marconi's W.T. Co.; E. Green; and N. E. Davis. Application date 12th July, 1939.*

532 173.—Aerial arrangement for a beacon station radiating a four-course navigational beam.

*Standard Telephones and Cables (assignees of E. N. Wendell). Convention date (U.S.A.) 30th September, 1938.*

532 499.—Directive aerial consisting of two spaced radiators each forming a narrow loop closed through a surge impedance. (Addition to 500 162.)

*Soc. Anon. des Industries Radio-Electriques. Convention date (France) 3rd September, 1938.*

532 547—Rotary condenser arrangement for switching the frame and vertical aerials used in direction finders to produce a reversed cardioid polar diagram.

*Marconi's W.T. Co. and C. S. Cockerell. Application date 29th August, 1939.*

### RECEIVING CIRCUITS AND APPARATUS

(*See also under Television*)

531 779.—Receiving set in which frequency-modulated signals are converted into amplitude-modulated signals by a frequency selective path controlled by back coupling.

*Standard Telephones and Cables (assignees of H. Nyquist). Convention date (U.S.A.) 24th August, 1938.*

531 827.—Electron-multiplier circuit in which the mean anode current is stabilised in order to regulate the mutual conductance of the valve for small grid voltage variations.

*E. L. C. White. Application date 10th July, 1939.*

531 977.—Lecher-wire coupling for a push-pull amplifier for ultra-high frequencies.

*Standard Telephones and Cables and D. H. Black. Application date 14th July, 1939.*

532 126.—Protective arrangement for a wireless set adapted to be energised either from A.C. or D.C. mains.

*A. A. Thornton (communicated by Philco Radio and Television Corporation). Application date 13th July, 1939.*

532 139.—Tightening device for the cord transmission or drive in the tuning system of a wireless receiver.

*Philips Lamps. Convention date (Netherlands) 20th August, 1938.*

532 213.—Means for neutralising the "blocking" or secondary-emission effect of strong signals in an output power pentode.

*W. W. Triggs (communicated by Rogers Radio Tubes). Application date 22nd August, 1939.*

532 249.—Automatic gain control system applicable to secondary-emission amplifiers.

*Standard Telephones and Cables; D. S. B. Shannon; and P. K. Chatterjea. Application date 18th July, 1939.*

532 316.—Design of superhet set with a stage of radio-frequency amplification intended to simplify tuning and switching.

*A. A. Thornton (communicated by Philco Radio and Television Corporation). Application date 17th July*, 1939.

532 326.—Cross-coupled valve circuit for producing a large output current not necessarily proportional to the input.

*L. H. Paddle. Application date 20th July*, 1939.

## TELEVISION CIRCUITS AND APPARATUS

### FOR TRANSMISSION AND RECEPTION

531 495.—Arrangement and mounting of the component parts of a wireless set on a chassis comprising parts which are vibration-proof and parts which are not.

*Philips Lamps. Convention date (Netherlnnds) 27th July*, 1938.

531 612.—Decoupling arrangement for a mains-fed wireless set using iron-cored tuning coils.

*L. L. de Kramolin. Convention date (Germany) 25th May*, 1938.

531 623.—Wireless receiver arranged to operate either as a superhet or as a straight tuned set, at will.

*R. M. Electric and G. H. Bradbury. Application date 6th July*, 1939.

531 828.—Cathode-ray tube in which a photo-sensitive surface of oxidised metal is used to produce a beam of electrons representative of the light and shade of a televised picture.

*Baird Television and P. W. Willans. Application date 10th July*, 1939.

532 074.—Thermionic-valve circuit arrangement for correcting the steady off-centre deflection of the electron stream in a cathode-ray tube.

*Baird Television and D. V. Ridgeway. Application date 16th August*, 1939.

## TRANSMITTING CIRCUITS AND APPARATUS

(*See also under Television*)

531 982.—Arrangement for protecting a wireless transmitter from the effects of lightning.

*F. C. McLean. Application date 9th August*, 1939.

532 121.—Means for preventing frequency " drift " during the time the cathode of a valve generator is heating-up.

*Marconi's W.T. Co. and N. H. Clough. Application date 12th July*, 1939.

532 204.—Modulating system with means for preventing distortion due to envelope phase-shift.

*E. K. Sandeman. Application date 21st August*, 1939.

532,619.—Selective transmission network comprising a four-terminal transducer for attenuating waves of one frequency while transmitting waves of a different frequency.

*Standard Telephones and Cables (assignees of C. H. Dagnall). Convention date (U.S.A.) 5th November*, 1938.

533 138.—Modulating system with means for accentuating either the carrier-wave with respect to the side-bands, or vice versa.

*Philips Lamps. Convention date (Netherlands) 15th October*, 1938.

533 289.—Transmitting circuit with balancing means for producing a frequency-modulated signal, particularly for short-wave working.

*E. C. Cork and J. L. Pawsey. Application date 16th July*, 1939.

533 479.—Means for eliminating " noise " in a system in which at least two signals are transmitted on the same carrier frequency, one by amplitude and the other by frequency modulation.

*The British Thomson-Houston Co. Convention date (U.S.A.) 12th November*, 1938.

## CONSTRUCTION OF ELECTRONIC-DISCHARGE DEVICES

531 760.—Cathode-ray tube of the kind in which television images of large size are produced by using a secondary cathode and an incandescent anode.

*Marconi's W.T. Co. and L. M. Myers. Application date 12th July*, 1939.

531 903.—Thermionic valve comprising means for compensating for the effect on the electrodes of thermal expansion of the lead-in wires.

*Standard Telephones and Cables and A. I. Vangeen. Application date 11th July*, 1939.

531 904.—Construction and assembly of the electrodes of a thermionic valve with external and internal screening means.

*Standard Telephones and Cables and F. D. Goodchild. Application date 11th July*, 1939.

532 025.—Construction and assembly of the electrode system of an electron multiplier or cathode-ray tube to avoid undesired secondary emission.

*F. J. G. van den Bosch and Vacuum-Science Products. Application date 12th June*, 1939.

532 082.—Arrangement of the concentrating and dividing electrodes in a two-stage electron-multiplier tube.

*The M-O Valve Co. and G. W. Warren. Application date 16th August*, 1939.

532 525.—Method of making from silver and antimony the mosaic electrodes used in television cathode-ray tubes.

*Baird Television and K. A. R. Samson. Application date 24th July*, 1939.

## SUBSIDIARY APPARATUS AND MATERIALS

530 726.—Device for producing a stream of ions moving at high velocity.

*" Fides " G.m.b.h. Convention date (Germany) 26th March*, 1938.

530 957.—Means for increasing, by any desired factor, the impedance of a multiple-electrode piezo-electric crystal unit.

*Standard Telephones and Cables (assignees of J. F. Barry and H. G. Och). Convention date (U.S.A.) 3rd September*, 1938.

531 268.—Adjustable-capacity electrodes for mounting one or more piezo-electric crystal oscillators.

*E. L. Gardner and Simmonds Development Corporation. Application date 4th July*, 1939.

531 639.—Piezo-electric valve-oscillator circuit for generating frequencies of the order of 500 kc/s.

*Marconi's W.T. Co. and G. P. Parker. Application date 12th July*, 1939.

# Abstracts and References

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*For the information of new readers it is pointed out that the length of an abstract is generally no indication of the importance of the work concerned. An important paper in English, in a journal likely to be readily accessible, may be dealt with by a square-bracketed addition to the title, while a paper of similar importance in German or Russian may be given a long abstract. In addition to these factors of difficulty of language and accessibility, the nature of the work has, of course, a great influence on the useful length of its abstract.*

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## PROPAGATION OF WAVES

1577. LONGITUDINAL ELECTROMAGNETIC WAVES BETWEEN PARALLEL PLATES [offering Simple Example of Wave Propagation in Hollow Guides, with Solution in Terms of Simple Mathematical Expressions, so that Physical Aspect of Problem is Not Obscured, and Effect of Conductivity of Dielectric can be Seen].—V. C. A. Ferraro & H. T. Flint. (*Proc. Phys. Soc.*, 1st March 1941, Vol. 53, Part 2, pp. 170–181.)

1578. ON THE ULTRA-HIGHS [Increase of Sporadic-E ("Short Skip") Reception as Sunspot Cycle approaches Low Period: "Persistent Feeling" among Experimenters that Some Relation exists between Weather & U.H.F. Long-Distance Communication, due to a Common Cause: etc.].—E. P. Tilton. (*QST*, March 1941, Vol. 25, No. 3, pp. 50–53.)

1579. RECOMBINATION AND ATTACHMENT PROCESSES IN THE IONOSPHERE [Quantal Collision Considerations leading to Values for $\lambda$ $(=N_-/N_e)$ of 100 in E Region and 1 or Less in F Region, consistent with Dynamo Theory (apart from Possible Modifications by Appleton-Weekes Lunar-Tides Results)].—H. S. W. Massey. (*Bull. No.* 11, *Int. Union Geod. & Geophys.*, Washington Transactions 1939, pub. 1940, pp. 521–523.) For previous work *see* 3038 of 1939.

1580. DISSIPATIVE PROCESSES FOR ELECTRONS IN THE IONOSPHERE [Establishment of Balance between Negative Ions & Electrons reduces Effective Value of Electron-Production Rate and increases Effective Electron-Recombination Coefficient: Explanation of Pressure-Independence of $(\alpha_e + \lambda\alpha_i)$ in Regions E & $F_1$: Doubtful Importance of Photo-Detachment: Uncertainty whether Great Discrepancy between Estimated & Theoretical Summer $F_2$ Recombination Coefficients can be similarly attributed to Negative Ions].—E. V. Appleton. (*Bull. No.* 11, *Int. Union Geod. & Geophys.*, Washington Transactions 1939, pub. 1940, pp. 523–526.)

1581. SOME RECENT IONOSPHERIC RESEARCHES [including Estimation of Scale Height from Ionised-Layer Structures, Estimation of Air Densities from Electron-Collision Frequencies, Variation of Solar U-V Radiation during Sunspot Cycle, Reality of D Layer, Lunar Tides, & Tropospheric Reflections (from Water-Vapour Discontinuities, not from Ionised Layers)].—E. V. Appleton. (*Bull. No.* 11, *Int. Union Geod. & Geophys.*, Washington Transactions 1939, pub. 1940, pp. 516–521.)

1582. THE IONOSPHERE TEMPERATURES [Calculation, by Equation $H = kT/mg$, of Temperatures in E & F Layers, for Various Assumed Compositions].—R. Penndorf. (*Naturwiss.*, 22nd Nov. 1940, Vol. 28, No. 47/48, p. 751.)

"Pekeris [*see* 3291 of 1940] has calculated, from measurements on separate days, the variation of the carrier concentration in the $F_2$ layer as a function of the true height, and obtains for $H$ [the scale height] values between 20 and 30 km, values considerably smaller than those given by Appleton for this layer and for the same time of year [4292 of 1939 and 1581, above]. For values of $H$ given by Appleton for the E layer, and for those calculated by Pekeris [for the $F_2$ layer], the present writer has calculated the corresponding temperatures from the equation $H = kT/mg$. In so doing, important assumptions have had to be made as to the composition of the air at these heights. These assumptions are either taken from the latest work on the subject or are so chosen as to represent limits within which the composition may vary . . . The E layer contains nitrogen and oxygen, of which the former is not dissociated, whereas the latter, under the action of the sun's rays, begins to dissociate at this height, so that the two assumptions '$A_1$' & '$A_2$' [$N_2$, $O_2$ & $N_2$, O, proportions 81% & 19% in both cases] are taken as limiting cases. Thus the temperature certainly lies between 330° & 374° K. The composition assumed in '$A_3$' [67% $N_2$, 32% O] is based on the data of Mitra & Rakshit [3120 of 1938: this assumption gives a temperature of 308°]. These writers arrive at the composition '$B_2$' [93% $N_2$, 6% $O_2$] for a 250 km height if $N_2$ & $O_2$ are present, and '$B_4$' [36% $N_2$, 64% O] for the supposition that only $N_2$ & O exist beyond a 100 km height. The remaining compositions '$B_1$,' '$B_3$,' & '$B_5$' are the limiting cases of probable compositions ['$B_1$' & '$B_3$' being exactly as '$A_1$,' '$A_2$' for the E layer—*see* above—while '$B_5$' is 41% $N_2$, 40% N, & 19% O].

"The temperatures arrived at are all lower than those previously supposed to exist, but are more reliable since the true heights, and not the equivalent heights, are used as a basis for the calculation of the vertical distribution of carrier concentration. Moreover, the hitherto assumed rapid rise of temperature between the E and $F_2$ layers is reduced to an amount that appears completely credible." For the E layer the values have already been mentioned: for the $F_2$ layer they range (for compositions '$B_1$' to '$B_4$' in order) from 625° to 437° K for the Pekeris lower limit $H = 20$ km, and from 936° to 655° K for his upper limit $H = 30$ km.

1583. IONISATION AND DISSOCIATION OF DIATOMIC MOLECULES BY ELECTRON IMPACT [Mass-Spectrometric Study of Molecules $H_2$, CO, NO, $N_2$, & $O_2$: Analysis of Results].—H. D. Hagstrum & J. T. Tate. (*Phys. Review*, 15th Feb. 1941, Vol. 59, No. 4, pp. 354–370.)

1584. PROBLEMS OF UPPER-ATMOSPHERIC PHYSICS [Question of Local Terrestrial Influence on F-Region Ionisation: Problems of the Noon "Bite-Out" in Ion Density and of the Presence of an Annual Variational Component in Same Phase in Both Hemispheres: etc.].—L. V. Berkner. (*Bull. No.* 11, *Int. Union Geod. & Geophys.*, Washington Transactions 1939, pub. 1940, pp. 500–502.)

1585. OBSERVATORY TECHNIQUE OF IONOSPHERIC MEASUREMENTS [and the Problems encountered in Their Analysis].—L. V. Berkner. (*Bull. No.* 11, *Int. Union Geod. & Geophys.* [as above], pp. 417–437.)

1586. OBLIQUE-INCIDENCE RADIO TRANSMISSION AND THE LORENTZ POLARISATION TERM [Comparison of Theoretical & Observed Max.Usable Frequencies leads to Support for Sellmeyer Theory ($a = 0$): a Step-by-Step Method of Solving the Integral Equation involved].—Newbern Smith. (*Journ. of Res. of Nat. Bur. of Stds.*, Feb. 1941, Vol. 26, No. 2, pp. 105–116.)

1587. ECHO MEASUREMENTS IN LONG-DISTANCE TRANSMISSION AND THEIR RELATION TO ZENITHAL REFLECTIONS.—R. Eyfrig. (*Hochf: tech. u. Elek:akus.*, Dec. 1940, Vol. 56, No. 6, pp. 161–174.)

The pulse-transmission researches of Crone & others (3974 of 1936) could not be carried as far as was intended, and for this reason alone a further series of tests was desirable (it is mentioned, in passing, that in the above paper the similar work of Martyn—1727 of 1935—was overlooked). Meanwhile, however, a theoretical paper has appeared (Millington, 4220 of 1938) and also two by Newbern Smith (3592 of 1937 and 3108 of 1938: an abbreviated treatment adapted to practical requirements): this theoretical work allows the conditions for long-distance transmission (with its oblique ray incidence) to be calculated from observations on vertical echoes (zenithal reflections). It became, therefore, additionally desirable to extend the original tests, in order to check these theoretical results. Four transmitters were available, at Herzogstand near Kochel (two), Adlershof, and Berlin. The second transmitter at Kochel was of the Goubau "continual rotation" type, giving pulses of a frequency which varied continuously over the range 1–10 Mc/s in a period of 3 minutes, then remained at a fixed value (61.6 or 46 m wave) for the rest of the hour until the next 3-minute "traverse" ("Durchlauf") was automatically started. The tests covered about 3800 hours in the periods June/Dec. 1938 and Jan./Aug. 1939.

Author's summary:—"In the first part of this paper the zenithal reflections of two stations at a distance of 560 km are compared. For the F layer good agreement was found, provided that the pulses were not in the immediate neighbourhood of the critical frequency [in which case, as might be expected from the more southerly situation of Kochel, implying a higher electron concentration, echoes were liable to be found there at times when no zenithal reflection occurred at Berlin. In connection with this difference in latitude, it is pointed out that the 2° difference in longitude should have made the morning rise in concentration reach a given value over Berlin about 8 minutes earlier than over Kochel: actually, in 85% of the cases zenithal reflection occurred first over Kochel, followed in 3–20 minutes by Berlin: in the remaining cases Berlin led by 2–14 minutes. This indicates "that the effect of difference of longitude is completely masked by that of difference of latitude, and perhaps also by other influences"].

"As regards the abnormal-E layer the conditions at the two stations may be completely different, a confirmation of the belief that the abnormal-E layer covers a comparatively limited extent in a horizontal direction. A large number of observations appeared to show that the abnormal-E layer, or more correctly its producing agent [corpuscular rays], is in motion and possesses a high north/south component of velocity" [thus Table 1, p. 164, shows several cases, both by day and night, when abnormal-E ionisation appeared over Berlin 1½–2½ hours earlier than over Kochel and disappeared ½–3¼ hours earlier. The calculated north/south velocity component, 40–320 m/s, "is of the same order as that found by Aschenbrenner in his Munich Dissertation" [no definite reference given].

"In the next part of the paper the usefulness of Newbern Smith's formula for the calculation of the effective heights of reflection at the F layer for long-distance transmission is confirmed" [Tables I, II, & III: the cursive numerals give the calculated values. The formula referred to (eqn. 4b, p. 165, is that given by the simple theory of Smith's first paper referred to above: his more complicated treatment in the second paper, taking into account the earth's curvature (and also the magnetic field) is not considered, the present tests being over a distance of only 560 km. Farmer, Childs, & Cowie (4219 of 1938) have stated that Smith's formula is only applicable if the ionosphere is in a calm condition, as indicated by clear and regular magneto-ionic splitting such as that of Fig. 6. The present observations, however, show that even when the layer is disturbed, as indicated by the rather thick, blurred F$_2$ traces of Fig. 7, the observed and calculated heights for a 61.6 m wave agree well. But when multiple splitting occurs at zenithal reflection, serious discrepancies are found (*see* small table at bottom of p. 167), amounting in one case to as much as 95 km. Examination of all the data leads to the conclusion that wherever multiple splitting was found, the calculated height was *always* lower than the observed height (p. 168: the small table, however, shows one case, on 6th December, where the two values agreed although, presumably, multiple splitting was observed). "Owing to the complicated nature of the relations it is not easy to give a definite explanation of this result." The validity of the Smith formula was not checked for the E layer, since Smith's second paper had already confirmed this].

"In conclusion, 'transmission loops' and other special transmission phenomena in the neighbourhood of the critical frequency are discussed. The probability is pointed out of the existence of an occasionally occurring ionisation layer above the F$_2$ layer." The "transmission loops" here referred to are defined as follows:—for frequencies close to the critical frequency, two paths exist (Lassen, 1926), a shorter path resulting from approximately mirror-like reflection and a longer one in which the wave is propagated over a long stretch inside the ionised layer. If the electron concentration becomes smaller and approaches the value at which no more reflection can occur, these two paths come together, and with a further decrease in ionisation the transmission breaks down. In long-distance records this effect shows itself by the appearance of "hooks," which "were correctly interpreted for the first time in the Crone, Krüger, Goubau, & Zenneck paper [already referred to above]. A corresponding effect occurs as long-distance transmission sets in when the previously insufficient ionisation rises to a high enough value. Now it often occurs that the ionisation fluctuates in such a manner that the two paths persist during the whole time: the communication breaks off and is restored. In this way 'transmission loops' are formed, consisting of two 'hooks' in opposite directions" [Figs. 8–11]. Characteristic points about these loops are discussed. Since they are a regular feature in F$_2$ records, they might also be expected to occur with the E layer. No such traces, however, were found in all the 500 hours when the presence of the E layer afforded an opportunity for them to present themselves. This would imply that near those frequencies at which long-distance waves are just reflected at the E layer, the longer alternative path, in the layer itself, is not possible—presumably because of the steep gradient in that layer and its small thickness. The writer is not dogmatic on this point: he agrees that the number of observations may have been too small, or the resolving power of the apparatus too low; although certain points he makes regarding the "transmission loops," such as the indication that during a decrease in electron concentration the gradient in the layer becomes steeper ("which may be explained by contraction"—bottom of p. 171), convince him that the technique employed is so sensitive that it brings out facts hitherto unnoticed. It is mentioned that on many occasions the records show simultaneous reflections at the F$_2$, F$_1$, and E layers, due to the different angles of incidence at the various layers.

As regards the occasional appearance of a layer above the F$_2$ region, this is dealt with in sub-section b on pp. 172–173 (where it is also mentioned that "hooks" do not always occur at the setting-in or breaking-off of long-distance transmission: the upper path is often absent, perhaps because of the much greater absorption in the passage over a long stretch of the layer. It is also mentioned here that transmission by double reflection at the F layer [2 × F$_u$ in Fig. 14] may persist longer than that by single reflection [F$_u$], in spite of the steeper incidence in the former case). The occurrence of this additional layer is deduced from the occasional appearance of small "loops" in the upper branch: such loops "can only occur if the 'traverse' in the neighbourhood of the critical frequency of the F$_2$ layer has a cusp": Fig. 16 is stated to show three such loops: "this is only possible if one assumes that above the usual F$_2$ layer yet another ionisation step occurs, but only occasionally. This is shown in Figs. 17 and 18. Moreover, such a layer has already been observed" [*see* the Crone paper already referred to].

1588. Relation between Actual and Virtual Ionospheric Height.—H. G. Booker & S. L. Seaton. (*Bull. No.* 11, *Int. Union Geod. & Geophys.* [as above], pp. 503–515.) Already dealt with in 2145 of 1940.

1589. Suggested Lines for Further Investigations of Upper-Air Physics.—J. A. Fleming. (*Bull. No.* 11, *Int. Union Geod. & Geophys.* [as above], pp. 527–531.)

1590. Results of Continuous Multi-Frequency Ionospheric Recordings at the Huancayo Magnetic Observatory, Peru, Dec. 1937 to Dec. 1938.—H. W. Wells & H. E. Stanton. (*Terr. Mag. & Atmos. Elec.*, Sept. 1939, Vol. 44, No. 3, pp. 326–334.) For later work *see* 25 of January.

1591. The Ionosphere.—E. O. Hulburt. (*Scientific Monthly*, May 1939, pp. 420–430.)

1592. The Reflection of Electromagnetic Waves from a Layer with a Negative Dielectric Constant [and the Origin of the Luxembourg Effect].—S. M. Rytov & F. S. Yudkevich. (*Journ. of Exp. & Theoret. Phys.* [in Russian], No. 8, Vol. 10, 1940, pp. 887–902.)

The difficulties arising in the study of the propagation of electromagnetic waves in a space whose properties vary continuously from point to point are discussed, and a short critical survey is given of the work on the subject done by various writers. The problem is then confined to a plane electromagnetic wave falling on a plane layer whose dielectric constant $\epsilon$ may decrease to zero and even acquire a negative value (all other factors such as the absorption due to the conductivity of the layer, the effect of the earth's magnetic field, etc., are neglected). A special type of layer is considered, characterised by a continuous variation of the function $\epsilon(x)$ from a positive value $\epsilon_1$ at $x \to -\infty$ to a negative value $\epsilon_0$ at $x = 0$ and to a positive value $\epsilon_2$ at $x \to +\infty$ ($\epsilon_1$ and $\epsilon_2$ being assumed to be equal); $d\epsilon/dx$ has only one discontinuity, namely at $x = 0$ (Fig. 2). It is pointed out, however, that the consideration of a special case does not invalidate the general significance of the conclusions reached.

The wave equation (2, 3) is written down and its solutions (3, 1) are obtained. The reflection of the wave from the layer is discussed in detail and conditions for total reflection are represented graphically in Fig. 3. General equations (4, 1) and (4, 2) are derived determining respectively $|E_1|^2$ in space $x < 0$ where a superposition of the incident and reflected waves takes place, and $|E_2|^2$ in space $x > 0$. An analysis of equation (4, 1) shows that in the case of total reflection and a sufficiently small slope of $\epsilon$, the intensity of the electric field of the wave is considerably increased (sometimes as much as 100 times) in front of region $\epsilon < 0$ (Figs. 4, 5, & 6). This phenomenon must favour the appearance of non-linear effects, and it is suggested in a brief discussion (p. 900) that it explains completely the origin of the Luxembourg effect.

In an appendix a general formula (d) is derived for determining the density $u$ of electric energy for any law of dispersion and any "achromatism" of the field.

1593. The Study of the Sudden Fade-Outs of Short Radioelectric Waves.—R. Jouaust. (*Bull. No.* 11, *Int. Union Geod. & Geophys.* [as above], pp. 413–416: in French.) Summarising the work dealt with in 3449/3452 of 1939.

1594. On the Link between Solar and Magnetic Phenomena [Statistical Examination of Tamanrasset Quiet-Day Magnetic Records, with Their Indications of Chromospheric Eruptions: Maurain's 2½-Day Interval between Spot & Storm (Significance Unknown): Hale's 26-Hour Interval confirmed for Sudden, Not Exceptionally Intense Storms].—J. Coulomb. (*Bull. No.* 11, *Int. Union Geod. & Geophys.* [as above], pp. 391–393: in French.) *See* also 3053 of 1939.

1595. The Determination in Advance of the Critical Frequencies of Ionised Layers. —K. M. Kosikov & V. A. Gromov. (*Elektrosvyaz* [in Russian], No. 9, 1940, pp. 40–45.)

The connection between the critical frequencies of the ionised layers and solar activity is discussed, and it is suggested that by using solar-activity indices it is possible to predict the critical frequencies for a considerable time in advance. Wolf's number $R$ in the form proposed by Stewart & Eggleston (3454 of 1939) is chosen for this purpose.

One of the methods proposed consists in plotting an $R$ curve, calculated from formula 1 ($R = F(r - S)^a \cdot e^{-b(r - S)}$), for the month or year in question, and also curves showing the relationship between the observed values of $R$ and the critical frequencies of the $F_1$ and $F_2$ layers. With the aid of these curves the critical frequencies can be predicted with sufficient accuracy for practical purposes. In the case of the E layer use is made of the formula $f_E = f_{E_0} \sqrt[4]{\sin h}$, where $f_{E_0}$ is the critical frequency of the layer when $h$ (the height of the sun over the horizon) is 90°, and of a curve (Fig. 8) showing the relation between $f_{E_0}$ and $R$.

1596. Periodicities in Solar Variation reflected in the Weather [Corrections].—C. G. Abbot. (*Nature*, 5th April 1941, Vol. 147, p. 414.) *See* 13 of January.

1597. A New Zone of Activity of the Solar Corona [Latitude 63°: No Accompanying Phenomena in Photosphere or Chromosphere].—M. Waldmeier. (*Naturwiss.*, 7th March 1941, Vol. 29, No. 10, p. 150.)

1598. The Continuous Spectrum and the Colour-Temperature of the Sun in the Region 3000–7000 Angstrom Units.—Kienle. (*Naturwiss.*, 28th Feb. 1941, Vol. 29, No. 9, pp. 124–129.)

1599. P-Radiation [from M-Regions of Great Activity on Sun's Surface: responsible for Auroras and Night Ionisation of Upper Atmosphere: coming in Clouds of Various Sizes forming More or Less Continuous Stream].—Carnegie Institution. (*Science*, 7th March 1941, Vol. 93, Supp. pp. 10 and 12.) A short note based on recent studies.

1600. Report of the Auroral Committee.—C. Störmer. (*Bull. No.* 11, *Int. Union Geod. & Geophys.* [as above], pp. 204–224.)

1601. "Das Polaricht und die Probleme der Höchsten Atmosphärenschichten [Aurora and Problems of the Upper Atmosphere: Book Review].—L. Harang. (*Naturwiss.*, 7th Feb. 1941, Vol. 29, No. 5/6, pp. 83–84.)

1602. A Possible Method of Measuring the Effect of Particle Emission on the Earth's Magnetic Field [Sun as Pseudo-Thermionic Emitter, with Fluctuations of Same Nature as Shot Effect & Flicker Effect: Possibility of A.C. Amplifier/Multilayer-Coil Combination capable of detecting Fluctuation Field of $5.2 \times 10^{-10}$ Gauss].—E. A. Johnson. (*Bull. No.* 11, *Int. Union Geod. & Geophys.* [as above], pp. 544–547.)

1603. The Disturbance-Field of Magnetic Storms [Chapman's Current-System checked by Independent Derivations of Currents required in Atmosphere for Selected Hours of Four Magnetic Storms].—E. H. Vestine. (*Bull. No.* 11, *Int. Union Geod. & Geophys.* [as above], pp. 360–381.)

1604. Study of the Severe Magnetic Storm of April, 1938.—A. G. McNish & H. F. Johnston. (*Bull. No.* 11, *Int. Union Geod. & Geophys.* [as above], pp. 348–353.) For the March 1940 storm *see* 15 of January.

1605. Various Hypotheses regarding the Origin and Maintenance of the Earth's Magnetic Field.—E. H. Vestine, M. A. Tuve, & E. A. Johnson. (*Bull. No. 11, Int. Union Geod. & Geophys.* [as above], pp. 354–360.)

1606. Variation in Earth-Current Activity with the Sunspot-Cycle [High Degree of Correlation between Annual (and also Month-to-Month) Changes].—W. J. Rooney. (*Bull. No. 11, Int. Union Geod. & Geophys.* [as above], pp. 467–473.)

1607. The Density of the Upper Atmosphere from Photographic Meteors [Indications that Temperature rises to Maximum (about 365°K) near 60 km and drops to Minimum (about 180°K) at or above 82 km (Noctilucent-Cloud Height): 60 km Maximum may extend 30 km or more, with Very Abrupt Drop to Minimum: a Seasonal Variation in Densities].—F. L. Whipple. (*Bull. No. 11, Int. Union Geod. & Geophys.* [as above], pp. 499–500.)

1608. On the 27-Day and 13.5-Day Waves in Cosmic-Ray Intensity, and Their Relation to Corresponding Waves in Terrestrial-Magnetic Activity [Both Waves are Quasi-Persistent: caused by External Magnetic Field superposed on Earth's Permanent Field at Times of Magnetic Disturbances].—S. E. Forbush. (*Bull. No. 11, Int. Union Geod. & Geophys.* [as above], pp. 438–452.) *See* also 1342 of 1940.

1609. Distribution of Ozone in the Stratosphere [Radiosonde Observations to 27 km, passing through 65–70% of Ozone & Other Ultra-Violet-Absorbing Constituents (if Any), chiefly localised between 15 & 27 km, with Wide Maximum of Concentration at 24–25 km].—W. W. Coblentz & R. Stair. (*Journ. of Res. of Nat. Bur. of Stds.*, Feb. 1941, Vol. 26, No. 2, pp. 161–174.) *Cf.* Strong, 1297 of May.

1610. On Maxwell's Theory for Dielectric and Magnetic Media [Modification to include Materials with Properties varying with the Field Strength].—Kneissler-Maixdorf. (*See* 1799.)

1611. The Measurement of the Dispersion and Absorption of Electromagnetic Waves in Heavy Water.—M. A. Divilkovski & D. I. Mash. (*Journ. of Exp. & Theoret. Phys.* [in Russian], No. 8, Vol. 10, 1940, pp. 903–907.)

It has been suggested that the sharp distinction between the properties, physical and chemical, of $D_2O$ and $H_2O$ is due not to the peculiarities in the molecular structure but to differences in intermolecular forces. If this is correct, the ratio of the relaxation times of the two substances should be equal to the ratio of viscosities. Accordingly, the relaxation-time ratio was calculated, using formulae derived elsewhere (727 [and 1958/1960] of 1940), from the dielectric constants and conductivities of the two liquids; the latter values were determined experimentally by observing the temperature rise in the liquid when placed in a magnetic or electric field (at wavelengths of 451 and 23.6 cm). The ratio was found to be $1.31 \pm 0.05$, while the ratio of viscosities was 1.23. This result is considered satisfactory, "since the slight discrepancy is probably due to experimental errors not yet accounted for."

1612. A Modern Representation of Gullstrand's Work on Geometrical Optics.—H. Epheser. (*Ann. der Physik*, Ser. 5, No. 7/8, Vol. 38, 1940, pp. 501–541.)

1613. Waves in an Open Oscillating Tank [containing Inviscid Liquid: Development of Approximate Theory for Small Displacements].—Binnie. (*Engineering*, 21st March 1941, Vol. 151, pp. 224–226.)

## ATMOSPHERICS AND ATMOSPHERIC ELECTRICITY

1614. Trends of Research in Terrestrial Magnetism and Electricity.—J. A. Fleming. (*Bull. No. 11, Int. Union Geod. & Geophys.*, Washington Transactions 1939, pub. 1940, pp. 41–61.)

1615. Ionic Equilibrium in the Troposphere and Lower Stratosphere.—O. H. Gish & K. L. Sherman. (*Bull. No. 11, Int. Union Geod. & Geophys.* [as above], pp. 474–491.)

1616. Need for Measurements to supplement Observations of Potential-Gradient and of Conductivity at Atmospheric-Electricity Observatories [*n*, *N*, & *q* All require Measurement before Interpretation is Attempted].—O. W. Torreson & G. R. Wait. (*Bull. No. 11, Int. Union Geod. & Geophys.* [as above], pp. 460–466.)

1617. Some Meteorological Effects and Their Relation to the Electrical Condition of the Lower Atmosphere.—G. R. Wait & O. W. Torreson. (*Bull. No. 11, Int. Union Geod. & Geophys* [as above], pp. 491–499.)

1618. New Measurements of the Effect of Atmospheric Pressure and Temperature on Cosmic Rays.—F. Göttlicher & W. W. Dittrich. (*Physik. Zeitschr.*, 1st/15th Sept. 1940, Vol. 41, pp. 402–406.)

1619. Change in Height of a Mesotron-Producing Layer of Air [Results indicating that Blackett's Assumption of Decaying Mesotron formed at Height varying from Day to Day may explain some Variations in Cosmic-Ray Intensity at Surface].—N. F. Beardsley. (*Phys. Review*, 15th Feb. 1941, Vol. 59, No. 4, p. 402.) *Cf.* Duperier, 1027 of April.

1620. The Daily Variation of the Cosmic Radiation [Recent Observations showing Systematic Differences between the Times of Appearance of the Extreme Values in the Daily Curve, for Different Azimuths: Explanation demands Increased Radiation at Certain Times of Day from Preferred Directions: Possible Interpretations].—W. Kolhörster. (*Physik. Zeitschr.*, 15th Feb. 1941, Vol. 42, No. 2/3, pp. 55–57.)

1621. THE COUNTER TUBE AS A MEASURING INSTRUMENT [Very Reliable & Consistent Results obtainable with Suitable Circuits].—W. Kolhörster & E. Weber. (*Physik. Zeitschr.*, 1st Jan. 1941, Vol. 42, No. 1, pp. 13–19.)

## PROPERTIES OF CIRCUITS

1622. REPORT ON THE PROPERTIES OF WIRES AT FREQUENCIES UP TO 400 Mc/s [including Thermal Method of measuring Skin Effect (applicable also to Current Measurement) of Magnetic & Non-Magnetic Wires: Comparison with Theoretical Values: Effect of Magnetic Fields on Resistance of Mumetal: etc.].—G. G. Sutton. (*Electrician*, 4th April 1941, Vol. 126, p. 202.) Summary of E.R.A. Report M/T 69.

1623. SURVEY OF THE PROBLEM OF MATCHING [for Maximum Power: Under- & Over-Matching in Output Valves: for Maximum Voltage: Resonance Matching: Resonance Matching with Double Lines at Ultra-High Frequencies: etc.].—H. Pitsch. (*Funktech. Monatshefte*, Jan. 1941, No. 1, pp. 11–16.)

1624. THE VALUE OF REACTANCE DIAGRAMS IN THE STUDY OF FILTERS, ETC. [illustrated by Example of Quartz-Crystal Resonator].—L. E. C. Hughes. (*Electrician*, 28th March 1941, Vol. 126, p. 197.)

1625. PAPER ON THE STUDY OF "GATE" AND OTHER FILTERS BY PHOTOGRAPHIC RECORDING, USING SQUARE-WAVE EXCITATION WITH AUTOMATIC REPETITION.—Turney. (*See* 1729.)

1626. APPARATUS FOR SURVEYING THE RESONANCE CURVES OF SIMPLE OSCILLATORY CIRCUITS AND BAND-FILTERS.—J. H. von Duhn. (*Funktech. Monatshefte*, June 1940, No. 6: Addendum, Jan. 1941, No. 1, p. 10.)

In the addendum the partial similarity between the writer's apparatus and the Philips "Frequency Modulator Type GM 2881" is acknowledged, but it is pointed out that in the latter apparatus the resonance curve "is displaced sideways past a fixed mark, and it may happen that the curve disappears completely or in part from the screen," whereas in his apparatus it remains unchanged on the screen.

1627. RECENT RESULTS OF THE THEORY OF LINEAR ALTERNATING CURRENT CIRCUITS [Linear Networks].—W. Cauer. (*Arch. f. Elektrot.*, 14th Dec. 1940, Vol. 34, No. 12, pp. 689–700.)

From the author's summary:—"A series of characteristic examples of the theory of linear networks are dealt with: oscillation condition for amplifier with negative feedback, calculation of the imaginary component from the real component of an impedance, reactance theorem, symmetrical quadripole, quadripole representation of a cable, chain-system band-filter with Tschebyscheff's quadripole damping, representation of a curve of equal subjective auditory sensitivity by a reactance quadripole with open-circuited output, representation of the CCI noise-level curve according to Lee & Wiener's method, an open-circuited-output broadcast band-filter, a low-pass filter with Tschebyscheff behaviour of the effective attenuation, six-pole frequency-separating filters with constant effective resistance, the establishment of a general law that every dipole consisting of inductances, mutual inductances, ohmic resistances, and capacities is equivalent to a dipole with only one single ohmic resistance, or what comes to the same thing, to a reactance quadripole closed by an ohmic resistance [Figs. 10 a–c: p. 699].

"In connection with these examples, the following conceptions and laws of circuit-theory . . . are discussed: equivalence, duality" . . . and the ability, given by the theory, to represent any curve which in a given frequency interval runs as an arbitrary positive continuous function, with any desired degree of accuracy as the attenuation of a symmetrical quadripole of constant effective resistance: "the advantages of such a method over the older, still widely employed methods of 1928 [Zobel and others] are obvious." A forthcoming book by the writer, "Theory of Linear Alternating-Current Circuits, Vol. I", is frequently referred to, as giving a comprehensive treatment of the wave-parameter theory of filters.

1628. WIDE-BAND TRANSFORMERS: PRACTICAL CALCULATION AND BALANCING [particularly for Television].—Hegner. (*See* 1701.)

1629. THÉVENIN'S THEOREM: AN EXAMPLE OF ITS VALIDITY IN TRANSIENTS AND OPERATIONAL CALCULUS.—T. H. Turney. (*Electrician*, 18th April 1941, Vol. 126, p. 234.) For other work on this theorem *see*, for example, 464 of 1937 and 2237 of 1938.

1630. ON THE THEORY OF PARASITIC BACK-COUPLING IN A RESISTANCE-COUPLED AMPLIFIER.—V. L. Lebedev. (*Elektrosvyaz* [in Russian], No. 9, 1940, pp. 59–65.)

It is pointed out that in investigating the self-excitation of resistance-coupled amplifiers using a rectifier for anode power supply, it is usual to regard the output impedance of the rectifier as equal to the reactance of the rectifier filter output condenser (Krize, 1353 of May). This would be correct if the critical frequency at which self-excitation conditions are created were much higher than the natural frequency of the filter. Theoretical considerations and experiments have shown, however, that these two frequencies lie close together, which makes the above assumption inadmissible. Accordingly another theoretical investigation of the problem is presented, and three-stage amplifiers with and without a decoupling anode filter are considered separately (Figs. 5 and 2 respectively). For each of the above cases equations are derived determining the amplitude/phase characteristic and critical frequency of the amplifier, and in accordance with Nyquist's principle conditions are established for stable operation.

1631. ON CHOOSING A CIRCUIT FOR A BAND-PASS AMPLIFIER.—N. I. Chistyakov. (*Elektrosvyaz* [in Russian], No. 9, 1940, pp. 74–78.)

It is shown in a book by the author that the band width $\Delta f_0$ at a frequency $f_0$ of a circuit with a damping $d$ is determined by a parameter $\alpha_0 =$

$2\Delta f_0/f_0 d$. It follows from this formula that $f_0 d = 2\Delta f_0/\alpha_0$ and that the relationship between $f_0 d$ and $\Delta f_0$ can be represented by a straight line with a slope $2/\alpha_0$. It is further stated that for each type of circuit there exists a definite relationship between $\alpha_0$ and the frequency distortion coefficient $\gamma$. Accordingly, 14 different circuits (one tuned circuit, two single non-coupled circuits, two-section filter with an optimum coupling between the sections, etc.) are considered and eight nomograms are drawn each showing a family of 14 straight lines for a definite value of $\gamma$. From these nomograms, according to the given data, an optimum circuit can be easily selected. Numerical examples are given.

1632. A Simple Amplifier for Very Small Current Pulses.—Riezler. (*See* 1784.)

1633. The Construction of Vector Diagrams for Damped Oscillations.—S. Reisch. (*Zeitschr. f. tech. Phys.*, Vol. 21, 1940, pp. 176–177.)

1634. A Circuit for Firing Thyratrons in Timed Sequence [primarily for Control of Cathode-Ray-Oscillograph Sweep and Thyratron Stimulators in Action-Potential Studies : Cycle Length from a Few Milliseconds to 4 Seconds. Cycle Spacing Half to 8 Seconds].—R. G. Loeffel. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, pp. 102–103.) For another circuit with the same object *see* 166 of January (Marshall & Talbot).

1635. The Theory of the Leaky-Grid Auto-Oscillator.—Evtyanov. (*See* 1645.)

## TRANSMISSION

1636. On Ultra-High-Frequency Oscillations generated by means of a Demountable Thermionic Tube having Electrodes of Plane Form [Experiments with Symmetrical Double-Cathode, Double-Positive-Grid Arrangement (1360 of 1938) : Advantages over Barkhausen-Kurz Connection : Relationships between Voltage, Electrode Distances, & Frequencies : Results possibly explained by Modification of Benham-Müller Negative-Conductance Theory : etc.].—W. A. Leyshon. (*Proc. Phys. Soc.*, 1st March 1941, Vol. 53, Part 2, pp. 141–156.)

1637. On the Theory of an Electron-Beam Oscillator with Phase Focusing.—V. I. Kalinin. (*Elektrosvyaz* [in Russian], No. 9, 1940, pp. 46–54.)

The theory of the ultra-short-wave oscillator proposed by Brüche & Recknagel (2325 of 1938) is discussed and formulae are derived which can be used as a first approximation in the design work. A simplified circuit diagram of the oscillator is shown in Fig. 2, where the mesh plates of condenser I are used as a "lens," while condenser II is placed at its focus. The "focusing" of electrons is examined with the aid of a graph, Fig. 4, where the movement and "bunching" of three typical electrons a, b, and c is indicated. A formula (5) is derived determining the conditions for ideal focusing, corresponding to an infinitely large density of the electron current, and also a formula (11) for calculating the current density at the focal point. Using formula 11 in a modified form (12) the curves of the current density at the focal plane are examined, and it is shown that they have a well-defined maximum which in certain conditions may split into two separate peaks. Thus the oscillator can also be used as a frequency multiplier if the frequency determined by the separation between the two peaks is separated from the oscillator output. The power delivered to circuit II is next determined (formula 18), and formula 19 is derived showing the efficiency of the oscillator. Methods are also indicated for determining the power outputs and efficiencies on separate harmonics. From a few numerical examples, it appears that an efficiency of the order of 50% may be obtained, which is much higher than the efficiencies of valve and magnetron oscillators operating on ultra-short waves. Finally, conditions for self-oscillation are established (eqn. 29).

1638. The Phase Focusing of Electron Beams travelling in a Straight Line [Velocity-Modulated Oscillators & Amplifiers]. — F. Borgnis & E. Ledinegg. (*Zeitschr. f. tech. Phys.*, No. 11, Vol. 21, 1940, pp. 256–261.)

In such devices, "the property of the modulator of bunching together the electrons at certain points is called 'phase focusing.' Brüche & Recknagel have pointed out the far-reaching analogy between this process and the focusing of light rays by a lens [2325 of 1938]. In further researches the focusing has been investigated particularly for the practically important case of a sinusoidal shape of the modulating potential $u(t)$ [references are here made to the work of Kockel & Mayer (2218 of 1940), Mayer (1657 of 1939), Geiger (1639, below), and Lüdi (3777 of 1940)].

"The procedure given in the present investigation for a thorough consideration of the path/time diagram of the electron paths ('electron time-table') enables a very simple and general view of the processes to be obtained ; in particular, the idea of phase focusing of higher order is given a very clear significance." This path/time diagram—the $(s,t)$ diagram—is first described : $s$ is the distance travelled beyond the modulator, along the "drift path" between modulator and catcher ; $t$ is time passing, $\tau$ the time of departure from the modulator, so that if $v(\tau)$ represents the velocity of an electron as it leaves the modulator at time $\tau$, the value of $s$ at any moment $t$ is given by eqn. 1, $s = v(\tau) . (t - \tau)$. This equation represents a family of straight lines with $\tau$ as parameter. In Fig. 2 the paths are shown of two neighbouring electrons leaving the modulator at times $\tau$ and $\tau + \Delta\tau$, the electron leaving at the latter moment being assumed to have a slightly higher velocity than the other. The neighbouring paths meet at time $t'$ at the position $s'$ : such a point $s'$ represents a focus of the first order. The envelope of the straight-line family of eqn. 1 with $\tau$ as parameter forms the geometrical locus of the first-order foci. The equation of the envelopes (referred to as the caustic by analogy with optics, the modulator representing the lens) is given in parametric form in eqn. 3 : $s =$

$v^2(\tau)/\dot{v}(\tau)$ ; $t = \tau + v(\tau)/\dot{v}(\tau)$, where the dot represents a differentiation with respect to the variable $\tau$.

Fig. 3 shows three paths, with $v(\tau_2) > v(\tau_o) > v(\tau_1)$. The following simplifying assumptions are made :—the function $v(\tau)$ is periodic, with the period $\tau_3 - \tau_1$ $(\tau_3 > \tau_2 > \tau_1)$ ; always greater than zero ; increasing monotonously in the interval $(\tau_1, \tau_2)$ ; the first derivative possesses one and only one extreme value in that interval ; and $\dot{v}(\tau_1) = \dot{v}(\tau_2) = 0$. Under these assumptions the envelope possesses a singular point, a sharp tip, as at $s_F$ (Fig. 3), as follows from eqn. 4 : $v(\tau) \cdot \ddot{v}(\tau) = 2\,\dot{v}^2(\tau)$. This applies to all functions $v(\tau)$ : if $v(\tau)$ is given, eqn. 4 gives the value of $\tau$ and thus (from eqn. 3) the value $s_F$ at the sharp point. If not more than 3 neighbouring paths meet here, $s_F$ represents a second-order focus : if the number of paths is $n + 1$, an $n$th order focus. A special case occurs when eqn. 4 is fulfilled identically ; that is, when it can be regarded as the differential equation for $v(\tau)$. The solution is $v(\tau) = s_F/t_F - \tau)$, and if this is combined with eqn. 3 it follows that $s = s_F$ : the whole caustic shrinks into a fixed point. Thus for this special course of $v(\tau)$ all the paths combine at one point (focus of infinite order).

Consideration of another method of representation, the $(s,\tau)$ diagram with $t$ now as parameter (Fig. 4), shows that although a second-order focus always exists, an $n$th order focus can occur only if all the conditions of eqn. 6 are fulfilled, namely $\dot{s}(\tau) = 0$, $\ddot{s}(\tau) = 0$, . . . $s^n(\tau) = 0$. One possibility is to depart from the above assumptions regarding $v(\tau)$ by giving the modulation a form such as that of a Fourier series with the necessary number of Fourier coefficients. Another theoretical possibility is to use several lenses one behind the other, their distances being so adjusted that the relative phase conditions of the modulating potentials $u(t)$ allow the whole system of eqn. 6 to be satisfied. Thus Fig. 5 shows an arrangement of two lenses (modulators) with spacing $s_1$. " A focus of higher than second order can naturally be obtained by such a combination of two lenses only if $s_1$ comes out a real number : we shall show below that for a pure sinusoidal variation of $v(\tau)$ and arbitrarily small depths of modulation the necessary conditions in eqn. 6 cannot be fulfilled by a real $s_1$ " [*see* final paragraph of abstract].

The density distribution along the path of the ray is then considered : Fig. 6 shows two neighbouring paths, one following the other at an interval of $\Delta\tau$. The ray density is given by eqn. 11 (a footnote points out that this value of density is identical with the total current density only outside the caustic). At the caustic itself the density is infinite. The positions of the minima of ray density are given by the condition $v\ddot{v} = 2\dot{v}^2$, which is identical with eqn. 4 (*see* above), so that the minima must be on those paths which pass through the focus of second or higher order, independent of the position $s$. The paths traversing the tip $s_{F2}$ of the caustic which lies *below* the axis $s = 0$ have to be taken into account, although this point has no real significance as a focus. The values of the minima are given by eqn. 13. At the focus itself $(s = s_{F1})$ the ray density (and here also the total current density) fluctuates between infinity and $j_o(1 + s_{F1}/|s_{F2}|)$, where $j_o$ is the ray density at $s = 0$. If $s_{F1}$ and $s_{F2}$ are symmetrical to the axis $s = 0$, the smallest ray density at the focus is equal to $\frac{1}{2}j_o$.

The final section II deals with the special case of a pure sinusoidal modulation of depth $\alpha$. Fig. 9 shows the position $s_F$ of the higher-order focus as a function of $\alpha$. For small values of $\alpha$ the symmetry condition mentioned above is practically fulfilled (Fig. 8), so that the ray density at the focus fluctuates between $\frac{1}{2}j_o$ and infinity. Consideration of a two-lens combination, with pure sinusoidal modulation of small amplitude, leads to eqn. 26 for the condition that a third-order focus should be obtainable, and this equation cannot be satisfied by real values of $s_1$, so that the result mentioned earlier is found, namely that under these conditions the second-order focus is the highest possible. A supplementary note on the Fourier analysis of $v(\tau)$ at low modulation depths will appear in the next issue.

1639. CURRENT-FLOW CHARACTERISTICS IN VELOCITY-MODULATED VALVES.—M. Geiger. (*Telefunken-Röhre*, No. 16, 1939, p. 177 onwards.)
A summary was dealt with in 2950 of 1940. The paper is referred to in 1638, above

1640. ON THE THEORY OF " DRIFT TUBES " [Hahn-Metcalf Velocity-Modulated Tubes].—H. E. Hollmann & A. Thoma. (*Hochf:tech. u. Elek:akus.*, Dec. 1940, Vol. 56, No. 6, pp. 181–186.)

" Path-time compression . . . was used first for the generation and amplification of ultra-short waves, in the Heil ' out-coupling ' generator [3380 of 1935] ; later, in the double-grid retarding-field valve with reversal-space free from high frequencies [Allerding & others, " Resotank," 2258 of 1938 : German Pat. No. 665 619] ; and finally in the latest American path-time devices, the Klystron [Varian, 2773 of 1939] and the ' drift tubes ' of Hahn & Metcalf [1901 of 1939 : for later work *see* 537/8 of 1940].

" Now that the theory of path-time compression has been developed by Webster [3950 of 1939 : for later work *see* 908 of 1940], and extended and tested experimentally with the help of ballistic models [Hollmann, 2544 of 1940], in the following pages the most interesting points of the drift tubes described by Hahn & Metcalf are investigated mathematically."

The writer deals first with the modulating system —" nothing more or less than the Heil ' out-coupling ' generator " : the condition for max. velocity modulation is obtained, and a formula for the optimum length of the modulating cylinder is found : if the former condition is satisfied, the input impedance of the cylinder is practically infinite and the modulation process takes up no energy. Next he considers the path-time compression between the modulating stage and the " work system " : *i.e.* along the drift tube or compression space. For the optimum condition at the modulator (*i.e.* $\phi_{1o} = \pi$) the compression factor is twice as large as in the Klystron, so that the beam can be fully modulated with half the modulating voltage or with half the compression angle.

Treatment of the " work system " deals with the final velocity of the beam electrons, the additional path-time compression in the "work cylinder" (superposed on that due to the modulating system and representing a type of anode retroaction), and the permissible voltage-modulation at the "work cylinder," limited primarily by the condition that the final velocity given by eqn. 3b should not be imaginary.

Section IV then considers the efficiency. The theoretical best efficiency comes out at 54%, compared with 58% for the Klystron: "since, however, it requires alternating voltages only half as high, the drift tube is superior to the Klystron particularly in the region of extremely short waves, where the matching may easily present difficulties." The internal resistance of the "work system" comes out at 1.35 × $10^4$ ohms for a beam velocity of 1000 volts and a beam current of 20 mA, so that low-loss cavity resonators can be found to match.

Section V takes advantage of the possibility, offered by the theory developed, of investigating the setting-up of oscillations through the negative internal resistance of the "work system" acting as a Heil "out-coupling" generator, "if only the repose current $I_0$ enters it: that is, if the velocity modulation arising from the modulating system disappears." The best efficiency then comes out at 30.5%. This leads to the final section VI, dealing with the Hahn-Metcalf modification of the original drift tube of Fig. 1 into the "reflection generator" circuit of Fig. 5, where the modulating system is made to function also as the "work system," the beam after emerging from the modulating system being returned to it by a stationary retarding voltage. Ordinarily, an efficiency of only about 38% is to be expected, but if working conditions and electrode spacings are so adjusted that a "sorting-out" of slow and fast electrons is obtained, the theoretical maximum becomes about 67%. Various factors, such as secondary emission, would prevent such a value being obtained in practice, but "the theory gives a convincing explanation of the good results obtained by Hahn & Metcalf with such devices."

1641. Band Width and Readability in Frequency Modulation.—Crosby. (*See* 1797.)

1642. The Theoretical Foundations of Modulation [Simple Mathematics of Amplitude, Phase, & Frequency Modulation: Comparison of the Last Two Types: Methods of Modulation: the Nature of the Armstrong System].—O. Schmid. (*Funktech. Monatshefte*, Jan. 1941, No. 1, pp. 1–6.) For the fundamental frequency-modulation methods the reader is referred to Weizenmiller's paper (1643, below).

1643. Frequency Modulation by Valves.—Weizenmiller. (*Funktech. Monatshefte*, April 1940, No. 4, p. 17 onwards.) Referred to in 1642, above.

1644. A Modulation Method for Ultra-Short-Wave Transmitters [to avoid Disturbance of Frequency & Oscillation Stability by Modulation of Electrode Voltages: Radiating Dipole mounted on Vibrating Dielectric Diaphragm close to Open End of Feeder]. — J. Pintsch A.G. (*Funktech. Monatshefte*, Feb. 1941, No. 2, p. 32.) German Patent No. 639 190.

1645. The Theory of the Leaky Grid Auto-Oscillator.—S. I. Evtyanov. (*Elektrosvyaz* [in Russian], No. 9, 1940, pp. 66–73: to be concluded.)

The Meissner leaky-grid oscillatory circuit (Fig. 1) is considered and two differential equations determining the operation of the system are written down (lower half of page 66). Using Van der Pol's method, these equations are reduced to two autonomous differential equations of the first order (end of section 2, p. 68), on which further analysis is based. In section 3 it is assumed that the static characteristics $I_a\ (e_g)$ and $I_g\ (e_g)$ can be represented by straight lines (Fig. 2), and methods are indicated for determining the amplitude $I_{a1}$ of the first harmonic of the anode current and the constant component $I_{g0}$ of the grid current. In section 4 a third equation (for $da/db$: beginning of the section) is derived from the two equations referred to above, and particular points of this equation on the phase plane $(a, b)$, *i.e.* points for which $da/db = 0/0$, are found.

1646. A Gang-Tuned Variable-Frequency Oscillator [with Advantages of Electron-Coupled Type (Electronic Isolation & Compensating Effect for Supply-Voltage Fluctuations) without Its Defect (e.c.o. Cathode above Ground Potential for R.F.)].— B Goodman. (*QST*, March 1941, Vol. 25, No. 3, pp. 14–17 and 74.)

## RECEPTION

1647. Reversal of Rectification by Heat in Crystal Contacts, and Its Analogy to a Thermoelectric Phenomenon [Experiments on Bornite Detector with Copper-Pin "Whisker": Support for Eccles Thermoelectric Theory of Rectification].—M. A. E. Sherbini & Y. L. Yousef. (*Proc. Phys. Soc.*, 1st March 1941, Vol. 53, Part 2, pp. 120–125.) Further development of the work dealt with in 2959 of 1939.

1648. A Compact 56 Mc/s Converter: a Two-Tube Single-Control Unit with 3 Mc/s Output.—B. Goodman. (*QST*, Feb. 1941, Vol. 25, No. 2, pp. 8–11.)

1649. Some Thoughts on Amateur Frequency-Modulation Reception: an Inexpensive Adapter for Use with Communications Superhets.—G. Grammer. (*QST*, March 1941, Vol. 25, No. 3, pp. 9–13 and 70 . . 74.)

1650. Phase Selection in Radio Communication [for Two-Channel Telephony].—E. G. Momot. (*Elektrosvyaz* [in Russian], No. 9, 1940, pp. 8–27: to be concluded.)

Continuing previous work (2977 of 1940) a theoretical discussion is given of a detector system suitable for two-channel radio-telephony. The system proposed by Pistolkors and Siforov in 1934 is essentially as follows. In the transmitter two modulators are used to which voltages are applied, coming from a common carrier-frequency oscillator but 90° out of phase (Fig. 5). In the receiver, the output of a synchronous beat-oscillator is added to the received double signal voltage, at an angle of approximately 90° to that modulation voltage which it is desired to eliminate (Fig. 6). In the present paper suitable detector circuits are shown (Figs. 9 & 10) and various aspects of their operation, such as the optimum phase angle of the local oscillator, synchronisation of this oscillator, distortion due to imperfect synchronisation, and frequency-stability requirements, are discussed in detail.

1651. Experiences of the Owner of a 400 Watt 20 m Telephone Transmitter in treating Neighbouring Broadcast Receivers to eliminate Interference.—C. Wesman. (*QST*, March 1941, Vol. 25, No. 3, pp. 43–47 and 104, 106.)

1652. Radio Interference from Thermostats in Refrigerators and Irons.—S. F. Pearce & S. Whitehead. (*Electrician*, 4th April 1941, Vol. 126, p. 202.) Summary of E.R.A. Report M/T 67.

1653. The Internal Resistance of Pentodes and Hexodes in Automatic Volume Control on the Distributing [Retarding] Grid: the Influence of the Screen & Retarding Grids on the Internal Resistance.—H. Pitsch. (*Funktech. Monatshefte*, Feb. 1941, No. 2, p. 28.)

The term "distributing grid" is given to the retarding grid (next to the anode) because when a volume-control voltage is applied to this grid it alters the distribution of the electron flow between the anode on the one hand and the screen grid on the other, and thus changes the slope of the control grid with respect to the anode current, so that the grid-voltage/anode current characteristic is tilted. This amplification control is used in addition to that at the control grid, to heighten the over-all control. As the volume-control voltage on the retarding grid becomes more negative, an electron cloud forms between screen and retarding grids, on which the anode alternating voltage exerts a stronger influence than on the electron current: the result is that the upper part of the valve behaves like a triode, in which the anode alternating voltage penetrates the control grid and the internal resistance falls, causing excessive damping of the following circuit. This effect led to the introduction of an additional screen grid between the retarding grid and the anode, with a low penetration coefficient (German Patent No. 622 513). The difficulty can also be avoided (as in the low-noise h.f. regulating pentode EF13) by spacing the retarding-grid spiral so widely that the electron cloud is reduced.

1654. Practical Design of Mixer or Converter Circuits: Comparison of Tube Types, and Checking Performance.—C. R. Hammond. (*QST*, Feb. 1941, Vol. 25, No. 2, pp. 38–43.)

1655. Mixing Arrangement for Superheterodyne Receivers [Difficulty of obtaining Necessary Oscillator Alternating Voltage over a Wide Frequency Range with Hexodes or Octodes: Objections to the Push-Pull Method of overcoming This: Improved Circuit with Octode combined with Triode].—H. J. Stanienda. (*Funktech. Monatshefte*, Nov. 1940, No. 11, p. 175.) A Schaleco-Radio patent.

1656. The Calculation of the Oscillator Circuit in the Superheterodyne Receiver [Choice of the Three Tracking Frequencies: Formulae for Shortening & Trimmer Condensers: Dependence of Former on Coil & Switch Capacities, etc: Nomogram: Interpolation Formulae for More Exact Calculation for Special Requirements: Calculation of Inductances].—O. Meisinger. (*Funktech. Monatshefte*, Nov. 1940, No. 11, pp. 161–164.) *Cf.* Wald, 1839 of 1940.

1657. Constant Band-Width Tuning: Use of "Staggered" Inductance Values.—R.C.A. (*Wireless World*, April 1941, Vol. 47, No. 4, pp. 105–106.)

1658. The Design of the Iron Core of Transformers [A.F. Output Transformers for Loudspeaker Supply: Physical Principles].—H. Pitsch. (*Funktech. Monatshefte*, Nov. 1940, No. 11, pp. 168–170.) Further development of the work dealt with in 3518 of 1939 and back reference.

1659. The AEG Broadcast Receivers 1940/41 for Export [Details of Types Super-430, Push-Button Super-D440, "Orchestra" Super 709, & a Small Battery Model 450B].—W. Hering. (*AEG-Mitteilungen*, Jan./Feb. 1941, No. 1/2, pp. 49/56.)

1660. Test Report: Philips Model 296A [Short, Medium, & Long Bands].—(*Wireless World*, April 1941, Vol. 47, No. 4, pp. 116–117.)

1661. Overhauling Old Receivers: Rejuvenating Veterans for Wartime Listening.—(*Wireless World*, April 1941, Vol. 47, No. 4, pp. 114–115.)

## AERIALS AND AERIAL SYSTEMS

1662. The Study of Short-Wave and Ultra-Short-Wave Aerials and Feeders by Model Tests at Much Lower Frequencies.—L. E. C. Hughes. (*Electrician*, 18th April 1941, Vol. 126, p. 233.)

1663. A Mast Radiator with a Regulated Current Distribution.—G. Z. Ayzenberg [Eisenberg]. (*Elektrosvyaz* [in Russian], No. 9, 1940, pp. 28–39.)

A comparison between mast radiators, as used at present for medium waves, and the T and L types of aerial is made and the desirability of improving the current distribution along the mast, and of extending its operating wave-band, is pointed out. Accordingly, consideration is given to an insulated tubular mast with a wire running up the centre, the wire terminating at the top in a lumped capacity formed by two divergent conductors. Four methods of operation are considered: (a) Mast fed at base, and base of mast and wire connected through a series *LC* circuit (Fig. 1a); (b) as "a" but with the *LC* circuit from wire to ground (Fig. 1b); (c) as "a" but with feed to the wire instead of to the mast-base, and *LC* circuit from base of mast to ground (Fig. 3); and (d) a simplification of "c" in which the mast is effectively grounded and a variable impedance is connected between a point some way up the mast and ground, for current adjustment.

For each of the above cases formulae are derived for determining the current and potential distribution and the effective height of the mast. Experiments were also made with a model of the type (a) mast which showed that throughout the whole wavelength range of the experiments (16 to 40 m) the current distribution along the mast could be easily regulated by varying $C$, and that in particular it was possible to maintain the current antinode at the middle of the mast. It was also found that the effective height of this mast is double that of an ordinary mast.

1664. A New Aerial-Measuring Instrument from the Rohde & Schwarz Laboratory.—O. Macek. (*Funktech. Monatshefte*, Nov. 1940, No. 11, pp. 171–173.)

A mains-driven instrument for measuring the natural frequency, equivalent capacity, resistance, and loss factor of an aerial, and the equivalent values of added coils and condensers. The calibrated signal generator has a range of 100 kc/s to 10 Mc/s.

## VALVES AND THERMIONICS

1665. On Ultra-High-Frequency Oscillations generated by means of a Demountable Thermionic Tube having Electrodes of Plane Form.—Leyshon. (*See* 1636.)

1666. On the Theory of an Electron-Beam Oscillator with Phase Focusing.—Kalinin. (*See* 1637.)

1667. The Phase Focusing of Electron Beams travelling in a Straight Line [Velocity Modulation], *and* Current-Flow Characteristics in Velocity-Modulated Valves.—Borgnis & Ledinegg: Geiger. (*See* 1638 & 1639.)

1668. On the Theory of "Drift Tubes" [Hahn-Metcalf Velocity-Modulated Tubes].—Hollmann & Thoma. (*See* 1640.)

1669. "Electron-Inertia Effects" [Book Review].—F. B. Llewellyn. (*Proc. Phys. Soc.*, 1st March 1941, Vol. 53, Part 2, pp. 199–200.) One of the "Cambridge Physical Tracts."

1670. Methods of Reducing the [Shot Effect] Noise of Valves [including Electron-Multipliers].—J. Gröber. (*Hochf:tech. u. Elek:akus.*, Dec. 1940, Vol. 56, No. 6, pp. 174–181.)

The "weakening factor" $F$, by which the Schottky expression for the mean square of the shot-effect current fluctuation in the saturated régime must be multiplied to obtain the corresponding value in the space-charge régime, is always smaller than unity: its minimum theoretical value has been found to be 0.1, while the smallest reliable experimental value is that of 0.22 obtained by Jacobi & Kirchgässner for cylindrical electrodes (*see* ref. 4 at end of paper). With commercial valves $F$ values only down to about 0.5 are obtained: this fact is attributed to the potential drop at the cathode (in directly heated valves), to cooling at the filament ends (producing saturation at those points), and to ion noise due to residual gas.

The first method now investigated for reducing $F$ is that of "high-frequency interruption in the saturation régime." Döhler & Hecker, in their paper on "a new rectifying mechanism for centimetric waves" (4383 of 1939), found that at these high frequencies the transit time of the electrons from the cathode to the potential minimum had a rôle to play. They showed that a rapid rise of the potential in the first moment caused the whole space charge between cathode and anode to fly to the anode. Now if the saturating voltage is interrupted periodically as in Fig. 1, being applied for times $t_1$ and cut off for times $t_2$, then during $t_2$ the space charge will collect, and since it will do so close to the cathode only a very small displacement current, with correspondingly small fluctuations, will flow during $t_2$. In time $t_1$ this space charge will overcome the potential minimum and, since the distance potential-minimum/anode is comparatively large, will reach the anode only after several time intervals. In this space charge the fluctuations occurring during its formation-time $t_2$ will already have been smoothed out, so that the total fluctuations should be reduced. This consideration only applies for times $t_1 + t_2$ so small that stationary values according to the three-halves law have not yet set in: this time is smaller than $3 \times 10^{-9}$ sec. "If, therefore, a frequency greater than $3 \times 10^{8}$ c/s is selected, a smaller fluctuation current must flow with this interruption, if the assumption is correct. If this effect is to predominate, the rise of the voltage pulse must be sharp, so that the space-charge weakening produced by the appearance of a potential minimum during the time $t_1$ can play no part. Besides steep sides for the pulse, the amplitude must be large enough to reach with certainty the saturation region."

Experiments on a diode were carried out with the apparatus of Fig. 2 and the amplifier of Fig. 3 (with a filter which cut out practically all flicker effect and ion noise), the voltage pulses being generated by a 3-point generating circuit using a special R.C.A. valve on wavelengths 50–150 cm. The diode was connected at a potential antinode of the Lecher system, which was inductively coupled to the oscillator: the rectified anode current produced a voltage drop across a 15-kilohms shunt resistance, and the noise component of this was led through a condenser to the amplifier. The measurements were repeated with the anode of the diode supplied with continuous positive potential, and the noise-values compared. The weakening factor $F$ decreased progressively from 0.97 to 0.44 as the interruption frequency was increased by decreasing the oscillator wave from 150 cm to 60 cm: here, of course, $F$ represents no longer the comparison between saturation and space-charge régimes, but between the "continuous" and the "interrupted" saturation.

The second method investigated is that of applying a magnetic field. The weakening effect of a space charge on the shot noise is due to the fact that each emerging electron causes a potential change in the valve and exerts thereby an effect on the passage of the other electrons: this reaction is so directed that it produces a reduction of the square of the current-fluctuation. Now Möller has shown that a magnetic field in the direction of the cathode of a concentric-electrode system causes the electrons to rotate round the filament many times before they reach the anode. Each electron should therefore, because of its longer stay, exert a greater reaction on the remaining electrons, and a consideration of the equation for the total fluctuation current in the space-charge régime (half-way down p. 177, r–h column: taking into account both classes of electrons, those that reach the anode and those that return to the cathode) shows that there should be an optimum number of spirallings which would give the greatest total weakening of shot noise. There should therefore be an optimum magnetic field and an optimum inclination of this field to the filament, assuming that the electrode system is sufficiently accurately concentric and that the magnetic field is quite uniform. Further, in such an arrangement the magnetic field increases the slope of the valve, and this in itself should improve the freedom from noise, since the merit of a valve in this respect is directly proportional to the square of the slope.

Measurements were first made on commercial concentric-system diodes, but it was soon found that the imperfect centering and straightness of the filament led to conflicting results: for instance, the slope was decreased instead of increased by the magnetic field, parasitic oscillations were liable to occur, etc. Magnetrons were therefore used instead (with their segments short-circuited) as likely to have good centering, and this was confirmed: the magnetic field increased the slope (about 1.6 times) and decreased, for the same anode current, the noise current to about one-half. The greatest noise reduction occurred when the field formed an angle of about 2°–3° with the filament, although this angle must be zero if the magnetic field is to increase the valve slope. The weakening factor was not so low as that found by Jacobi & Kirchgässner (mentioned above) on account of the end-cooling of the cathode and the field distortions due to the end-plates of the magnetron. Fig. 12 shows, for two values of anode current, the noise-current as a function of the magnetic field-strength: for each anode current there is an optimum field as regards noise.

Measurements on commercial triodes again encountered the difficulty that imperfect centering produced a decrease in slope when the magnetic field was applied. In spite of this, large reductions in the noise were obtained, as much as a 9-times improvement in merit being about the best result. With a bar-grid valve (curves in Fig. 17) instead of a spiral-grid design, the slope could be maintained unreduced in the magnetic field, probably owing to the smaller distortion of potential field with this type of grid. Here the merit was improved 3 times, but an important fact from the point of view of electron-multiplier design was brought out, namely that the magnetic field considerably decreased the shot noise in the initial zone. Weiss has proposed to work electron-multipliers in the transition region between the space-charge and initial zones, where the ratio $S/i_a$ is favourable and the shot effect is limited by the space charge: but by the use of a magnetic field the shot effect can be reduced also in the initial zone, and the electron-multiplier can thus be used in that zone, where the ratio $S/i_a$ is distinctly better than in the transition region proposed by Weiss.

1671. THE MECHANISM OF THE ELECTRICAL DISSIPATION OF GAS [" Clean-Up Effect "] AT PRESSURES BELOW $10^{-4}$ mm Hg.—H. Schwarz. (*Zeitschr. f. Phys.*, 28th Dec. 1940, Vol. 117, No. 1/2, pp. 23–40.)

In a high-vacuum hot-cathode tube of special design, with ring-anode, a sudden variation of anode current (" electron-current jump ") between the values 0.1 and 30 mA was observed (anode voltage 4000 v). This electron-current jump is attributed to electrical charging of the glass wall produced by secondary electrons. It is independent of pressure within the range $2 \times 10^{-7}$ and $2 \times 10^{-3}$ mm Hg. The charging of the wall depends on the secondary-emission coefficient $\delta$ of the wall: if $\delta$ is less than unity, the wall becomes negatively charged: if greater than unity, it charges positively. Introduction of gas raises the secondary emission: $\delta$ may rise above unity and the wall become suddenly positively charged. Outgassing reduces $\delta$ below unity, and the wall becomes suddenly negatively charged. By applying a magnetic field, only electrons of low energy were allowed to reach the wall: $\delta$ then remained less than unity under conditions where it would be greater than unity if there were no magnetic field. The electrical conditions were reproduced by introducing a copper-foil cylinder into the tube and evacuating the tube thoroughly: by giving this wall-coating the anode potential, the same high anode current was obtained as after a positive electron-current jump, while by giving it the cathode potential the same low anode current occurred as after a negative jump.

After the occurrence of a negative jump (*i.e.* a jump from high to low anode-current values) the pressure was found to fall, too quickly to be followed, from $10^{-4}$ to $10^{-6}$ mm Hg: the positive gas ions being " shot " into the negatively charged glass wall. This clean-up effect could not be obtained with the foil-lined tube: in a tube lined with an open-meshed wire net it was obtained only within a limited potential range (+30 to +140 v) for the net. It is deduced that for the clean-up effect to occur it is not enough that the positive ions should be able to reach the wall: the electrons must also be able to reach it, since the wall-charge is so small that it is completely compensated by $10^{12}$ positive ions, so that no measurable clean-up effect will occur. Further tests indicated that the net-coated wall may be considered equivalent to a perfectly smooth glass wall coated with a 1.7-molecular gas layer.

1672. THE INTERNAL RESISTANCE OF PENTODES AND HEXODES IN AUTOMATIC VOLUME CONTROL ON THE DISTRIBUTING GRID.—Pitsch. (*See* 1653.)

1673. TRIODE OR PENTODE? [in Audio-Frequency Stages: Triode preferred for " Quality " Receivers, Pentode only for Fewest Possible Valves].—J. Bärisch. (*Funktech. Monatshefte*, Nov. 1940, No. 11, pp. 165–167.)

1674. Practical Design of Mixer or Converter Circuits : Comparison of Tube Types, and Checking Performance.—C. R. Hammond. (*QST*, Feb. 1941, Vol. 25, No. 2, pp. 38–43.)

1675. Problems of Series Filament Operation [and Circuits to avoid Common Faults in connecting 1.4 V Filaments in Series or Series-Parallel : Protection of Valves against Failure or Removal of Any One : etc.].—(*Sci. Abstracts*, Sec. B, Feb. 1941, Vol. 44, No. 518, pp. 32–33.)

1676. Circuit for Amplifier Valves heated by Alternating Current or Pulsating Direct Current [for Hum Elimination].—Siemens & Halske. (*Funktech. Monatshefte*, Nov. 1940, No. 11, p. 176.) German Patent No. 650 206.

1677. Hot-Cathode Valves [German Patent No. 639 468 for Method of maintaining Emissivity under Varying Load Conditions by Use of Auxiliary Cathode heated by Anode Current].—Siemens-Schukert. (*Funktech. Monatshefte*, Nov. 1940, No. 11, p. 176.)

1678. Hot-Cathode Valves with Two or More Alternative Filaments. — Siemens-Schukert. (*Funktech. Monatshefte*, Feb. 1941, No. 2, p. 32.)

German Patent No. 635 540, for high-voltage valves in which the filaments are subject to electromechanical forces : the leads of one filament take the form of tubes enclosing the solid leads (glass- or quartz-insulated) of the second filament.

1679. The Rôle of Copper in the W-Cu-Ba Cathode.—K. Brüning. (*Physik. Zeitschr.*, 1st/15th June 1940, Vol. 41, pp. 285–290.)

1680. Experimental Investigations to Test the Wave-Mechanical Theory of Field Emission of Electrons [from Pure & Coated Metal Points : Previous Lack of Exact Knowledge about Shape of Point (& consequently about Field Strength) remedied by Electron Microscope : Müller's Deviation from 3/2 Law (Barium on Tungsten) due to Formation of Crystallites : Theory Confirmed].—R. Haefer. (*Zeitschr. f. Phys.*, 21st Nov. 1940, Vol. 116, No. 9/10, pp. 604–623.)

1681. Success of Seven Years' Test of Glass/Metal Seals using Kovar [Alloy of Iron, Nickel, Cobalt, & Manganese with Same Expansion-Coefficient as the Glass employed].—H. Scott. (*Sci. News Letter*, 1st March 1941, Vol. 39, No. 9, p. 135.)

1682. Brazing in Electrical Furnaces [for Metal Valves, Condenser Plates, etc : Advantages, Practical Technique].—G. Simon. (*AEG-Mitteilungen*, Jan./Feb. 1941, No. 1/2, pp. 20–24.)

1683. The Diffusion of Hydrogen through Iron and Its Dependence on the Condition of the Surface : Its Relation to Catalysis.—H. Betz. (*Zeitschr. f. Phys.*, 28th Dec. 1940, Vol. 117, No. 1/2, pp. 100–118.)

Further development of the work of Güntherschulze & colleagues on the diffusion, through an iron cathode, of hydrogen in a glow-discharge tube. It was found that the diffusion was almost completely suppressed if the entrance surface of the iron was " smoothed " with emery, and that on the other hand it was increased some 2.4 times if the emergence surface was " smoothed " instead ; the first result, therefore, was due not to the " smoothing " process rendering the surface impermeable, but to its making easier the return of the hydrogen atoms into the gas space, so that they preferred to do this rather than to enter the iron. Further experiments, in which the irregular scratches made by the emery were replaced by straight lines scratched with a razor blade to form grids of different spacings, confirmed this conclusion : apparently the sharp edges produced by either method act as active centres which facilitate the return of the hydrogen atoms. An equation based on this supposition, and relating the rate of diffusion with the spacing of the scratched lines, agreed well with measured results. The phenomenon has an intimate connection with surface catalysis, the sharp edges acting as active centres which promote the catalytic recombination of the hydrogen atoms into molecules.

## ACOUSTICS AND AUDIO-FREQUENCIES

1684. Directive Sound : the Theoretical Foundations for the Directive Transmission and Reception of Sound Waves, and Their Practical Applications to Problems of Sound Propagation in Free Media [Submarine Signalling, Harbour-Entry Sound Beams, etc.].—F. A. Fischer. (*Naturwiss.*, 7th March 1941, Vol. 29, No. 10, pp. 138–146.) For correction (inversion) of Fig. 2 *see* issue of 28th March, No. 13, p. 200.

1685. Combining High- and Low-Frequency Loudspeakers : Simple Dividing Networks for Use after the Amplifier.—J. K. Hilliard. (*Wireless World*, April 1941, Vol. 47, No. 4, pp. 103–104.) Article based on Hilliard's paper in *Electronics*, Jan. 1941.

1686. The Design of the Iron Core of Transformers [A.F. Output Transformers for Loudspeaker Supply].—Pitsch. (*See* 1658.)

1687. " Mystery " Record Players : Details of the Wireless Link in American Radio - Gramophones. — (*Wireless World*, April 1941, Vol. 47, No. 4, p. 113.)

1688. New Instrument answers Telephone automatically [" Peatrophone " : speaks Message (*e.g.* giving Whereabouts) and states that a 30-Second Message can be Recorded].—(*Distribution of Electricity*, April 1941, Vol. 13, No. 142, p. 460 : summary only.)

1689. On the Internal Friction of Violin Wood [the Pine used for Cheap Violins: Logarithmic Decrement independent of Frequency from 10 to 10 000 c/s].—E. Rohloff. (*Zeitschr. f. Phys.*, 28th Dec. 1940, Vol. 117, No. 1/2, pp. 64–66.) Extension of the work dealt with in 570 of 1939.

1690. The Line Recording Process in Cathode-Ray Oscillography [for Economy in Photographic Film, primarily in Researches on Speech and Auditory Fatigue].—Silink. (*See* 1730.)

1691. "Acoustics" [Book Review].—A. Wood. (*Proc. Phys. Soc.*, 1st March 1941, Vol. 53, Part 2, pp. 196–197.) Vol. II of "The Student's Physics": "its readers should not be confined to those about to sit for examinations. . ."

1692. On the Theory of Acoustic Double Refraction of Colloidal Solutions [Analysis of Orienting Action of Supersonic Waves on Suspensions of Non-Spherical Particles: Variation of Relaxation Time with Size of Particles & Viscosity of Liquid: etc.]—S. Oka. (*Zeitschr. f. Phys.*, 21st Nov. 1940, Vol. 116, No. 9/10, pp. 632–651.)

1693. Effect of Supersonic Waves on the Magnetic Properties of Nickel [Large Irreversible Changes: Barkhausen "Jump" helped forward].—Schmid & Jetter. (*Naturwiss.*, 7th Feb. 1941, Vol. 29, No. 5/6, p. 85: short summary only.)

1694. A New Method for the Measurement of Supersonic-Wave Absorption [using Modified "Schlieren" Method giving, with White Light, Coloured Pictures of Sound Radiation with Zones of Equal Intensity all in Same Colour].—E. Schreuer & K. Osterhammel. (*Naturwiss.*, 17th Jan. 1941, Vol. 29, No. 3, p. 44.)

## PHOTOTELEGRAPHY AND TELEVISION

1695. The Limits of Performance of Electron-Optical Ray-Producing Systems.—E. Gundert. (*Zeitschr. f. tech. Phys.*, No. 11, Vol. 21, 1940, pp. 246–250.)

The ray-producing system of a cathode-ray tube is in general required to give a spot on the screen of adequate brightness and smallness. Since the luminous output of the screen can be taken as approximately constant for a given phosphor, the necessary ray power $I_a \times U_a$ is governed by the requirements as to brightness. For a given ray power, however, the larger we make the ratio anode-voltage $U_a$/ray-current $I_a$, the smaller can the spot be made, but the greater becomes the expenditure in generating the anode voltage and in deflecting the ray. The inclination is, therefore, to keep that ratio to as low a value as possible consistent with the production of a sufficiently small spot. The object of the present paper is to derive the limit to which the ratio can be reduced, in a form applicable to practical tube design.

Starting from the Abbe "sine condition" for distortionless image formation (eqn. 1), and assuming that the spot consists of the image, on the screen, of the cathode or a part of it, and that the emerging electrons have a Maxwellian velocity distribution, eqn. 7 is obtained. This shows that there is a minimum value for the product $r.\sqrt{U_a/I_a}$ (where $r$ is the radius of the ray in the deflecting field) which must not be gone below if the tube "sharpness" is to be satisfactory. If $r$ could be increased arbitrarily, it would be possible to keep the product above the limiting value and yet reduce the $U_a/I_a$ ratio as much as was desired: but this increase of $r$ would produce aperture error, deflection coma, deflection astigmatism, and (for a slanting screen) defective depth focus. The maximum value for $r$ (and consequently the desired minimum value of $U_a/I_a$) is derived for four cases: where only one type of aberration has to be considered; where both deflection errors (astigmatism and coma) have to be considered; where astigmatism only has to be considered but in conjunction with aperture error; and finally where an arbitrary number of errors, increasing with differing powers of the ray radius, have to be considered as occurring simultaneously.

1696. An Example of the Appearance of Disturbing Structures in Television Images [Interference-Effect between the Parallel-Line Raster & the Image-Structure (a Form of the "Lath-Fence Effect") shown by Photographed Images of a Test Star for Various Numbers of Lines: Peculiar Structure resulting from Interference].—R. Theile. (*Funktech. Monatshefte*, Feb. 1941, No. 2, pp. 29–30.)

The true interference effect is best seen in Fig. 4, where the line thickness has been increased so that the wide black spaces between the lines (when the line-number is low) are reduced. The genuineness of the interfering action is confirmed by Figs. 5 & 6, where exactly the same patterns are obtained by direct photography of the combination of a star and a parallel-line grating.

1697. Colour Television: Direct Pick-Up demonstrated in the States [Orthicon Camera: Colour Disc Synchronisation by Transmitter Impulses instead of by Common Mains: etc.]. — Columbia Broadcasting System. (*Wireless World*, April 1941, Vol. 47, No. 4, p. 110.) *See* also 1122 of April.

1698. The Television Broadcasting Service and Its Evolution.—K. Müller-Lübeck. (*Funktech. Monatshefte*, Nov. 1940, No. 11, Supp. pp. 41–44.)

Including short descriptions of the equipment at the Berlin studios (for wireless broadcasting as well as for cable transmission on a 4.2 Mc/s carrier to certain Berlin and Hamburg viewing centres) and of the testing and transmitting technique: limitations and possibilities of television.

1699. The Unit Control Rack in Television Transmission Service.—M. Kippenhan. (*Funktech. Monatshefte*, Feb. 1941, No. 2, Supp. pp. 5–7.)

In Fig. 2, showing the basic lay-out of the "EKG" (unit control rack), *B* is the picture-control tube for monitoring the controls of background brightness and sharpness of detail; *KO* is the smaller tube for peak-value control (with fixed amplifier); the sound-control monitor is at the bottom. Wireless and wire broadcasting is provided for. The ubiquity of the " EKG " is seen clearly in the general station diagram given in Fig. 1.

1700. ULTRA-HIGH-FREQUENCY SUPERHET DESIGN FOR IMPROVED PERFORMANCE IN AUDIO AND VIDEO RECEPTION.—D. A. Griffin. (*QST*, Feb. 1941, Vol. 25, No. 2, pp. 27–29 and 90: to be concluded.) For the original receiver *see* Sherman, 3091 of 1940.

1701. WIDE-BAND TRANSFORMERS: PRACTICAL CALCULATION AND BALANCING [particularly for Television]—Th. Hegner. (*Funktech. Monatshefte*, Feb. 1941, No. 2, pp. 17–27.)

Further development of the work referred to in 48 of 1940. The present paper deals in a practical way with the two types of transformer, the unsymmetrical/unsymmetrical (one end of each winding earthed: in a television amplifier, for a frequency-band of 2 × 3 Mc/s on an i.f. carrier of 8.4 Mc/s: comparative advantages of one-sided and two-sided damping) and the unsymmetrical/symmetrical (secondary connected to push-pull amplifier or rectifier).

In general, one-sided damping is to be preferred (usually in the primary circuit): it gives a higher secondary voltage. Two-sided damping has, however, the advantage of a wider frequency band: it may be chosen when the measured limiting frequencies come out inside the required limits even with very close coupling, and the pass-band will then be increased $\sqrt{2}$ times. The coupling coefficient, for any particular core, shows only a slight dependence on the number of turns. It has a definite relation to the ratio of the limiting frequencies. The requirement that the limiting frequencies should lie symmetrically on either side of the carrier yields, by the formulae derived, all the characteristic frequencies. The estimation of the capacities on the primary and secondary sides allows approximate values to be derived for the primary and secondary self-inductances: a practical measuring method for checking these rough values is described. The design of a transformer for a push-pull stage has only one special requirement: that the secondary circuit should be made completely symmetrical: the capacities across the two halves of the secondary winding then have no effect on the functioning of the transformer as a band-filter. The secondary winding must be tuned as a whole to the resonance frequency. The results of the theory can be applied to transformers working in conjunction with rectifiers: the application is particularly complete for the whole-wave rectifier.

1702. STUDY OF COMPOSITE PHOTOCATHODE BY ELECTRON DIFFRACTION [Cs introduced into Chamber containing Oxidised Silver Film: Diffraction Pattern becomes Diffuse as Amount of Cs is increased and Photoelectric Current appears: later, becomes Sharp again as Photosensitivity disappears].—Uyeda & others. (*Sci. Abstracts*, Sec. A, Feb. 1941, Vol. 44, No. 518, p. 50.)

1703. MEASUREMENTS ON COMPOSITE PHOTOCATHODES: II.—P. Görlich. (*Zeitschr. f. Phys.*, 5th Dec. 1940, Vol. 116, No. 11/12, pp. 704–715.)

For Part I *see* 3695 of 1938. Summary of results:—(a) The Richardson straight lines for [Ag]-$Cs_2O$,Ag,Cs-Cs layers were measured and the work functions calculated from these were compared with those derived by the photoelectric method. Previous investigators had found large differences between the values given by the thermal and photoelectric methods, suggesting that the equation $e\phi = h\nu_0$ has no validity for composite cathodes: this would mean that a smaller energy is necessary for the thermal ionisation of adsorbed atoms than for the photoelectric ionisation. Table 1 shows the writer's results: although there is a tendency for the thermal value to lie below the photoelectric value, the differences are far smaller than those previously found.

(b) From new and previous results the writer obtains a picture of the constitution and emission mechanism of [Ag]-$Cs_2O$,Cs-Cs and [Ag]-$Cs_2O$,Ag,Cs-Cs layers.

(c) Layers of composition [Ag]-$Cs_2O$,F,Cs-Cs have their long-wave maximum more and more displaced towards shorter wavelengths, the larger the atomic volumes of the added foreign metal F, where F represents Mo, Al, Pb, Ni, or Mn. This rule does not apply to alkali or alkali-earth metals, or to silver itself, as the foreign metal. The sensitivity is increased considerably (Table 2) unless too much of the foreign metal is added (Table 4).

(d) A comparison of layers of composition [T]-$Cs_2O$,Cs-Cs and [T]-$Cs_2O$,T,Cs-Cs shows that the introduction of some of the carrier metal has a good effect for carriers other than [Ag]: here [T] represents Be, Mn, Pb, or Cu.

(e) Investigation of layers [T]-$Cs_2O$,Ag,Cs-Cs shows that the foreign metal determines not only the conductivity and the position of the long-wave maximum but also the over-all sensitivity; and that silver plays a specially important rôle as foreign metal (in some cases increasing the sensitivity 10 times). It is deduced that an interaction takes place, between the ionisable Cs atoms and the foreign-metal atoms, which has a decisive influence on the photoionisation of the Cs atom and hence on the sensitivity. The quite different action of a deposited foreign metal on the sensitivity of antimony-alloy photocathodes is discussed in section 7: here no increase in sensitivity is produced, but rather a decrease.

A bibliography is given at the end of the paper, and a footnote points out that the " new high-sensitivity photosurface " described by Glover & Janes (4370 of 1940) is evidently one of the composite cathodes dealt with above.

1704. THEORY OF ACOUSTIC DOUBLE REFRACTION OF COLLOIDAL SOLUTIONS [Orienting Action of Supersonic Waves on Suspensions of Non-Spherical Particles].—Oka. (*See* 1692.)

## MEASUREMENTS AND STANDARDS

1705. A NEW CONDUCTOMETER FOR THE FREQUENCY RANGE OF 0.1 . . . 100 Mc/s [in Two Models, 0.1–10 & 10–100 Mc/s: for

Measurement of Valve Input Impedances, etc.].—G. Opitz. (*Arch. f. Tech. Messen*, Nov. 1939, No. 101, double p.T 142.) Based on the work of Rohde & Opitz, 1128 of 1940.

1706. The Performance Limits of Thermal Radiation-Measuring Instruments [Vacuum Thermoelements, Radiometers, Bolometers, etc.].—W. Dahlke & G. Hettner. (*Zeitschr. f. Phys.*, 28th Dec. 1940, Vol. 117, No. 1/2, pp. 74–80.)

Some of these instruments can be classified as "heat engines" in which the radiation is converted into heat in an absorbing body (the "receiving system"), a fraction of this heat being made to perform the "deflection work." Czerny, in 1932, derived an upper limit for the "useful action" of such a device: for a temperature-rise of the receiving system of some $10^{-7}$ degree, this limit was given as around $10^{-9}$; actually, in practice, about $10^{-10}$ is attained. Another group, including the bolometer, cannot be classified as heat engines, because the deflection work is performed by a current source and the temperature-rise only acts as a release. Surprisingly, however, the performance of the most sensitive bolometer is only about the same as that of a heat-engine device. It is this problem, pointed out by Czerny, that the present writer examines.

He shows that the "energy threshold" of all such meters, and therefore their performance, is governed by the spontaneous energy and temperature fluctuations of the receiving system. The threshold can theoretically be lowered, and the performance improved, by lowering the temperature of the receiving system and everything with which it is in thermal exchange, or by decreasing the thermal capacity of the receiving system. The former process "encounters serious practical difficulties": the latter plan involves a consideration of the time during which the receiving system must be exposed to the radiation. He arrives finally at the conclusion that for a given ambient temperature the optimum performance depends only on the thermal-exchange rate $\lambda$ of the receiving system (eqn. 12), and concludes that the total thermal losses, useful and unavoidable, are likely to be of the same order in all types of device, which would account for the similarity in performance. The only hope of improving this performance would seem to lie in arranging for the best possible thermal isolation of the receiving system.

1707. The Differential Phasemeter.—V. M. Lavrov. (*Elektrosvyaz* [in Russian], No. 9, 1940, pp. 55–58.)

A new type of phasemeter has been developed in which use is made of two pairs of crossed coils mounted on a common spindle (Fig. 1). The angle $\alpha$ between the axes of the first pair 1 and 2 can be varied without altering the direction of the bisectors of the angles formed by these coils. The two other coils I and II are fixed with their axes coinciding with these bisectors. If currents of the same amplitude but displaced by an angle $\phi$ are passed through 1 and 2, a rotating magnetic field, generally of an elliptical form, will be produced. E.m.fs induced by this field in I and II will differ by $\Delta E = k \cos \frac{1}{2} (\phi \pm \alpha)$. If $\alpha$ is made such that $\phi = \pi \pm \alpha$, the rotating field will be circular and $\Delta E$ reduced to zero. In the experimental model built, $\Delta E$ is measured by a current indicator connected in a balanced thermocouple circuit (Fig. 2) and $\phi$ is read directly off the scale when $\Delta E = 0$. An accuracy within about 1% was obtained, and it is stated that with improved construction this can be made still better.

1708. A Circuit for testing Current Transformers [or Potential or Power Transformers: Ratio & Phase-Angle measured by Variation of Three-Voltmeter Method].—E. A. Walker. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, pp. 85–86.)

1709. A New Aerial-Measuring Instrument from the Rohde & Schwarz Laboratory.—Macek. (*See* 1664.)

1710. Apparatus for Surveying the Resonance Curves of Simple Oscillatory Circuits and Band-Filters.—von Duhn. (*See* 1626.)

1711. Electronic A.C. Voltmeter [for Frequencies 10 c/s to 150 kc/s: Special Logarithmic Indicator: Stabilisation & Linear Rectification by Negative Feedback: Model 300].—Ballantine Laboratories. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, p. 107.)

1712. A Wide-Range Vacuum-Tube Voltmeter: A.C.-Powered Instrument for D.C., A.C., and R.F. Measurements.—T. J. Kelley. (*QST*, Feb. 1941, Vol. 25, No. 2, pp. 32–35 and 82.)

1713. Voltage Measurement by a Photoelectric Null Method.—F. Ender. (*Physik. Zeitschr.*, 1st/15th June 1940, Vol. 41, pp. 297–302.)

1714. A Mixer Tube as Electrodynamometer for the Selective Measurement of Very Small Alternating Currents.—S. Singer. (*Zeitschr. f. tech. Phys.*, Vol. 21, 1940, p. 175 onwards.)

1715. A Contact and Timing Indicator for Insulation Measurements [for Insulation Resistance or Breakdown Tests on Radio Components in Mass Production: Danger of passing Faulty Items owing to Failure, or Too Short Duration, of Application of Voltage: a Thyratron Saw-Tooth Generator Circuit (with Neon Stabilising Diode) indicating Contact & Elapsing of Specified Time].—T. J. Rehfisch. (*Journ. of Scient. Instr.*, April 1941, Vol. 18, No. 4, pp. 63–65.)

1716. The Interval Selector: a Device for measuring Time Distribution of Pulses.—A. Roberts. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, pp. 71–76.) A summary was referred to in 2763 of 1940.

1717. New Application Possibilities for the Incandescent Lamp in Measuring Technique [Filament Resistance constant over Many Years if worked at only 8–10% of Nominal Voltage: Use for Extending or Compressing the Lower End of Meter Scales: etc.]—W. Oesinghaus. (*AEG-Mitteilungen*, Jan./Feb. 1941, No. 1/2, pp. 37–41.)

1718. Optical Lever Mirror [for Galvanometers, etc: Reflections from Air/Glass Surface of Usual Concave Mirror avoided by Replacement by Plano-Convex Lens with Silvered Back (Plane) Surface].—Taylor. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, pp. 104–105.)

1719. An Approximate Analytic Expression of the Ballistic Sensitivity Curve, and Its Application to Rapid Measurement.—de Gerszonowicz & Gerszonowicz. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, pp. 98–99.)

1720. Concerning Resistivity in Electrical Prospecting: a Practice to be Rejected [Mental Aberration in Use of Ohms/cm$^3$ or Ohms/m$^3$].—P. L. Mercanton. (*Bull. No. 11, Int. Union Geod. & Geophys.*, Washington Transactions 1939, pub. 1940, pp. 543–544: in French.) "An electrical resistance divided by a volume has no physical significance".

1721. On the Use of Silver Alloys as Resistance Materials [particularly for Standard Resistances: Investigation of Electrical & Mechanical Properties of Silver-Manganese-Tin Alloys NBW 108, 139, & 173: Large Negative Temperature-Coefficients of Resistance when Cold-Worked, reduced to about Zero by Suitable Heat Treatment].—Schulze. (*Physik. Zeitschr.*, 1st Jan. 1941, Vol. 42, No. 1, pp. 6–13.)

1722. Mutual Inductance of Two Helices whose Axes are Parallel [as in Ayrton-Jones Current Balance].—C. Snow. (*Journ. of Res. of Nat. Bur. of Stds.*, Dec. 1940, Vol. 25, No. 6, pp. 619–671.)

1723. Inductance Calculations as applied to Air-Cored Coils [with Table & Curve of $K$ in Modified Nagaoka Formula].—S. W. Amos. (*Wireless World*, April 1941, Vol. 47, No. 4, pp. 108–109.)

1724. "Quartz Oscillators and Their Applications" [Book Review].—P. Vigoureux. (*Proc. Phys. Soc.*, 1st March 1941, Vol. 53, Part 2, p. 197.) A notice was referred to in 1535 of 1940.

## SUBSIDIARY APPARATUS AND MATERIALS

1725. Kerr-Effect Oscillograph with Two-Coordinate Deflection.—Eder. (*Zeitschr. f. tech. Phys.*, Vol. 21, 1940, pp. 203–208.)

1726. On the Pressure of Electron Beams.—Selényi. (*See* 1804.)

1727. The Western Electric 330-Type Triple-Gun Cathode-Ray Tube.—(*Bell Lab. Record*, Jan. 1941, Vol. 19, No. 5, p. 164: photograph & caption only.)

1728. Adapting a Commercial Cathode-Ray Outfit for Direct-Coupled, Single-Sweep Applications [with Single Linear Sweeps up to 1 Second, and Long Time-Constant in Vertical Amplifier, as in Physiological Studies of Slow Transient Components].—Talbot. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, pp. 100–101.)

1729. Photographing Transients: Observation Simplified by Automatic Repetition [Hard-Valve Electronic Relay Switch Circuit, modified by Addition of Two Power Triodes in Parallel (as a Cathode Follower) and "Ammeter Valve," for Square-Wave Testing in Filter-Circuit Research: Results on "Gate" Filters (and Comparison with Ladder Type)].—Turney. (*Wireless World*, April 1941, Vol. 47, No. 4, pp. 98–100.) For the original "switch" circuit *see* Clothier, 4350 of 1939.

1730. The Line Recording Process in Cathode-Ray Oscillography [for Economy in Photographic Film].—Silink. (*Funktech. Monatshefte*, Jan. 1941, No. 1, pp. 7–10.)

Prague researches on certain diseases, by recording the initial changes of speech (particularly the sound of consonants in the middle of words), met with difficulties when ordinary mirror or cathode-ray oscillographs were employed for recording: the consumption of film was excessive, and the intensity of the sound source and sensitivity of the film did not allow the latter to be run fast, with the result that details were unreadable. The completely fortuitous superposition of a 50 c/s mains frequency on the c-r-o record of a relaxation oscillation (Fig. 1) led to the development of the modified recording method here described, in which a scanning action is applied to the ray in such a way that, allowing for the slant which would otherwise be produced by the motion of the film during the period of each line, the phenomenon is recorded in a close series of lines straight across the width of the film (Fig. 2c), the fly-back between the lines being too rapid to leave its trace.

The comparatively simple circuit is shown in Fig. 5. The time-base voltage is taken to the horizontal plates of the electrostatic oscillograph and to a voltage regulator, from which a certain fraction of it is led, together with the process-voltage, to the vertical plates. Since the ray is deflected more or less diagonally by the time-base voltage (to compensate for the film movement) the ray intensity can be increased considerably without any damage to the screen, so that much more rapid oscillations can be recorded than is possible with ordinary methods. To avoid over-exposure of a line in repose (*i.e.* without vertical deflection by the phenomenon) Hollmann's plan of regulating the ray intensity by a full-wave diode rectifier was employed: the rectifier is fed with the alternating voltage of the phenomenon and the rectified voltage applied to the Wehnelt cylinder so as to regulate the ray intensity in accordance with the phenomenon voltage. The great improvement produced by this refinement is seen by a comparison of Figs. 6 and 7, both of the same phenomenon. The advantages of the whole method, and its possible applications to purposes other than that for which it was developed, are discussed and illustrated on pp. 9–10.

1731. Success of Seven Years' Test of Glass/Metal Seals using Kovar.—Scott. (*See* 1681.)

1732. THE LIMITS OF PERFORMANCE OF ELECTRON-OPTICAL RAY-PRODUCING SYSTEMS.—Gundert. (*See* 1695.)

1733. ELECTRON-OPTICAL SYSTEMS IN CATHODE-RAY TUBES [Elementary Principles].—Diels. (*Funktech. Monatshefte*, Jan. 1941, No. 1, Supp. pp. 1–4.)

1734. ON THE APERTURE ERROR [Spherical Aberration] OF ELECTRON LENSES: REPLY TO A PAPER BY W. GLASER, *and* REMARKS ON THE FOREGOING REPLY.—Rebsch: Glaser. (*Zeitschr. f. Phys.*, 5th Dec. 1940, Vol. 116, No. 11/12, pp. 729–733: pp. 734–735.)

"W. Glaser has recently calculated a magnetic lens which is claimed to have no aperture error [1165 of April]. This claim contradicts previous work, so that it seems justifiable to examine it more closely. Von Scherzer has shown that the aperture error of the space-charge-free electron lens can have only one sign and is always greater than zero. Later it was shown that this error can theoretically be made arbitrarily small," by making the magnetic or electric field strength near the object change very rapidly over a very short length $l$, so that $l = (H/H')_{\max}$ or $l = (E/E')_{\max}$ is very small. Since $l$ is limited by the fineness of workmanship, there is a practical limit to the smallness of the possible aperture error: an empirical approximate value for the minimum attainable dispersion-circle radius is given by $\rho = \frac{1}{4} f V \delta^3$, where $f$ is the focal length, $V$ the magnification ratio, and $\delta$ the objective aperture. "The objectives of present-day electron microscopes have an aperture error more than ten times this value. It will be shown below that the field calculated by Glaser . . . is unsuitable for image-forming purposes. We calculate, for this purpose, the paths of the electrons proceeding from the middle of the object plane. It is seen that these electrons do not come together again at a point but traverse the field almost rectilinearly. . . . A further lens of adequate refracting power must be added for image formation: then however a finite aperture error is reintroduced. . . . To obtain the smallest possible aperture error one must return to the conditions given above, namely the sharpest possible field decrease at the object."

In his reply, Glaser disputes the validity of Rebsch's formula for the minimum value of $\rho$, which was based on magnetic fields having nothing to do with minimum aperture error and chosen merely because they were easily integrated. Fields can be obtained with much smaller values of $\rho$: in a later work he will give numerical details. The calculated field given by him was obviously not intended to be applied directly: the necessary departure from the ideal field, for practical purposes, must be made on the lines indicated in his paper. *See* also 1735, below.

1735. SPHERICAL ABERRATION IN ELECTRON-OPTICAL IMAGE FORMATION [Scherzer's Formula showing that Sp.A. cannot be Completely Eliminated: Glaser's Formula for Aberrationless Field: Proof that Latter Field cannot form Real Image: Scherzer's Dictum is Correct].—Recknagel. (*Zeitschr. f. Phys.*, 28th Dec. 1940, Vol. 117, No. 1/2, pp. 67–73.) *Cf.* 1734, above.

1736. FRESNEL ELECTRON DIFFRACTION.—Boersch. (*Naturwiss.*, 1st Nov. 1940, Vol. 28, No. 44/45, pp. 709–711.)

Hitherto, only the Fraunhofer type of diffraction has been encountered in electron optics (and has indeed been given the general term "electron diffraction"), although the writer pointed to the occurrence of Fresnel diffraction also, in connection with his investigations on the resolving power of the electron "shadow"-microscope—3715 of 1939, 1571 (and 2710) of 1940: also *Jahrb. AEG-Forsch.*, 1940, Vol. 7, p. 34. The difficulties in finding, with electrons, the specially interesting interference maxima of a straight edge (for Fresnel diffraction at a slit is complicated by its dependence on the width of the slit) are due to the shortness of the de Broglie wavelengths of the electrons and the consequent very close spacing of the maxima. To enable these maxima to be separated, the lack of sharpness due to the size of the electron source must be made small compared with their spacing: thus to resolve the maxima $n$ and $n + 2$, the diameter $d$ of the source must not exceed $\sqrt{\lambda . a}\,(\sqrt{n+2} - \sqrt{n})$. A suitable source ($d$ = 140 AU) was obtained as described in 1571 of 1940 (*see* also 1174 of April), and with it records were obtained of Fresnel diffraction at an edge (Fig. 2): four or five maxima could be distinguished, which agrees with the "coherence" condition of the above formula. Since the spacing of the maxima is only of the order of 20$\mu$, the original photograph has had to be enlarged some 112 times, so that the layer grain is prominent.

The spacing thus found is in agreement with eqn. 1 on p. 709 (hitherto confirmed only for visible light) if $\lambda$ is replaced by the de Broglie wavelength. Thus the properties of the electron are most simply described, for this experiment also, as de Broglie waves; and the Fresnel theory of diffraction, with its further development by Kirchhoff, Sommerfeld, and others, is also valid, within the present limits of accuracy, for electron waves.

The special importance of Fresnel diffraction at an edge, for electron optics, lies in the fact that the spacing of the maxima, according to eqn. 1, is independent of the geometrical dimensions of the obstacle, and that submicroscopic magnitudes such as atomic spacings play no rôle. Consequently the determination of the electron wavelength according to eqn. 1 is based only on the *direct* measurement of the distance between electron source and object and of the spacing between the maxima, whereas hitherto it has had to depend on Fraunhofer diffraction tests at crystal lattices whose spacings had to be measured by X-ray methods.

In the case of other objects such as apertures or screens, the phenomena are greatly complicated by their dependence not only on the object dimensions but also on $\lambda$ and $a$. The "double-wall" effect on images of the flagella of bacteria, and the "ring structure" of the background, found in previous shadow-microscope records, are to be attributed to such Fresnel diffraction phenomena. Estimation of the object size from such diffraction figures would at present seem to be difficult owing to their dependence on the transparency of the object. *See* also 1737, below.

1737. Fresnel Diffraction Phenomena in the Supermicroscope.—Boersch. (*Naturwiss.*, 1st Nov. 1940, Vol. 28, No. 44/45, pp. 711–712.)

A letter pointing out the implications of the writer's results (1736, above) as regards the electron microscope. He concludes that the divergence of the incident incoherent beam in the microscope as at present developed (irradiation aperture say $10^{-3}$ cm, wavelength say $5 \times 10^{-10}$ cm) would, by its displacement of the interference system belonging to each primary ray, require the distance $l$ between object and focusing plane to be so small, if the first two edge-diffraction maxima are to be separated, that the separation would come beyond the limit of resolving power of the instrument, of the order of 50 AU. Although the actual observation of the diffraction maxima would therefore be prevented, the *effects* of the Fresnel diffraction may nevertheless make themselves evident. For instance, the lack of sharpness of the contour-edges found by Mahl and attributed to diffraction effects (*Jahrbuch. AEG-Forsch.*, 1940: *see* also 2102 of 1940) is attributable to such an action. Other objects, such as the flagella of bacteria, show for the same reason a "doubling" effect, as is seen in shadow-microscope observations: this effect must also appear with the ordinary electron-microscope when the focusing is not sharp. To avoid erroneous conclusions regarding the image content it is therefore desirable that incorrect focusing should not allow Fresnel-diffraction phenomena to be resolved: this can be arranged by increasing the irradiation aperture. Such an increase tends to bring with it a decrease in resolving power, but the latter can be avoided by the use of small object apertures (*see* the writer's *Jahrbuch* paper mentioned in 1736, above, and also 1174 of April). On the other hand, if it is desired to observe the Fresnel-diffraction phenomena in the ordinary electron microscope, this should be made possible by decreasing the irradiation aperture.

1738. On the Appearance of Lines of Blackening in the Electron-Microscopic Images of Crystalline Lamellae [Not Attributable to Mass-Thickness Structure of Object: an Unknown Effect (made evident by the Sensitivity of the Modern Electron Microscope to Small Changes in Direction) possibly due to Mechanical Strains in the Object].—von Ardenne. (*Zeitschr. f. Phys.*, 5th Dec. 1940, Vol. 116, No. 11/12, pp. 736–738.) *See* also 3153 of 1940.

1739. The Effect of Electron Interference on the Images of Crystals in the Supermicroscope [Surprisingly Marked Changes in Character of Image, produced by Very Small Changes in Angle of Incidence of Beam].—von Borries & Ruska. (*Naturwiss.*, No. 23, Vol. 28, 1940, p. 366.) Mentioned in von Ardenne's paper, 1738, above.

1740. The Development of the Electron-Supermicroscope with Electrostatic Lenses [Survey, including Photographs of Constructional Details and Specimen Records].—Brüche. (*Zeitschr. V.D.I.*, 8th March 1941, Vol. 85, No. 10, pp. 221–228 and Plates.) From the AEG laboratories.

1741. The Phase-Contrast Method and Its Applications in [Optical] Microscopy, *and* The Observation of Chromosomes by the Phase-Contrast Method.—Köhler & Loos: Michel. (*Naturwiss.*, 24th Jan. 1941, Vol. 29, No. 4, pp. 49–61: pp. 61–62.)

1742. Note on the Best Focus [of an Optical System] in the Presence of Spherical Aberration.—Ta-Hang. (*Proc. Phys. Soc.*, 1st March 1941, Vol. 53, Part 2, pp. 157–169.)

1743. A Modern Representation of Gullstrand's Work on Geometrical Optics.—Epheser. (*Ann. der Physik*, Ser. 5, No. 7/8, Vol. 38, 1940, pp. 501–541.)

1744. The Structure of Tin-Containing Halide Phosphors.—Hüniger & Rudolph. (*Zeitschr. f. Phys.*, 28th Dec. 1940, Vol. 117, No. 1/2, pp. 81–99.)

The property of small additions of the heavy metals thallium, copper, silver, and lead, of producing fluorescence in certain halides, is by no means limited to the alkali halides: such additions produce fluorescent powers in halides of the alkaline earths and of zinc, cadmium, and ammonium. Moreover, there are other heavy metals which form phosphors when introduced into alkali or alkaline-earth halides. Tin is particularly active in this way, making the iodides, bromides, and chlorides of all alkalis and alkaline earths, and some ammonium halides, fluoresce very brightly. The present paper deals with an investigation of such halides activated with divalent tin. The ultra-violet spectrum of the hydrogen continuum, given by a 3000-volt, 500-mA hydrogen-discharge tube, was chosen as the exciting source because of its uniform energy distribution above about 280 mμ (Fig. 1).

The spectral excitation distribution of a large number of the phosphors in powder form was investigated. Preliminary measurements with a spectrophotometer had confirmed, for these materials, the assumption that the emission from a phosphor is, as regards spectral composition, independent of the wavelength of the exciting light (Fig. 2, which shows, for two materials separately, how the 3 emission distribution curves taken with 3 different exciting wavelengths all coincide). This fact is necessary for the soundness of the method used for the main measurements. Here, because of the rather low intensity of the exciting source, a photographic method was employed instead of a photoelectric: to keep the surplus ultra-violet exciting light which was not absorbed by the phosphor from reaching the moving film, the glass plate carrying the phosphor specimen (Fig. 3) was coated with a Durophen-varnish layer which absorbed all light under 400 mμ. The blackenings of the moving film, corresponding to the various emission intensities under different exciting wavelengths, were measured with a microphotometer and interpreted with the help of the curve for that particular film.

The shape of the resulting characteristic was fundamentally the same for all the phosphors (Figs. 4–6): the same light centre would appear to be active in all, and it is obvious that the tin ion is mainly responsible for the results, although the halogen ions, and to a smaller degree the cations of the base material, have their effects on the position of the band systems of the curves. The excitation spectrum agrees, as simultaneous absorption measurements show (pp. 88–90), with the absorption spectra of those phosphors which could be prepared in single-crystal form and with those of concentrated aqueous halide solutions containing small quantities of tin in the form of co-ordinatively saturated complex salts (Werner complex salts). This leads to the conclusion that the structure of the light centres is similar to that of these complex bodies. A comparison of the absorption measurements on the solutions with those on the single crystals makes it possible to estimate the number of light centres (table 2): the proportion is something like $10^{-4}$ or $10^{-5}$.

Finally, a comparison of some emission spectra of these divalent-tin phosphors (Figs. 14–17, taken by the spectrophotometer mentioned earlier) with the chemiluminescence spectra obtained by Polanyi & Schay by the reducing action of vaporised sodium and potassium on the halides of tetravalent tin, suggests very strongly that the emission of light from a crystalline phosphor is connected with an equation resembling that for the second stage of the reaction deduced by those workers: namely $SnCl_3 + Na = NaCl + SnCl_2 + 74$ kcal. If this is so, the presence of $SnCl_3$ and metallic sodium is essential, and this involves some process to change the divalent tin and monovalent sodium ions originally in the crystal phosphor. "It is an obvious suggestion to make the exciting absorption responsible for this process": equations for the absorption and emission processes are suggested at the bottom of p. 98.

1745. The Polarisation of the Fluorescence of Complex Molecules [of a Vapour].—Dashevski. (*Journ. of Exp. & Theoret. Phys.* [in Russian], No. 8, Vol. 10, 1940, pp. 874–877.)

Referring to an investigation by Suppe (*Zeitschr. f. Phys.*, 1939, Vol. 113, p. 281) in which the polarisation (exceeding 30%) of the fluorescence of $C_{18}H_{10}$ vapour was observed, a theoretical discussion is presented establishing a relationship between the degree of polarisation $P$ and the pressure $p$. Using the methods of the classical kinetic theory of gases and assuming that the depolarising effect is due to the rotation of the fluorescent molecule and its collisions with other gas molecules, a formula (3) is derived determining the required relationship. From this formula and experimental data given by Suppe (Fig. 1) the limiting value $P_0$ of polarisation of the vapour in question (corresponding to the case of an isolated molecule) and the average duration $\tau_0$ of the excitation state of a molecule were found to be 40% and $1.6 \times 10^{-7}$ sec. respectively.

1746. The Transformation from Phosphorescence to Fluorescence produced by Oxygen [Adsorbates of Aromatic Compounds].—Kautsky & Müller. (*Naturwiss.*, 7th March 1941, Vol. 29, No. 10, pp. 150–151.)

1747. Demonstration of Excitation of Luminescence by Flame [Bluish-Green Light from Boron Nitride in Contact with Flame, quite Different from Ordinary Temperature-Radiation].—Minchin. (*Proc. Phys. Soc.*, 1st March 1941, Vol. 53, Part 2, pp. 190–191.)

1748. The Fading of Colour in Alkali-Halogen Crystallites [and Its Dependence on Particle Size: Experiments with KBr & NaCl].—Kurzke & Rottgardt. (*Naturwiss.*, 17th Jan. 1941, Vol. 29, No. 3, p. 46.)

1749. The Coagulation of Metal dissolved in an Alkali-Halide Crystal [Kinetics of Process taking place in NaCl Crystal saturated in Na Vapour]. Smirnov. (*Journ. of Exp. & Theoret. Phys.* [in Russian], No. 8, Vol. 10, 1940, pp. 910–920.)

1750. On the Mechanical and Optical "Excitation" of Colour Centres [Researches on NaCl Crystals without & with Impurities].—Smekal. (*Zeitschr. f. Phys.*, 21st Nov. 1940, Vol. 116, No. 9/10, pp. 525–546.)

1751. On the Photochemistry of the KH–KBr Mixed Crystal.—Thomas. (*Ann. der Physik*, Ser. 5, No. 7/8, Vol. 38, 1940, pp. 601–608.)

1752. The Visual Observation of a Lattice Transformation [Sudden Change in $K_2Cr_2O_7$ Crystal Lattice at Transition Temperature].—Schwab & Schwab-Agallidis. (*Naturwiss.*, 28th Feb. 1941, Vol. 29, No. 9, pp. 134–135.)

1753. A Vacuum-Tight Sliding Seal [giving Unlimited Translational & Rotational Motion].—Wilson. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, pp. 91–93.)

1754. The Mechanism of the Electrical Dissipation of Gas ["Clean-Up Effect"] at Pressures below $10^{-4}$ mm Hg.—Schwarz. (*See* 1671.)

1755. The Diffusion of Hydrogen through Iron and Its Dependence on the Condition of the Surface: Its Relation to Catalysis.—Betz. (*See* 1683.)

1756. "Metalle und Legierungen für hohe Temperaturen" [Metals & Alloys for High Temperatures: Book Review].—Hessenbruch. (*Physik. Zeitschr.*, 1st Jan. 1941, Vol. 42, No. 1, p. 23.)

1757. Brazing in Electrical Furnaces [for Metal Valves, Condenser Plates, etc: Advantages, Practical Technique].—Simon. (*AEG-Mitteilungen*, Jan./Feb. 1941, No. 1/2, pp. 20–24.)

1758. Phase of Arc-Back in Rectifiers [Thyratrons: Experimental Results interpreted by Kingdon & Lawton's Theory of Charging-Up of Small Nonconducting Particles on Anode Surface].—Hull & Elder. (*Phys. Review*, 1st Jan. 1941, Vol. 59, No. 1, p. 115: summary only.)

1759. On the Efficiency of the Negative Glow [Experimental Investigation]. — Fischer. (*Naturwiss.*, 10th Jan. 1941, Vol. 29, No. 2, pp. 27–28.)

1760. The Propagation of the Vapours of Electrode Material in a Spark Discharge.—Rayski. (*Journ. of Exp. & Theoret. Phys.* [in Russian], No. 8, Vol. 10, 1940, pp. 908–909.)

Extended spectral diagrams of sparks were obtained with the aid of a revolving mirror for electrodes made of Mg–Zn, Zn–Li, and Li–K alloys. It appears that in each case the velocities of the propagation of both elements are the same. The phenomenon is therefore independent of molecular velocities, and being similar to an explosion or ejection under pressure is of the hydrodynamic type.

1761. On the Dual Behaviour of Lead Sulphide as a Semiconductor [both as Oxidation (Deficiency) and Reduction (Surplus) Type: Comparison with Uranium Dioxide: Conductivity & Thermovoltage, for Varying Sulphur Content].—Hintenberger. (*Naturwiss.*, 7th Feb. 1941, Vol. 29, No. 5/6, pp. 79–80.) Schottky has suggested the adjective "amphotere" for such semiconductors.

1762. Reversal of Rectification by Heat in Crystal Contacts, and Its Analogy to a Thermoelectric Phenomenon.—El Sherbini & Yousef. (*See* 1647.)

1763. Report on the Properties of Wires at Frequencies up to 400 Mc/s.—Sutton. (*See* 1622.)

1764. A Determination of the Magnetic Saturation Induction of [Pure] Iron at Room Temperature.—Sanford & Bennett. (*Journ. of Res. of Nat. Bur. of Stds.*, Jan. 1941, Vol. 26, No. 1, pp. 1–12.)

1765. A Note on Concentrated Ferromagnetic Amalgams [Attempts to obtain a Ferromagnetic Liquid Amalgam of Nickel & Mercury].—Bates. (*Proc. Phys. Soc.*, 1st March 1941, Vol. 53, Part 2, pp. 113–115.)

1766. Magnetisation near Saturation in Polycrystalline Ferromagnets [taking into Account the Internal Magnetic Field arising from the Magnetisation Itself, neglected by Akulov & Gans].—Holstein & Primakoff. (*Phys. Review*, 15th Feb. 1941, Vol. 59, No. 4, pp. 388–394.)

1767. On the Migration of Atoms in Iron-Nickel Alloys.—Owen & Sully. (*Phil. Mag.*, April 1941, Vol. 31, No. 207, pp. 314–338 and Plate.)

1768. An Interferometric-Dilatometer with Photographic Recording [primarily for Investigations on Order-Disorder Transformations in Alloys].—Nix & MacNair. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, pp. 66–70.)

1769. Effect of Supersonic Waves on the Magnetic Properties of Nickel.—Schmid & Jetter. (*See* 1693.)

1770. The Variation in the Resistance of a Dielectric (Mica) in a Magnetic Field.—Pruzhinina-Granovskaya. (*Journ. of Exp. & Theoret. Phys.* [in Russian], No. 8, Vol. 10, 1940, pp. 878–886.)

The increase in the resistance of mica when placed in a transverse magnetic field (longitudinal effect) was measured at various field intensities and temperatures. The intensity of the electric field was also varied. Experimental curves are shown and a detailed theoretical discussion, mainly concerning the electron structure of mica, is given.

1771. Further Relationships between the Anomalies of Insulating Materials.—Böning. (*Zeitschr. f. tech. Phys.*, No. 11, Vol. 21, 1940, pp. 250–256.)

The anomalies of actual insulating materials can be reproduced in a model consisting of ideal condensers and resistances: *see* 4556 of 1938. The phenomena occurring in the model are directly connected with one another, from which it may be deduced that the anomalies of the actual insulator are also attributable to a common cause. The cause itself is a contested point: one theory (Maxwell-Wagner) assumes that the insulator consists of layers or inhomogeneities, so that it is electrically identical with the model: a second is based on dipole rotation (Debye): and a third (the writer's) makes the displacement of mobile cations ("Gleitionen") responsible for the anomalies. The mere occurrence of the anomalies says nothing in favour of one theory more than of another, and attempts to make the temperature and frequency characteristics of the loss factor act as a criterion for the applicability of the inhomogeneity theory or of the dipole theory have not been completely successful. The present work investigates what differences are to be expected between the characteristics of the "settle potential" and "back potential," according to the inhomogeneity theory, and those according to the writer's adsorption theory (*see* 4570 of 1938), and which result is the better supported, so far, by actual measurements.

The meaning of "settle potential" ("Setzspannung") is made clear by the model of Fig. 1, in which two condensers in series, only one of which is shunted by a finite resistance, are connected to a potential source for so short a time that only the geometrical capacity becomes charged and no appreciable charges can flow through the shunting resistance: the model is then left to itself, and the potential comes to a state of equilibrium with a "settle potential" $P_s$ [$= P . C_1/(C_1 + C_2)$] remaining across the un-shunted condenser $C_2$: the discharge curve is seen in Fig. 2. Turning now to actual dielectrics, "if a condenser is charged in a short time and left to itself, the potential sinks rapidly at first and then more slowly. With many dielectrics the potential reaches an almost constant value, called the 'settle potential.' It appears that the charges have then taken up a final position."

Now according to the inhomogeneity and dipole theories, for various charging potentials $P$ the ratio $P_s/P$ should remain constant: according to the writer's absorption theory, on the contrary, the curve of this ratio as a function of $P$ should have a definite shape (Fig. 8, eqn. 46). The plotting of this characteristic should therefore give an indication in favour of one or other of the theories. The decay curves of condensers appearing in the literature " refer only to the case of long charging times," except those given by Gross (275 & 2985 of 1938) which were for very short charging times but were all taken with the same charging potential. " Some investigations by the writer on various materials including marble and composite cellulosic materials [" Hartpapier "], with short-time charging gave curves of the form of Fig. 2, with their initial portion falling extremely quickly while their continuation ran almost horizontally for a long time." Although the quotations in this paragraph are taken from section 3, entitled " Comparison of the theoretical results with measured results," it seems impossible to find either there or elsewhere in Part A of the paper any indication whether the writer's curves were plotted for different charging potentials, and if so whether the $P_s/P$ characteristic was or was not of the shape foretold by his adsorption theory. Part B, dealing with the relation between the " settle potential " and the " back potential " $P_r$ and the behaviour of the ratio $P_r/P$ as a function of $P$, according to the writer's theory, seems equally inconclusive: the characteristic should, according to eqn. 64, be approximately the mirror-image of the $P_s/P$ curve of Fig. 8, but no measured characteristics are given.

1772. On the Theory of Solid Insulators [Survey of the Writer's Success in applying the Electron-Gas & Lattice-System Hypothesis to Insulators: including Sections on the Excitation of Phosphors]. — Möglich & Rompe. (*Naturwiss.*, 21st & 28th Feb. 1941, Vol. 29, Nos. 8 & 9, pp. 105–113 & 129–134.) Leading to " the elucidation of a series of phenomena which have hitherto resisted any simple interpretation ". *See* also 1773, below.

1773. On the Statistics of " Multiple Impacts " [between Electrons & Sound Quanta in Solid Insulators].—Möglich & Rompe. (*Zeitschr. f. Phys.*, 28th Dec. 1940, Vol. 117, No. 1/2, pp. 119–124.)

" In several papers [*see* for example 4406 of 1940, on the energy transformation in crystal phosphors, and 1772, above] we have been able to show that a number of phenomena in insulators can be interpreted satisfactorily with the help of the band model of the electron gas, provided that the interaction of the electrons with the lattice is taken into account. It was thus found that the coupling of the electrons with the lattice could not always be regarded as loose, but that this coupling could be quite strong at high temperatures and for high electron energies. The transition from weak to strong coupling occurs extremely abruptly and is marked by the frequent occurrence of a process which we have termed ' multiple impact '. This is characterised by the fact that a quantity of energy given up by the electron gas to the lattice is represented by the emergence not of one single sound quantum but of a large number. There is also an inverse process, in which the energy of a large number of sound quanta is used simultaneously for the excitation of an electron state in the electron gas." In the present paper the temperature-dependence of the expression for the frequency of multiple impact between the electrons and sound quanta of a solid body is calculated from the requirement that the thermodynamic equilibrium defined by Planck's equation should not be upset by the multiple impacts.

1774. On the Diffusion of Gases through High Polymer Materials: I—A Simple Apparatus for Measuring the Diffusion of Gases through Foils.—Müller. (*Physik. Zeitschr.*, 15th Feb. 1941, Vol. 42, No. 2/3, pp. 48–53.)

1775. On the Composition of Porcelain and Its Variants [including H.F. Insulating Ceramics].—Funk. (*Naturwiss.*, 10th Jan. 1941, Vol. 29, No. 2, pp. 18–27.)

1776. Crystallo-Chemical Viewpoints in the Interpretation of the Constitution of Glasses.—Dietzel. (*Naturwiss.*, 7th Feb. 1941, Vol. 29, No. 5/6, pp. 81–82.)

1777. Geometrical Considerations in Glass [including Miscibility & Immiscibility, and Anomalies in Certain Physical Properties].—Warren. (*Sci. Abstracts*, Sec. A, Feb. 1941, Vol. 44, No. 518, p. 29.)

1778. Survey of the Preparation, Properties, and Uses of the Commercial Plastics.—Hoey. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, pp. 111–113: long summary.)

1779. Plastics from Coffee Beans [Caffelite, with " Very Good Electrical Properties at Low Frequencies]: Synthetic Resins from Melamine [with " Good Water-Resisting & Electrical Insulating Properties "]: Speeding-Up Curing Times of Urea Moulding Materials.—(*Electrician*, 18th April 1941, Vol. 126, p. 227.)

1780. " Industrial Solvents " [including a Chapter on Plasticisers: Book Review].—Mellan. (*Nature*, 22nd Feb. 1941, Vol. 147, p. 222.) " A mine of information."

1781. " Practical Applications of Recent Lac Research " [Book Review].—Sen. (*Current Science*, Bangalore, Jan. 1941, Vol. 10, No. 1, p. 36.)

1782. A Contact and Timing Indicator for Insulation Measurements.—Rehfisch. (*See* 1715.)

1783. The Electrical Strength of Compressed Gases: Part II [leading to a Development of Slepian's Thermal-Ionisation Theory of Breakdown].—Gänger. (*Arch. f. Elektrot.*, 14th Dec. 1940, Vol. 34, No. 12, pp. 701–712.)

For Part I *see* 1196 of April. After a criticism of Townsend's theory and other explanations of the breakdown process, the writer arrives at the following picture as the only one which satisfies the observed results: An electron at the cathode/gas boundary layer is accelerated towards the anode and on its way, if the field strength is high enough, splits up neutral gas molecules; the resulting avalanche produces a withdrawal of energy from the external field; of this energy only a small fraction appears again as ionising energy, the greater part being transferred, by collisions of low energy, to neutral gas molecules in the form of thermal motion. The heating of the gas leads finally to thermal ionisation as the result of collision processes of neutral molecules, eventually by way of metastable excitation states. The carrier source thus produced is very fertile. The voltage at which this ionisation becomes important is equivalent to the initial voltage of the discharge, and thus to the sparking voltage in a uniform field. "For such a field, therefore, we arrive at the conclusion that the breakdown occurs when enough carriers are produced thermally at the anode to make the resulting current reach a definite value." The theory allows Paschen's law to be derived. Since the electron velocity may rise to a considerable fraction of the velocity of light, it is concluded that for medium sparking distances breakdown times of $10^{-8}$ second may be expected, and only slightly longer times for wider gaps. Breakdown in an inhomogeneous field is treated on pp. 708–712.

1784. A Simple Amplifier for Very Small Current Pulses [specially designed for recording Ionisation-Chamber Pulses (Alpha-Particles or Protons) occurring only about 300 Times per Hour: used with Galvanometer with a One-Second Swing: Freedom from Mechanical Disturbances, etc.].—Riezler. (*Zeitschr. f. tech. Phys.*, No. 11, Vol. 21, 1940, pp. 241–243.)

1785. The Interval Selector: a Device for measuring Time Distribution of Pulses.—Roberts. (*Review Scient. Instr.*, Feb. 1941, Vol. 12, No. 2, pp. 71–76.) A summary was referred to in 2763 of 1940.

1786. A Circuit for firing Thyratrons in Timed Sequence.—Loeffel. (*See* 1634.)

1787. Retarded-Release Time-Delay Relays for High Switching Frequency [1000 or more per Hour] with Large Range of Adjustment [General Considerations, leading to New Improved Circuit].—Schmideck. (*AEG-Mitteilungen*, Jan./Feb. 1941, No. 1/2, pp. 41–46.)

In the new circuit (Fig. 6) the main magnet winding $S_h$ and the low-resistance low-turns winding $S_g$ (which is in *series* with the electrolytic condenser) both work together while the condenser is charging: the discharge current flows through $S_g$ and may either weaken, extinguish or reverse the original magnetisation, according to requirements. The various advantages are described on p. 46.

1788. Thermal Relays [primarily for Telephone Work, to give Delays of 5 to 40 Seconds].—Bloxsidge. (*Sci. Abstracts*, Sec. B, Feb. 1941, Vol. 44, No. 518, p. 32.)

1789. Electronic Relay [using a Type OA4G Cold-Cathode, Starter-Anode, Gas-Filled Tube & 3000-Ohm Relay].—Rudy & Fugassi. (*Sci. Abstracts*, Sec. B, March 1941, Vol. 44, No. 519, pp. 40–41.)

1790. Materials for Electrical Contacts.—Chaston. (*Engineering*, 11th April 1941, Vol. 151, pp. 285–286: to be continued.) An I.E.E. paper.

1791. Electrical and Thermal Contact Resistances of Metallic Contacts [of the Type in which the Electron Passage depends on the "Tunnel" Effect, *i.e.* Contacts with Very Thin (probably Monomolecular) Separating Film, Not Conductive].—Kohler. (*Naturwiss.*, 14th March 1941, Vol. 29, No. 11, pp. 164–165.) *See* also 1792, below.

1792. Thermal Contact Resistance of Metals and the Resulting Temperature Jump in the Contact: New Type of Thermo-Electric Force in Single-Metal Circuit, and Its Relation to the Benedicks Effect.—Kohler. (*Ann. der Physik*, Ser. 5, No. 7/8, Vol. 38, 1940, pp. 542–554.) *See* also 1791, above.

1793. The Melting-Time of Protective Fuses: III.—van Liempt & de Vriend. (*Zeitschr. f. Phys.*, 28th Dec. 1940, Vol. 117, No. 1/2, pp. 18–19.)

Further development of the work dealt with in 1226 of 1936. Meyer's constant $C$ is measured for a number of metals and alloys, in the form of round wires ranging from $45\mu$ to $600\mu$ in thickness. Measurements on square-sectioned copper wire and on nickel tape confirmed the prediction (from the theoretical derivation of Meyer's formula) that the form of cross section has no influence on $C$.

## STATIONS, DESIGN AND OPERATION

1794. Summary and Discussion of a Paper on Micro-Wave Links using Relay Stations.—Vecchiacchi. (*L'Elettrotec.*, 10th Oct. 1940, Vol. 27, Supp. A, Fasc. 1, pp. 47–49.) In the Proceedings of the 44th Annual Reunion of the A.E.I.

1795. Installations for Wireless Telephony with Ultra-Short Waves [in Alpine Winter-Sports Localities: rented at 7.50 Fr. per Month: connected with Telephone Network].—(*Bull. de l'Assoc. suisse des Élec.*, No. 25, Vol. 31, 1940, p. 590: in German.)

1796. A New Portable Ultra-Short-Wave Transceiver [for Emergency Use, using Dry Batteries: Two Valves, Both employed in Transmission & Reception: 5-Piece Rod Aerial: Wave-Range 4.7–5.3 m: Weight 9.0 kg].—Hasler A.G. (*Bull. de l'Assoc. suisse des Élec.*, No. 25, Vol. 31, 1940, pp. 589–590: in German.)

1797. Band Width and Readability in Frequency Modulation [Effect of Channel Width on Weak-Signal Voice Reception: Listening Tests show Optimum Deviation Ratio to be Unity for Max. Readability & Range: Superiority of F.M. over A.M. (using Same Band Width) as regards Readability].—M. G. Crosby. (*R.C.A. Review*, Jan. 1941, Vol. 5, No. 3, pp. 363–370: *QST*, March 1941, Vol. 25, No. 3, pp. 26–28 and 86.)

1798. Phase Selection in Radio Communication [for Two-Channel Telephony].—Momot. (*See* 1650.)

## GENERAL PHYSICAL ARTICLES

1799. On Maxwell's Theory for Dielectric and Magnetic Media. — Kneissler-Maixdorf. (*Arch. f. Elektrot.*, 14th Dec. 1940, Vol. 34, No. 12, pp. 713–726.)

Maxwell's equations, exactly correct for empty space, are also to a wide extent valid in the presence of materials for which the dielectric coefficient $\epsilon$ and magnetic permeability $\mu$ are constant, that is, independent of the field strength. If $\epsilon$ and $\mu$ vary with the field, and particularly if this variation depends on the electromagnetic history of the materials, the theory can no longer be formulated in an equally exact way. "The following work will show that such an exact formulation can be made if the Maxwellian theory is subjected to a modification which is in no way fundamental" and which consists in the change that, instead of assuming that in addition to the fields themselves only the electric *charges* are electromagnetically active, it is assumed that the electric *currents* are also active. The equations thus derived contain, apart from the specific resistance, no quantities which are bound up with material properties. They give a partially different view of the processes. Hysteresis heat appears as current heat of the elementary currents; the expression for the density of the field energy is likewise free from material values, and shows that the material is to be considered as source and "sink" of the electromagnetic energy.

1800. On the Statistics of "Multiple Impacts" [between Electrons & Sound Quanta in Solid Insulators].—Möglich & Rompe. (*See* 1773.)

1801. Ionisation and Dissociation of Diatomic Molecules by Electron Impact.—Hagstrum & Tate. (*See* 1583.)

1802. The Calculation of the Energy of Repulsion.—Mamotenko. (*Journ. of Exp. & Theoret. Phys.* [in Russian), No. 7, Vol. 10, 1940, pp. 740–742.)

In a previous paper a method was proposed for determining the energy of repulsion in the case of two similar atoms: here the method is applied to the case of dissimilar ions $Li^+$, $H^-$ and simple molecules $H_2$, $H_2$.

1803. The Radiometric Effect in Liquid Helium.—Strelkov. (*Journ. of Exp. & Theoret. Phys.* [in Russian], No. 7, Vol. 10, 1940, pp. 743–745.)

The radiometric effect was observed in helium II and the deflection of the radiometer vane on which a beam of light was directed was found to be in the same direction as in the case of a rarefied gas. The deflection was measured under different temperatures and light intensities. It is suggested that the radiometric effect is closely related to the temperature creep in helium.

1804. On the Pressure of Electron Beams [Failure of Previous Workers to demonstrate Its Existence, even Qualitatively: Additional Importance of the Problem as Only Method of measuring Longitudinal Mass of Electron: Writer's Successful Application of Modern Vacuum & Valve Techniques to Demonstration & Measurement: Preliminary Report].—Selényi. (*Naturwiss.*, 7th Feb. 1941, Vol. 29, No. 5/6, pp. 78–79.)

## MISCELLANEOUS

1805. Thévenin's Theorem: an Example of Its Validity in Transients and Operational Calculus.—Turney. (*See* 1629.)

1806. A Theorem on Maxima and Minima with an Application to Differential Equations.—Court. (*Journ. of Math. & Phys.* [of M.I.T.], Jan. 1941, Vol. 20, No. 1, pp. 99–106.)

1807. Contribution to the Simple Preparation of Nomograms, with Some Examples.—Schaer. (*Bull. Assoc. suisse des Élec.*, 17th Jan. 1941, Vol. 32, No. 1, pp. 1–6: in German.)

1808. The Statigraph Graph-Drawing Machine.—Mills. (*Engineering*, 21st March 1941, Vol. 151, pp. 226–228.)

1809. Training in Scientific Theory [and Need for Closer Alliance of Theory & Practice, with Mathematics as Principal Instrument in This Union].—Mórse. (*Science*, 28th Feb. 1941, Vol. 93, Supp. p. 6.)

1810. Leading Nations in Science and the Nobel Prize.—Gunter: Brill. (*Science*, 24th Jan. 1941, Vol. 93, pp. 82–83.) Prompted by Brill's article, 1285 of April.

1811. The Poor Delivery of Scientific Papers [Correspondence, with Criticisms & Suggestions].—(*Science*, 14th & 21st Feb. 1941, Vol. 93, pp. 158 & 184–185.) Continued from previous issues.

1812. The Application of Microfilm to Records of Scientific Literature, and a Suitable Projection Apparatus for Viewing such Records [Demonstration].—Lancaster-Jones & Johnson. (*Proc. Phys. Soc.*, 1st March 1941, Vol. 53, Part 2, pp. 191–195.)

1813. Cycles per Second.—Campbell. (*Journ. of Scient. Instr.*, April 1941, Vol. 18, No. 4, p. 68.) A denunciation of the "dogmatism" of the note dealt with in 1535 of May.

1814. The Use of E.R.A. Reports [and the Problem of Reducing the Gap between Research Worker & User of His Conclusions.]—Marshall: E.R.A. (*Electrician*, 21st Feb. 1941, Vol. 126, pp. 113–114: pp. 117–118.)

1815. Physics in the Electrical Industry [in 1940], *and* Physics in 1940.—Editorial: Osgood. (*Journ. of Applied Phys.*, Feb. 1941, Vol. 12, No. 2, p. 83: pp. 84–99.)