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CONTENTS

Television

THERE may possibly be some optimists who think that they will be able to switch on their television receivers next Armistice Day and see the victory celebrations.

More probably, there are some who hope that after the first excitement has died down and the war is over, they will be able to tune in to Alexandra Palace within a few months and see Miss Cowell again as well as hearing her.

To both super-optimists and ordinary optimists, Sir Noel Ashbridge's words in his Presidential address to the I.E.E. will have an unpleasant sound. Dealing with post-war problems of television, he says:

"There are fundamental problems to be settled which will affect the future of a new industry at least for many years, if not almost permanently, with great scope for the making of wise and unwise decisions on an almost unlimited scale. There will be the obvious necessity of a rapid restoration of the service, but it cannot be assumed that this should be immediately restarted without regard to the lapse of time which has taken place. It cannot even be assumed that the same fundamental standards of definition should be adopted. Not many budding industries in the nature of a public service have had the advantage (some people might say it was a disadvantage) of making a new beginning after two or three years of regular working, and it is hoped that the fullest advantage will be taken of this almost unique position. There is, besides, a financial problem, which I have already mentioned briefly."

In an earlier part of the address, which is abstracted in this issue, he also points out that the expenditure on television is out of all proportion to the number of viewers, a fact that was fully appreciated before the war put a stop to programme transmissions.

What can be inferred from these remarks? It is only reasonable to suppose that the B.B.C. having several years arrears of maintenance and development to overtake will be unwilling to devote funds immediately to the restoration of a most expensive service which will be of direct benefit to a very limited number of licence holders. But assuming that at the end of one or even two years they find themselves in a position to open up the A.P. transmitter, will they maintain the standards which were used when the plant was shut down?

When the Television Committee laid down the standards and gave a form of guarantee that there would be no radical variation for a minimum period of service, they did not foresee that this country would have to stand still for a number of years, while experience was being gained in other parts of the world. It would be foolish for the owners of television receivers to insist (assuming for the moment that they had the power to do so) on the resumption of a service which developments had rendered out of date, and the B.B.C. might fairly argue that they were throwing good money after bad in reviving a transmission which was not the best of its kind.

It is quite possible, therefore, that the same fundamental standards of transmission will not be adopted after the war, and that a corresponding revision will have to be made in the receivers issued by the manufacturers.

The owners of receivers which are gathering dust at present will ask gloomily "What about the money we have spent?" The manufacturers of the receivers will ask the same question, and the reply to both might be in the popular phrase "It's just too bad."

There is little point in speculating further while the job of winning the war is on, but there is equally little point in indulging in false hopes that things will be just the same as they were.

SALVAGE.

Every engineer can help in the drive for waste paper. The need for salvage is vital and help must be given now.

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- **Periodicals**
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- **Lecture note-books**

Make an effort this week to go through your files in the office and at home and put out wastepaper for the national effort.

Your local salvage organisation will collect it—don't delay.

The Generation and Amplification of Microwaves

By C. E. LOCKHART

Part 4.—Inductive Output Amplifiers

IN the first three parts of this review which dealt with normal negative grid valves it was shown how the performance of this type of valve deteriorates with increase of frequency, and the reasons for this are summarised in Table I.

It is proposed next to discuss how and to what extent these limitations have been overcome in practice with designs incorporating radically new principles.

Reactive Loading

In order to obtain a reasonable efficiency and to meet the low reactive loading requirement of (6) with normal negative grid valves, it is essential first of all to make the valve electrode size small compared with the wavelength employed in order to eliminate the possibility of a serious voltage gradient being present along the electrodes. If the electrode system cannot be made a part of the resonant circuit it will then be necessary to make the reactive loading sufficiently small by a further reduction in size of the electrodes. The reactive loading may also be reduced by increasing the spacing of the electrodes while maintaining the required value for the transit angles Θ_1 and Θ_2 (between the cathode and the grid and the grid and the anode respectively), by a suitable increase in the applied voltages. However as the cathode current density I_0 is (*see* equation 11 part 2).

$$I_0 \doteqdot 8d_1\left(\frac{f}{\Theta_1}\right)^3 \times 10^{-5}\text{mA/cm}^2 \quad \ldots \quad (11a)$$

with f in megacycles d_1 in cms. and Θ_1 in radians, an increase of the grid-cathode gap d_1 is undesirable. An increase in the grid-to-anode or -screen gap (and screen-to-anode gap) may, however be feasible, as the transit angle Θ_2 between grid and anode (or screen) is given by

$$\Theta_2 \doteqdot \omega\tau_2 = \frac{f.d_2}{5\,[(V_{eff})^{\frac{1}{2}} + (V_a)^{\frac{1}{2}}]}\ \mu S \quad (13)$$

and therefore within certain practical limitations an increase in d_2 can be compensated by a suitable increase in V_a without increasing I_0

In general the reactive input loading will have to be reduced by using the smallest grid cathode gap and electrode dimensions in order to avoid excessive cathode current density. The output circuit reactive loading will be kept at a minimum by employing the highest possible operating voltages.

Resistive Input Loading

As shown in equations 1 and 2 Part I, and equations 6 to 12 Part 2 the input admittance is proportional to:

TABLE I.

Factors curtailing the performance of negative-grid valves at U.H.F.

		Phenomenon.	Valve used as : Amplifier.	Oscillator.
Transit Time effects	1	Due to the charge density modulation of the space current the input resistance of a valve drops rapidly with increase of frequency. With a given valve in order to maintain a given input resistance it is necessary to increase the cathode current density as the cube of the frequency.	*	*
	2	Due to the fact that current starts flowing in the anode as soon as the first electron leaves the cathode on its journey to the anode and only ceases when the last electron reaches the anode (or the last electron returns to the cathode), the effect of increasing the frequency of the input signal (with a finite transit time between anode and cathode) is to distort a short pulse of anode current obtainable at low and medium frequencies. With increase of frequency the pulse shape is flattened and its duration becomes a larger percentage of the period of the input signal. The result is a reduction in the fundamental frequency component of the anode current and a loss of power output and efficiency. In order to maintain a given performance it is necessary in addition to the increase of current density as in (1) to increase the anode and screen volts at least in proportion to the square of the frequency.	*	*
	3	(2) above also results in a phase shift of the fundamental component of the anode current. This seriously affects the required phase relations of a normal oscillator circuit but does not affect a properly screened or neutralized amplifier. The same frequency to current-density and voltage relations apply as in (2).		*
Feed back	4	Due to reactance of the leads to the electrodes and mutual inductance between leads carrying input and output currents. The loading caused by input and output electrodes can be very much greater than the magnitude due to transit time effects. This loading will generally increase as the square of the frequency and may be either positive or negative.	*	
	5	Residual reactances common to the input and output electrodes control the operational stability of an amplifier. In the case of wide-band amplifiers neutralization is very difficult and as the operating frequency is increased the problems of neutralizing or screening even a narrow band amplifier finally become intractable.	*	
Reactive Loading	6	The reactive loading of the tuned circuits caused by the effective reactance of the input and output electrodes, increases rapidly with frequency and limits the tuned circuit dynamic resistance that can be provided. This in effect largely limits the size of valve that may be used at a given frequency and is particularly serious in the case of wide band amplifiers.	*	*

* The asterisks show that the performance is affected by the phenomenon referred to.

$$\frac{1}{R_i} = \frac{g\Theta_1^2 K}{20} \propto f^2 \left(\frac{d_1}{I_0}\right)^{\frac{2}{3}} AK \quad \dots \quad (14)$$

where A is the cathode area in square cms.

When a limit has been reached to the reduction of d_1 and increase in I_C, the input loading can only be further reduced by decreasing the factor K. This factor can be reduced to a minimum of unity by increasing the value of the anode (or screen) voltage and by reducing the value of d_2.

Power Amplifiers

While the foregoing discussion is based on relations derived from small signal theory, we can draw the following general conclusions which should be reasonably applicable to the case of a power amplifier.

In order to obtain the best performance from a negative grid amplifier it is necessary to operate the cathode at the highest possible current density, use the smallest possible grid-cathode gap and the highest possible anode and screen voltage. The dimensions of the system which fix the cathode area and therefore the possible current output, are governed by whether the valve is to be used as an amplifier or oscillator and the type of circuit employed. In the case of amplifiers the input reactance Xi of the control grid and the reactance of the output (anode) electrode X_o have to be considered separately.

With screened power amplifiers the permissible values of X_i and R_i will be settled by the band width required and carrier frequency employed. For a simple plane electrode construction we may illustrate the approximate relationship between X_i and the carrier frequency f, transit angles Θ_1 and Θ_2 and the cathode current density I_C by

$$X_i \propto \frac{1}{A\left[K_1\left(\frac{f^4}{I_C\theta_1^3}\right) + K_2\left(\frac{f^2}{\theta_2(V_{eff}^{\frac{1}{2}} + V_s^{\frac{1}{2}})}\right) + K_3 f\right]} \quad (15)$$

where A is the active area of the electrodes, K_1 and K_2 are constants and K_3 depends on the actual electrode construction and lead-out arrangements.

The first term in the denominator represents the effect of the active grid cathode capacity the second term that of the active grid to screen-grid capacity, and the third term represents the effect of stray electrode and lead-out-capacities (K_3 is strictly therefore not independent of A).

From equations 11a, 13, and 15 it will be evident that for a given maximum permissible value for I_C and V_s, the required values for Θ_1 and Θ_2 can only be obtained by a suitable reduction in d_1 and d_2 as given by 11a and 13. The permissible electrode area for a given reactive loading thus decreases very rapidly with increase in frequency. The possible improvement obtainable by increasing V_s is severely curtailed by limitations in permissible screen dissipation.

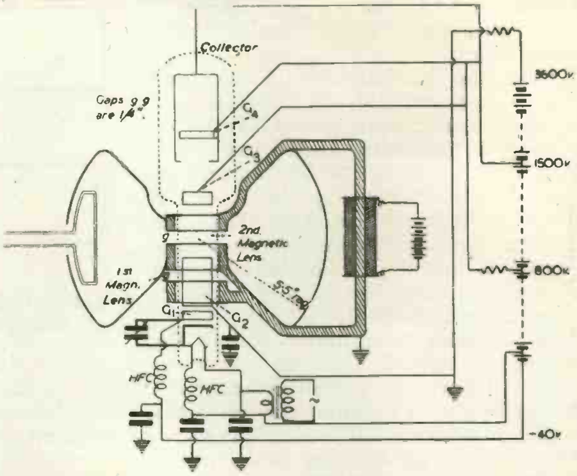

Fig. 1. R.C.A. 825 Inductive Output valve, and Fig. 2. The valve with its resonant chamber and focusing system. The two gaps g, g, are ¼" long. G_2, G_3 and G_4 have protective resistances in the supply leads as shown.

In any usable design the effect of resistive loading of the output electrode due to electronic and common reactance effects has usually been made small in comparison with the value of output load required. In order to be able to usefully employ a reasonable proportion of the output power the value of the reactance X_o must, however, be kept sufficiently high to enable the dynamic resistance of the anode tuned circuit to be made large compared with the required anode load.

With narrow band amplifiers and a selected value of X_o (which in effect determines the value of the obtainable tuned circuit R_{dyn} as well as the amplitude of anode current available) the power output can only be increased by raising the anode voltage. Two factors, however, limit the amount of extra power that can be obtained in this way.

(a) Increasing the voltage on the anode will increase the power dissipated by the anode and a stage will soon be reached when the anode temperature becomes excessive.

(b) In order to get an increased output when the anode volts are raised it is necessary to also suitably increase the value of the anode load resistance. As soon as the anode load is increased beyond the stage where it is no longer small compared to the dynamic resistance of the tuned circuit, a larger and larger proportion of the output power will be wastefully dissipated in the tuned circuit.

At very short wavelengths limitation (a) usually comes first.

With wide band amplifiers the maximum usable value of load resistance is itself a function of $X_o = 1/\omega C_{ao}$ and the band width.[46] The limited value of anode load available sets a limit to the maximum value of voltage output at the anode, and this in turn limits the magnitude of D.C. anode voltage that can be used before the anode dissipation begins to rise rapidly. The reason for this is that with a given maximum value for I_0 the power output above a certain anode voltage will only continue to increase as the anode voltage is raised, if the consequent reduction in Θ_3 (transit angle between anode and screen) is resulting in an appreciable improvement of the anode current pulse shape. Excessive anode temperature therefore again sets a limit to the realisable power output.

The maximum output obtainable from power amplifiers will therefore increase as the size (area) of the valve is increased up to the stage where the dynamic resistance of the output tuned circuit begins to drop rapidly due to excessive reactive loading. This statement is only true provided the extra power required to maintain the amplitude of the input voltage constant can be obtained. For a given input power and frequency there will therefore be an optimum size of valve, which gives the best balance between the relative sizes of the anode and cathode.

R.C.A.—Haeff 825 Inductive Output Valve [44, 50, 51]

During the last two years several successful attempts have been made to overcome the limitations given in Table I by a radical departure from the design of conventional negative grid valves.

The principal fundamental features common to all these new designs is the dissociation of the functions of output and collector electrodes, the use of inductive output circuits and the use of electron focusing to reduce the current collection by the accelerating electrodes.

The R.C.A.—825. Inductive Output Valve developed by A. Haeff and illustrated in Fig. 1 is primarily intended for use as a wide band amplifier at wavelengths below 100 cm (300 Mc/s). The design primarily overcomes the limitations of sections 2, 3, 4, and 5 and of the output reactive loading of section 6 of Table I.

From the illustrations of Figs. 1 and 2 it will be seen that the 825 consists of a long tubular bulb (about 8 in.) containing an indirectly heated cathode C and control grid G_1, two cylindrical accelerating electrodes G_2 and G_3, and a large cylindrical collector electrode with a secondary emission ring suppressor G_4 inside it. The tuned output system is mounted externally and concentrically to the bulb.

It is easier to initially follow the method of operation of the system by considering the simplified arrangement shown in Fig. 3 in which the two short magnetic lenses of Fig. 2 have been replaced by a long uniform field lens.

The cathode and grid structures of the 825 are specially shaped to provide a sharp cut-off for the anode current-grid voltage characteristic, and form an electron optical system which provides an initially convergent beam. Divergence of the beam which would be caused by the accelerating electrode G_2, can be prevented by the use of the magnetic lens which is adjusted to ensure that a minimum number of stray electrons are collected by the accelerating electrode G_2, or bombard the bulb.

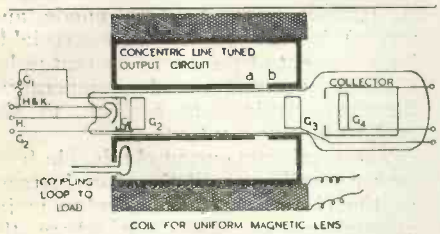

Fig. 3. Simplified circuit arrangement of Fig. 2 with concentric line output circuit and uniform field magnetic lens.

As the third electrode G_3 is operated at the same voltage G_2 the electrons in the beam travel at a constant velocity between G_2 and G_3. The field from the long uniform magnetic lens prevents the beam diverging in the space between G_2 and G_3 due the mutual repulsion between electrons. The danger of bulb bombardment is thus again avoided and the collection of electrons by G_3 also kept at a minimum. The electrons finally reach the collector electrode which operates at a voltage only just high enough to collect all the electrons.

Input Circuit

The operation of the cathode, grid No. 1 and grid No. 2 portion of the 825 is similar to that of a normal negative grid design. The application of an input signal to the control grid (G_1) will thus still produce the usual charge density modulation of the space current with the consequent electronic resistive input loading. This loading has, however, been reduced by employing a small gap between the control grid and cathode and keeping Θ_2 small by employing a high voltage for G_2, *i.e.*, 3,600 volts.

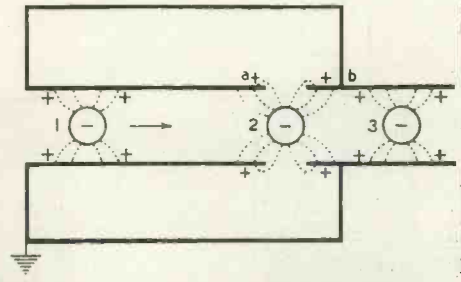

Fig. 4. Charges due to electrons in concentric line output circuit. (*after Haeff.*)

The reactive and resistive input loading [14, 17] due to electrode and lead reactance has been minimised by using a comparatively large gap between G_1 and G_2, as well as the use of two grid leads brought out to three pins, two cathode leads and pins and two G_2 leads and pins.

These latter features will reduce the resistive input loading effects of section 4. Table I.

Output Circuit

We have now a charge density modulated beam of electrons travelling from the cathode to the collector, and while appreciable induced currents may flow in the G_2 and G_3 electrodes their collection of electrons and dissipation may be made small.

To understand the principle of the method of extracting power from the system reference will be made to Figs. 4 and 5. Fig. 4 illustrates a similar concentric line tuned circuit as used for the output system of Fig. 3. With no beam current flowing the space inside the inner cylindrical conductor will be field free. If we, however, consider an electron entering the inner conductor and travelling in the direction of the arrow, then at the instant indicated by position 1 the negative charge on the electron will be imagined by induced positive charges wholly on the inner surface of the inner conductor. When after a very short interval of time the electron has travelled sufficiently to be in position 2 central in the gap a-b, the imaged charges will be partly on the inner surface and partly on the outer surface of the inner conductor on either side of the gap as shown by the lines of force in Fig. 4. A little later still the electron reaches position 3, where the conditions are similar to those of position 1.

As the electron moves from one side of the gap a-b to the other, the transference of the image charges from one side of the gap to the other causes a current to flow on the outside of the inner conductor and the inside of the outer conductor of the concentric line. This current flow will excite the line and produce a voltage gradient across the gap (*see* Fig. 5). If an electron traverses the gap at the instant the electric force is in the direction from b to a the electron will be decelerated, while if the force is in the direction from a to b the electron will be accelerated.

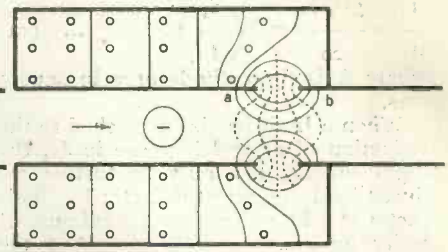

Fig. 5. Electric and magnetic fields in concentric line output circuit. (*from Electronics.*)

When the electron is decelerated it will lose some of its kinetic energy, and therefore energy will be given up to the circuit, when the electron is accelerated the reverse is the case and energy is abstracted from the tuned circuit.

If we now adjust the frequency of the input signal to resonate with the output circuit we will have a maximum voltage built up across the gap and the maximum amount of energy delivered to the tuned circuit because owing to the phase relationships at resonance and to charge density modulation the amount of energy absorbed from the tuned circuit during the half cycle when G_1 is going negative is appreciably smaller than the gain in energy by the tuned circuit during the half cycle when the voltage on G_1 is least negative. By coupling a load to the tuned circuit it is possible to abstract this gain in energy in the form of useful power; this coupling may take the form of a loop near a current anti-node as shown in Fig. 2 and 3. Fig. 5 illustrates the distribution of the electric and magnetic fields in the excited concentric line, the solid lines illustrate the electric field distribution, and the circles the magnetic lines of force, while the broken lines show the equipotentials in the gap. It will be seen that the majority of the space inside the inner conductor is field free, as the field from the gap as shown by the equipotential lines penetrates, but a short distance into this region.

Due to the finite electron transit time the voltage across the gap is varying as the electrons traverse the gap and this causes divergence of the beam. The most effective method of overcoming this defect is to provide a thin magnetic lens at a point central in the gap a-b. By providing the convergence required at G_2 with another thin magnetic lens, the long uniform field magnetic lens may be eliminated with a considerable saving in power and an improved performance (*see* Fig. 2).

The dissociation of the function of electron collection and output electrode possible with the inductive-output system reduces very considerably the limitation 6 of Table I. With the inductive system the collector electrode need no longer operate at a high voltage in order to keep the transit time low and can therefore be operated at only a slightly higher voltage than that required to collect all electrons.

In practice the voltage required is

of the order of the H.F. voltage across the gap a-b, 1,500 v. being used. In addition, as the static capacity of the collector is no longer loading the output circuit, this electrode can be made large in size and run at a reasonable temperature. The actual size of the collector necessary is therefore determined by the magnitude of the current that can be taken from the cathode.

Reactive Loading and Output Circuit

Having removed the loading of the collector electrode from the output circuit it is now pertinent to consider what form of output circuit will enable the largest power output to be obtained. As the cathode area and therefore the magnitude of the beam-current is mainly controlled by the power available for the input drive, the power output can only be increased by raising the value of the output load resistance.

It can be shown that for a given required band width, the lead resistance that can be employed with a line having uniformly distributed constants, is twice that for a circuit having a lumped tuning capacity of a value equal to the total distributed capacity of the line.

As the total distributed capacity is equal to lC_0(or$\frac{1}{4}\lambda C_0$ in the case of a quarter wave line) it might at first sight appear that we can increase the load resistance indefinitely by a continuous reduction of the operating wavelength. This, however, is by no means true as in addition to the reactive loading effect of the gap the maximum obtainable dynamic resistance with a concentric line drops with reduction of wavelength. These relations are strictly only correct for a line with no reactive loading, but they still hold when the effect of the lumped capacity of the gap is having but a small effect on the resonant length of the line (see ELECTRONIC ENGINEERING Data Sheets, 6-11, by the author). For efficient operation it is necessary to keep the transit angle through the gap reasonably small, an increase in the length of the gap must therefore be compensated for by an increase in the voltage applied to G_2 and G_3, the possible extent of this compensation is, however, limited by practical consideration.

As the wavelength is reduced it is necessary to reduce in proportion the lumped gap capacity and transit time through the gap, if the anode voltage cannot be appreciably increased, this can only be achieved by a simultaneous reduction in gap length and diameter. A reduction of the inner conductor diameter involves the design of a valve with a smaller beam section and therefore a smaller power output.

The output power that can be obtained is therefore mainly controlled by the maximum voltage that can be applied to G_2 and G_3. In practice at a wavelength of 60 cms. (500 Mc/s) gaps with capacities of only a fraction of a $\mu\mu$F and a total distributed capacity lC_0 of 1-2 $\mu\mu$F have been successfully employed.

Stability

As was seen in Fig. 5 the H.F. electromagnetic field penetrates but a short distance beyond the gap a-b. It is thus possible to position the electrodes G_2 and G_3 outside the gap field and so ensure negligible coupling between the output system and the remaining electrodes.

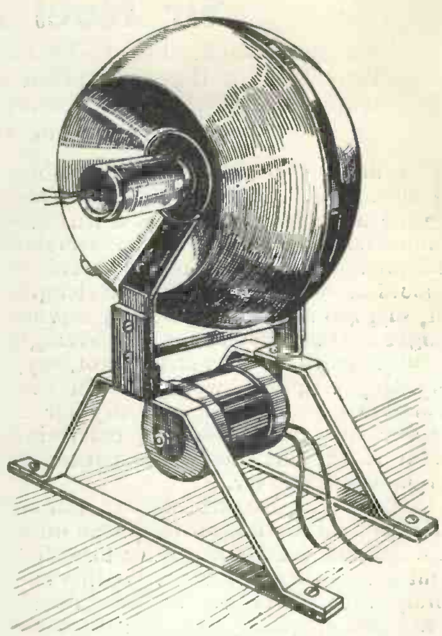

Fig. 6. Sketch of 500 Mc./s. amplifier resonant chamber with valve in position.

500 Mc/s Amplifiers

In Fig. 2 is shown a practical circuit arrangement for a 500 Mc/s amplifier. In order to conveniently provide the two thin magnetic lenses and maintain a short physical length near the valve neck, the concentric line has been replaced by the resonant chamber shown in Fig. 2 and also illustrated in Fig. 6. The efficiency of the focusing system is such that only 1 to 2 watts of power (about 1,000 amp. turns) is required. The iron parts in the H.F. fields are copper plated to reduce losses. The input circuit may consist of either a tuned line or a circuit of the type shown in Fig. 2 an input power of the order of $\frac{3}{4}$ watt is required.

From the foregoing it will be seen that the inductive output amplifier system provides a solution to all the sections of Table I that are not dependent on charge density modulation. As, however, the input control electrode does produce charge density modulation of the space current the problems of sections 1 and 4 still remain and the amount of power that can be obtained at a given frequency is still largely controlled by the power available for the input drive.

TABLE II.

R.C.A. 825. Inductive Output Amplifier.

		Inter Electrode Capacities.	$\mu\mu$F.
Heater Volts	6.3	g_1 to g_2	1.7
Heater Current (amps.)	0.75	g_1 to Cathode	3.4
[1]Mutual Conductance (mA/v) ...	5.5	g_2 to Cathode	0.9
Max. D.C. Collector Volts ...	2000	Max. Collector Dissipation (watts)	50
Max. D.C. Grid No. 4 Volts ...	1500	Max. g_4 input (watts)	7
Max. D.C. Grid No. 3 Volts ...	3600	Max. g_3 input (watts)	5
Max. D.C. Grid No. 2 Volts ...	3600	Max. g_2 input (watts)	7
Max. D.C. Grid No. 1 Volts ...	—100	Max. g_1 Dissipation (watts) ...	0.15
Max. D.C. Collector Current (mA)	50	Max. D.C. g_2 current (mA) ...	2.5

Typical Operation.

	R.F. Power Amplifier Class B Telephony [2].	R.F. Power Amplifier and Oscillator. Class C Telegraphy [3].
Max. Collector Input (watts) ...	50	100
D.C. Collector Volts	1500	1500
D.C. g_4 Volts	800	800
D.C. g_2 and g_3 Volts	3600	3600
D.C. g_1 Volts	—25	—40
Collector Current (mA)	25	45
g_4 Current (mA)	1	2
g_3 Current (mA)	0.3	0.5
g_2 Current (mA)	0.5	1
g_1 Current (mA) (approx.)	—	2.3
Peak R.F. Grid No. 1 Voltage ...	20	45
Power Output Watts (approx.) ...	9	35

[1] Taken with Ia = 50 mA. [2] Carrier conditions. [3] Key down conditions.

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Note.—For Bibliography references other than those given at the conclusion of this article, *see Electronic Engineering*, September, 1941, page 414.

Sir Noel Ashbridge's Inaugural Address

Sir Noel Ashbridge, Chief Engineer of the British Broadcasting Corporation, has been elected President of the Institution of Electrical Engineers. The following extracts are reproduced from his inaugural address, which reviewed the growth of broadcasting and the problems associated with sound and television programmes.

IN discussing the problem of ether space, one important difference between the requirements of a wireless broadcasting service and commercial telephony and telegraphy services should be mentioned. On a wavelength of, say, 400 metres, a telephony service might well be conducted under average conditions with a field strength of, say, 0.5 mV/m. or less, while at least five times this strength is necessary for a broadcasting service having entertainment value, particularly when listened to on a loudspeaker.

A somewhat, but not exactly, similar state of affairs exists for telephone lines used to connect a transmitter to a distant source of programme. A line entirely satisfactory as to background noise and frequency response for commercial speech may yet give a most disagreeable result when used for broadcasting, for which the standard in both these respects must be considerably higher. When the strength of signal required for commercial wireless telegraphy is considered in relation to that for broadcasting, the disparity is even more striking.

The important result is that the power of broadcasting transmitters has to be very much greater than that used for commercial purposes. The power ratio, expressed in very general terms, might be on an average about 25 to 1. This makes a broadcasting station an extremely unwelcome neighbour for any other wireless service, with considerable repercussions on the wavelength problem, since all other wireless services not only have attempted to avoid the allocation of wavebands to broadcasting which are near those used by themselves, but have also pressed for regulations limiting the power of broadcasting stations.

Regional Scheme

The problem of covering country areas satisfactorily was, and still is, a difficult one. A large number of additional stations was not practicable on account of the increased cost, quite apart from the wavelength troubles which soon began to appear. Increased power on medium waves would not have been a complete solution owing to the limitation of service area obtainable on these waves, particularly in hilly country. It was soon realised, however, by those responsible that the solution would be to use the highest possible power on the longest practicable wavelength. Thus it came about that an experimental station was built at the Marconi Works at Chelmsford, to work on a wavelength around 1,600 metres (187.5 kc./s.). This was successful and had a fully effective range of about 100 to 150 miles, but it was obviously not in the best place geographically for maximum coverage; in fact the Chelmsford station was never intended as a permanency. Consequently a new station was built at Daventry, with a power of 25 to 30 kW, and this soon became perhaps the best-known broadcasting station in Western Europe.

It soon became clear, however, that a system mainly of low-power stations, each occupying a separate channel, could not be looked upon as a permanent solution of the distribution problem, for two main reasons. The first concerned development on the Continent of Europe, where the increase in the number of stations had become alarming. It also became clear—and I think it was somewhat of a surprise to many wireless engineers—that during the hours of darkness a 1 kW station in, say, this country could seriously interfere with another 1,000 miles away if their carrier frequencies were within a few kilocycles of each other. This is mainly due to the audible beat frequency set up between the carriers of the two stations, since it could not be arranged in those days that they should work within a few cycles of the same frequency. It meant in practice that almost every station on the Continent would have to be allotted a separate wavelength. This was obviously serious, since to cover all countries in Europe with a reasonable service it would be necessary to establish several hundred stations, and obviously sufficient suitable channels could not be made available. It took some time for this to be recognised in all countries, and at that time and for some years afterwards there was a condition of impending chaos owing to the large number of stations trying to find clear channels.

The seriousness of the position was, I think, realised in this country sooner than in most others, and the necessity for reconstructing the transmitting system was made an opportunity for introducing a choice of two programmes, which in itself was highly desirable for purely programme reasons. The direct outcome was the system of stations known as the "Regional Scheme," whereby it was originally intended that the transmitters should have a power of 30 kW, but they were actually operated on 50 kW almost from the beginning.

Distribution by Wire

Some further alleviation of the wavelength shortage might be possible by an expansion of the system existing in a few countries, of distributing broadcasting programmes to listeners' homes by some form of line network. Before the war many such installations were in operation in this country, but the total number of listeners connected was only of the order of a quarter of a million out of a total of some 9 millions. Subscribers to these systems generally had a choice of two programmes, whereas, of course, a good wireless receiver gives a choice of considerably more.

There are several ways by which this system of distribution could be developed, the principal ones being the following:—

By audio-frequency distribution on special lines (almost the only method actually used in this country).

By carrier system on special lines.

By carrier system on existing telephone lines.

By carrier system on electric light mains.

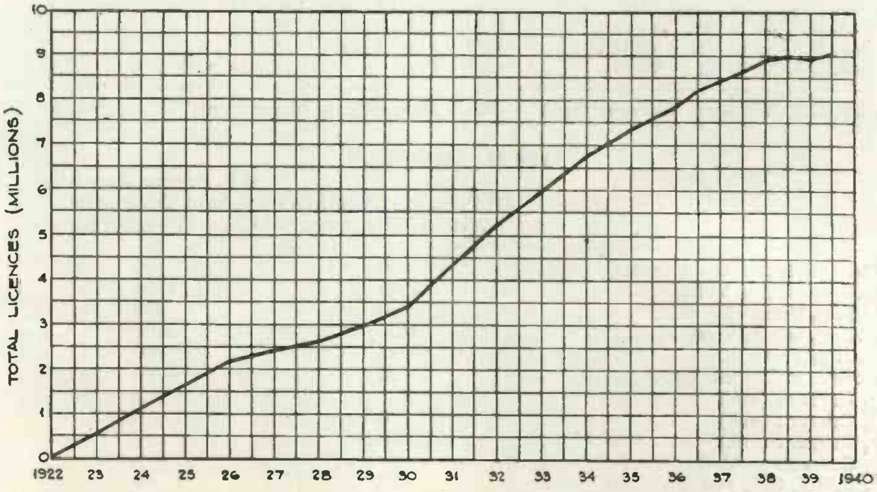

Chart showing the growth of British receiving licences from the commencement of broadcasting.

Naturally, any one or several of these methods might be further developed in the future. Generally speaking, those employing a carrier system are particularly suitable for the distribution of a considerable number of programmes, while the low-frequency system has the advantage of simplicity in relation to the apparatus necessary at the listening end.

It is a curious fact that this method of diffusing broadcast programmes has not been favourably received in the majority of countries, for no very clear reason. Apart from this country, such systems existed before the war on a fairly considerable scale in Holland and Switzerland, and in several British Colonies, notably those on the west coast of Africa, where the material diffused originated in distant countries, whence it was transmitted on short waves.

It is clear, however, that some method must be found for the proper development of broadcast distribution in peace time, without, if possible, a repetition of the undignified wrangling which was customary at international wavelength conferences before the war.

Frequency Modulation

While speaking of future transmission development, mention must be made of a new type of transmission employing "frequency modulation," which has progressed considerably in the United States during the past two years and which would certainly have been investigated experimentally before now in this country had the war not made this impracticable.

There seems to be no reason to doubt that frequency modulation will soon spread beyond the United States of America when conditions allow development to be resumed.

It is difficult to imagine that present methods of transmission will change suddenly after the war and necessitate many millions of new receivers; also it is not clear at the moment that the change would materially reduce the waveband congestion difficulties in Europe. It may be that the advantages of frequency modulation will be exploited in connection with television services, since in most countries there are no commitments with regard to system. This brings us to the general question of television broadcasting and its future.

Television

During the years before the war a great deal was written about television which seemed to me to fail to demonstrate a full appreciation of its potentialities. Sound broadcasting has become a social and political force, either for good or for evil, because it enables the voices of eminent men and the reading of important news to be heard in the home of everyone at very little cost and trouble to the listener. To this can be added the benefit of hearing music played by first-class artists without the necessity of buying or hiring gramophone records. No one would deny for a moment that in most cases benefit would be secured by making it possible to see as well as hear the speaker or the musicians, but it is questionable whether the effect of this absence of vision is keenly felt by most people, although undoubtedly it is by some. On the other hand, there are some broadcast programmes which, although they are popular, lose very seriously if transmitted by sound only. The most obvious of these are broadcasts of sporting and other outdoor events, drama and what is known as variety, as well as material of an instructional type which necessitates some form of illustration. To develop such programmes to a maximum, vision is essential and, in fact, will soon be looked upon as indispensable.

The fact that many people find that the broadcast items which they happen to like do not necessitate vision may to some extent have accounted for the comparatively slow response on the part of the public to the regular service of television, which was experienced during the years 1936-1939. Of course, there were contributory causes, such as the high price of receivers and the somewhat restricted area in which the service could be received, but the fact remains that after three years the number of people owning a television set was probably less than 30,000, although the number of households within the service area of the one station then working in London was of the order of 2½ millions.

The question had arisen whether the service could be extended to some at least of the heavily populated rural areas. There was no doubt that this and more must be achieved sooner or later, but there were three main difficulties, one financial, and the other two technical. It had, of course, been realised that the cost of producing, say, one hour of television programme would be much higher than an hour of sound.

Naturally the heaviest item was the production of the programme itself, owing to the large amount of rehearsal and preparation necessary as compared with a sound programme, but it also applied to the technical side. To set up a complete studio, outside broadcast, and transmission plant to serve an area of 30 miles radius with a television programme is, say, 15 times as costly as an equivalent plant for a sound programme, and the maintenance costs are in a similar proportion.

Expenditure on the London service exceeded what could have been covered by a licence fee two or three times greater than is now paid for sound, even had there been 10 times as many viewers.

The second problem, a technical one, is concerned with transmitting vision signals over considerable distances by cable or wireless link. So far as one can see at the moment, the former method involves the provision of special cables of the air-insulated type. There is not much doubt that this is feasible technically, but it would be costly, very much more so than the equivalent for the transmission of high-quality sound programmes. The second method is also feasible technically, but is likely to produce complications due to the wide space in the ether occupied by the radio channels necessary to create country-wide interlinkage. The provision of main-station channels constitutes the third problem referred to and, however the interlinking of stations may be achieved, this difficulty will remain. Sir George Lee, in his Presidential Address in 1937, referred to the possibility of distributing television broadcasts entirely by line networks. This is a method which must be considered when the time comes to take up again the problem of a national service. It is not, perhaps, quite certain that special cables would, as might be expected, be essential, since before the war a move had been made towards transmitting vision signals over short distances on ordinary telephone lines. This work was carried out in connexion with broadcasts of outside events, but it might conceivably be developed as a means of general distribution. A great deal of development and research work will be necessary before telephone lines can be used on an ordinary every-day basis on a considerable scale, and if special cables proved necessary the process of installation would be lengthy. What is certain, however, is that television will be developed seriously on a national scale, and it is quite out of the question that such difficulties as remain should be allowed to stifle an achievement which has already secured such a remarkable measure of success. This is a matter of first importance for post-war development, and one capable of absorbing a large number of the many radio engineers who ultimately will be released from war work.

Crosley v. Hazeltine

The Crosley Corporation of Cincinnati, Ohio, was recently sustained on appeal in its effort to enjoin the Hazeltine Corporation, Jersey City, New Jersey, from prosecuting nine suits against Crosley in Cincinnati for infringement of radio patents.

This action by a U.S. Court of Appeal follows several other decisions against Hazeltine in the last few months. In May of this year the Trube patent for combined magnetic and capacitive coupling was held to be invalid and not infringed. Later in May the Supreme Court of U.S. held that the Wheeler reissue patent for automatic volume control was invalid. In July of this year, a previous patent suit brought against Crosley was decided by the District Court in Cincinnati, holding that the MacDonald patents covering high inductance primaries were not infringed.

Frequency Modulation

Part II. — The Advantages and Disadvantages of Frequency and Phase Modulated Transmission

By K. R. Sturley, Ph.D., A.M.I.E.E.

THE first article of this series dealt with the differences between amplitude, frequency and phase modulation, using the vector representation of modulated carrier and of carrier and sidebands to illustrate their essential features. We can now consider the particular advantages to be gained from frequency and phase modulation and its limitations. Since frequency modulated transmission is more likely to be widely adopted we will deal with it first and in more detail.

Four important advantages[2] can be realised by frequency modulation in comparison with amplitude modulation, viz., greater signal-to-noise ratio; lower transmitter power for a given audio frequency output from the receiver, less amplitude compression of the audio modulating voltage, and larger service area with little interference between stations having adjacent carrier frequencies. These advantages can, however, be realised only under certain conditions of operation, chief of which is that reception must be confined to the direct ray from the transmitter. Indirect ray communication, as in short wave transmission over long distances, is subject to selective fading of carrier and sidebands due to several rays arriving at the receiver by different routes; the time delay on the longer path rays may result in certain frequency components arriving partly or completely out of phase with the same components in the shorter path ray thus causing a reduction in amplitude of these components. This selective fading causes serious distortion of the audio frequency signal at the receiver and it is worst when a large number of sidebands is being transmitted. One of the characteristics of frequency modulation is the large number of sidebands produced by low modulating audio frequencies and selective fading makes the output almost unintelligible. This effect and the need for a large pass band to accommodate the frequency deviation render frequency modulation impracticable except on ultra short waves.[1, 3] Phase modulation has fewer low-frequency sidebands so that selective fading is much less serious and it may be employed for short wave transmission.[4] Amplitude modulation is least affected by multipath selective fading because there are only two sidebands per modulating frequency.

To understand the reason for the greater signal-to-noise ratio obtained from a frequency modulated system it is necessary to state the characteristics of noise. Disturbances in or external to the receiver can produce noise in its output. Noise from sources outside the receiver is mainly of the impulse type and is due to atmospheric disturbances or interference from electrical machinery (the ignition system of a car, switching surges transmitted by the mains supply wiring, etc.); it often has high peak voltages and may be periodic, continuous or spasmodic. In a well designed receiver (with no faulty contacts) internal noise is due to the random motion of electrons in the conductors and in the valves; the important sources being the first tuned circuit and R.F. valve. Thermal agitation (conductor) and shot (valve) noise usually cause a hissing sound and the frequency components cover a very wide range and are continually varying in amplitude and phase In a receiver for amplitude modulation these noise voltages (if no carrier is being received) beat amongst themselves, the beats being made audible by detection, and the wider the band the worse is the noise. For example suppose the receiver has a band width of 900 to 1,100 kc/s, a beat of 5 kc/s is produced by two noise voltages at 900 and 905 kc/s as well as

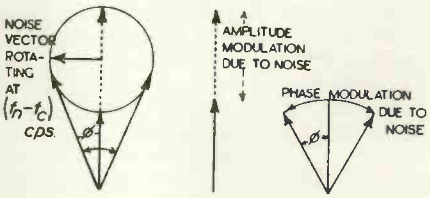

Fig. 1.

by two at 1,095 and 1,100 kc/s and this can be repeated for all the noise components. If a carrier is applied and is large enough to ensure linear detection, the noise voltages act as sidebands to the carrier and audible beats are now only produced between carrier and noise, *i.e.*, beats between the noise components themselves are suppressed. Hence only those noise components within audio range of the carrier contribute to the noise output, and the noise output should fall; in practice we more often find that the application of a carrier increases noise and this may be due to noise on the carrier itself (*i.e.*, from the transmitter) and also to the fact that the noise voltages alone are not large enough to cause linear detection. However, the fact is still true that in the presence of a carrier only those noise components within audio range of the carrier contribute to the output.

A device (a limiter) is always incorporated in a frequency modulation receiver to suppress any amplitude changes of carrier so that noise cannot have the same effect as in an amplitude modulated receiver. For the sake of clarity let us consider the action of a single noise frequency component f_N kc/s spaced an audio frequency $f_m = f_N - f_C$ kc/s from the carrier by taking the carrier vector as stationary the noise is a vector rotating round the carrier at f_m kc/s as illustrated in Fig. 1. We see that there is amplitude and phase change of the carrier vector, the former, which causes the noise output in the amplitude modulation receiver, is suppressed by the limiter and the latter, which produces phase modulation and hence frequency change of the carrier, gives noise at the output of the frequency modulation receiver. An important feature of phase modulation is that the carrier frequency deviation is directly proportional to the frequency of a constant amplitude modulating signal so that noise sidebands near to the carrier give much less frequency deviation and consequently much less audio output from a frequency modulation receiver than those distant from the carrier. This "triangular" distribution of effective noise makes the signal-to-noise power ratio with a maximum frequency deviation equal to the audio range ± 15 kc/sec., 1.7 times higher than for an amplitude modulation receiver working under corresponding conditions.[2] In the case of impulse noise from motor car ignition systems, etc., the signal-to-noise ratio is twice that for amplitude modulation. It is not necessary to confine the frequency deviation of carrier to the audio range and by increasing this the signal output can be increased; hence the signal-to-noise ratio may be further raised by the ratio frequency deviation/maximum audio modulating frequency, *e.g.*, if the carrier deviation is ± 75 kc/s and the maximum audio frequency 15 kc/s, the signal-to-noise ratio is increased five times. Taking the conservative figure of 1.7 to 1 improvement due to "triangular" noise distribution we have a total improvement in signal-to-noise ratio of 8.5 to 1 (9.3 db). The increase in receiver band width to accommodate the greater frequency deviation introduces extra noise sidebands, but if the carrier is large in comparison with the noise (at least twice the peak value of noise) there is no increase in noise output because the phase modulation of the carrier by the additional sidebands is outside the audible range. When the peak carrier-to-noise ratio is less than 1, interaction occurs between noise components and noise is increased and signal-to-noise ratio decreased by increasing the frequency deviation. This causes a well defined threshold area[5] to appear round a frequency modulated transmitter; outside this area better reception is obtained with a lower frequency deviation and narrower receiver pass band.[7] Inside this area the reverse is true.

Signal-to-noise ratio can be still further improved by the use of "pre-emphasis,"[6] increased amplitude of the higher modulation frequencies, at the transmitter followed by "de-emphasis," restoration of aural balance by reduced amplification of the high modulation frequencies, at the receiver. Pre-emphasis and de-emphasis can also be applied to amplitude modulated transmission, but the improvement in signal-to-noise ratio is not so great as in the case of frequency modulation which, because of phase modulation of the carrier by the noise, produces greatest noise in the higher audio frequency ranges. An improvement in signal-to-noise ratio of about 5.5/1 (7.4 db) is realised by pre-emphasis giving a total increase of 46.8 to 1 (16.7 db) for frequency in comparison with amplitude modulation.

The second advantage of frequency modulation is that less power is taken from the mains supply for a given audio power at the receiver output. In the power amplifier stage of an amplitude modulated transmitter the D.C. current must be sufficient to allow 100 per cent. modulation without serious distortion, *i.e.,* it must be able to accommodate a carrier of twice the unmodulated amplitude. This means that the D.C. current must be twice the value required if the carrier were maintained at its unmodulated amplitude. Since a frequency modulated carrier has constant amplitude it follows that the power required from the mains is half that of its amplitude modulated counterpart. Alternatively for a given mains power frequency modulation can give an audio signal power at the receiver of twice that for a corresponding amplitude modulated system. This means a further increase in signal-to-noise ratio of 2 to 1 giving a total of 93.6 to 1 (19.7 db). Successive stages of improvement in signal-to-noise power ratio are illustrated in Fig. 2.

Reduced compression of the audio signal in a frequency modulated transmitter really arises out of the increased signal-to-noise ratio. For an amplitude modulated system the maximum modulation percentage for reasonable distortion (less than 5 per cent.) is 90 per cent. and a suitable minimum value is 5 per cent. if low level sounds are not to be marred by noise so that the maximum possible change in audio output power is limited to 320 to 1, 25 db (note that percentage modulation represents voltage, which must be squared to give power). Clearly the maximum change of 10,000,000 to 1 (70 db) between fortissimo and pianissimo orchestral passages would sound unnatural in a normal room and some compression is essential. A power ratio higher than 320 to 1 is however desirable, and it can be raised to 32,000 to 1 (45 db) by virtue of the higher signal-to-noise ratio (shown above as approximately 100 times better) in frequency modulation.

Apart from noise a very important problem in wireless communication is the separation of desired from undesired programmes. In an amplitude modulated system this limits the closeness of spacing between the carrier frequencies. If the separation between the two carriers is equal to an audio frequency an audible note is produced in the receiver output causing serious interference with the desired programme unless the desired signal at the receiver aerial is at least ten times that of the undesired. This limits the service area of either transmitter and between the two there is a large area in which reception of one programme is marred by the other. Increased separation of the carrier frequencies can remove the carrier separation frequency outside the audio range but the desired signal service area is still limited by sideband overlap[8] from the undesired. The sidebands of the latter react with the desired carrier causing the characteristic frequency-inverted "monkey chatter." Powerful transmitters need to be separated by at least 50 kc/s if the interference area between them is not to be large.

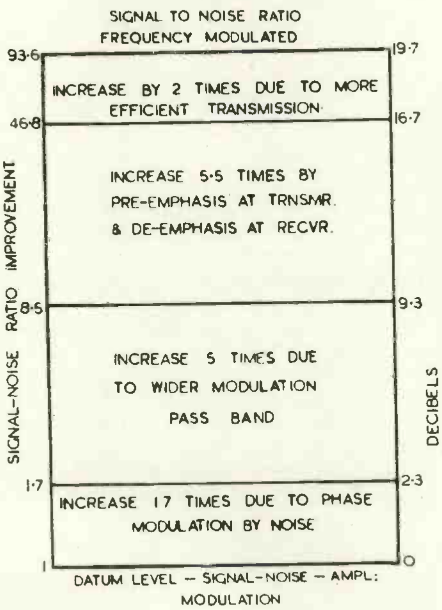

Fig. 2.

A different state of affairs exists with two frequency modulated systems, because the receiver suppresses amplitude change. Interference, as in the case of noise, occurs due to phase modulation of the desired by the undesired carrier. This phase modulation results in an audio output of frequency equal to the carrier separation and of amplitude directly proportional to the separation (phase modulation is equivalent to frequency modulation with modulating amplitude directly proportional to the modulating frequency). Thus for small carrier separations the interference is small; it is actually most noticeable for about 5 kcs. separation[6] for though greater separations give greater equivalent modulation the resultant output becomes less audible. We therefore find that two frequency modulated systems can be operated with small carrier spacing with quite a small interference area (where the desired to undesired carrier ratio is less than 2 to 1) between them. Interference is worst when both carriers are unmodulated. Although it is possible to operate with small carrier spacing it is usually considered better to adopt a spacing slightly beyond the audio range. This does not in any way modify the statements on the smaller interference area obtained with frequency as compared with amplitude modulation.

Phase modulation possesses much the same advantages as frequency modulation. Signal-to-noise ratio is greater than for amplitude modulation by virtue of the increased frequency deviation coverage though it is less than for frequency modulation since the triangular noise spectrum effect is absent because noise itself phase modulates the carrier. Lower transmitter mains power is required by reason of constant amplitude and less audio compression is needed. As stated above it may be used for short wave transmission when multipath selective fading is experienced and it then has the advantage of lower transmitter power in comparison with amplitude modulation.

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Review of Progress in Electronics

IX.—Measurement of the Electron

By G. WINDRED, A.M.I.E.E.

" The modern view of electricity is based on an enormous mass of experimental evidence, to which contributions are made, not only by the phenomena of electrostatics, but also by the phenomena of almost every branch of physics and chemistry."—Sir James Jeans, " The Mathematical Theory of Electricity and Magnetism," Cambridge, 1927.

THE branches of electronics discussed in previous articles in this series call for no very detailed ideas concerning the properties and characteristics of individual electrons. In applied electronics we find the conception of electrons necessary for explaining observed phenomena, but we are not obliged to devote much thought to the nature of the electron itself as a physical entity. It is when we come to a consideration of the more advanced aspects of electronic theory that an understanding of the properties of the electron becomes necessary. Even apart from this consideration, a study of the methods by which some of the properties of the electron have been revealed forms an excellent introduction to one of the most interesting and instructive branches of experimental physics.

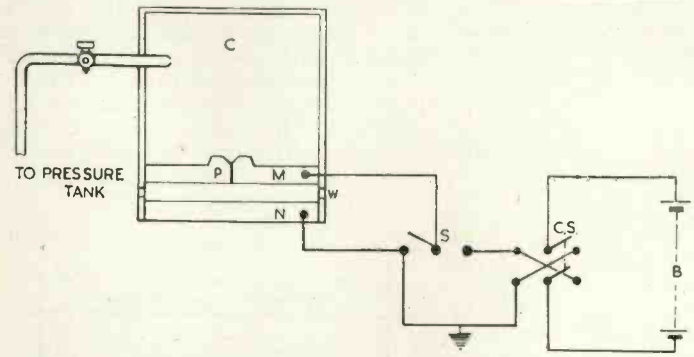


Fig. 1. Diagram to illustrate the principle of Millikan's early apparatus for measuring electronic charge.

The Electronic Charge

The first attempt at a direct determination of the electric charge carried by an electron was described in a paper[1] by J. S. Townsend read before the Cambridge Philosophical Society on February 8, 1897. This work was based on the observation that when the charged gases liberated in the electrolysis of sulphuric acid are bubbled through water they form a cloud which can be removed by bubbling through sulphuric acid without losing more than about 25 per cent. of the original charge on the gas. Townsend assumed that each ion acquired condensation in the process of cloud formation, so that the number of droplets in the cloud was the same as the number of ions present. It was a relatively simple matter to measure the charge per unit volume of the gas, so that if the number of droplets in the cloud could be arrived at it would be possible to calculate the charge per ion. Townsend proceeded to find the weight of the cloud per unit volume by bubbling it through successive jars of sulphuric acid interconnected by drying tubes and then measuring the increase of weight of the tubes.

An estimate of the average weight of each droplet in the cloud was then made by means of a purely theoretical formula developed some time previously by the mathematician, Sir George Stokes, without any idea that it might form an indispensable part of research in electron physics. Stokes' theorem, which is dealt with, for example, in Lamb's famous treatise on Hydrodynamics, states that the velocity of fall v of a spherical body through a gas of viscosity V under the action of gravity is given by

$$v = 2ga^2\,D/9V, \qquad \ldots \quad (1)$$

where g is the gravitational constant, a the radius of the sphere and D its density. By observing the rate of fall of the cloud, and with a knowledge of previous determinations of V for air it was then easy to calculate the average radius a of the droplets (assuming that their movement obeyed Stokes' law) as follows:

$$a = (9Vv/2gD)^{\frac{1}{2}} \qquad \ldots \quad (2)$$

The weight of each droplet, regarded as a sphere was then given by the formula

$$m = 4\pi a^3\,D/3 \quad \ldots \quad \ldots \quad (3)$$

After this the number of droplets in the cloud (assumed to be equal to the number of ions) could be easily found by dividing the weight of the cloud, as measured by weighing the drying tubes, by m. Finally, the charge on each ion was arrived at by dividing the measured charge on the gas by the number of droplets.

There are evident sources of error in this investigation, such as the assumption that the number of ions forming the charge is equal to the number of droplets, and the possibility that Stokes' theorem might not be valid in the case of such small drops. However, from this and later work Townsend came to the conclusion that the average charge on each ion was approximately 3×10^{-10} e.s.u.

Thomson's Method

In 1898, J. J. Thomson used a similar method of measuring the ionic charge. Ions were produced in a vessel by means of an adjoining X-ray tube, and the ionised space subjected to a small difference of potential E between two electrodes, the resulting current being measured. If n is the number of ions of one sign (either positive or negative) per cubic cm, and u and v are the respective ionic mobilities of the positive and negative ions, that is to say the velocities imparted to them by the action of unit e.m.f., then the current per unit area will be given by

$$I = ne\,(u + v)\,E \qquad \ldots \quad (4)$$

where e is the quantity of electricity carried by each ion. The mobilities of ions in gases at atmospheric temperature and pressure had been determined by Rutherford in 1897, and I could be measured directly, so that ne, representing the charge of one sign per cubic cm. of gas produced by a constant rate of ionisation by X-rays could be calculated directly. In order to find the value of e it was necessary to estimate n, and Thomson did this by employing a discovery made by C. T. R. Wilson during the years 1895 to 1897. This discovery was that sudden expansion and consequent cooling of the space occupied by a gas caused the ions to acquire condensed moisture and thus produce a cloud. Thomson calculated the weight of a cloud from the theoretical amount of cooling resulting from the expansion and the difference between the densities of saturated water vapour at the lower temperature and at normal ambient temperature. The value of n was finally calculated with the aid of Stokes' theorem as in Townsend's experiment.

The uncertainties in this determination are no less than in Townsend's experiment; possibly the results are even more subject to disturbing factors. After several measurements Thomson gave as his final result $e = 6.5 \times 10^{-10}$. In 1903 he published results of further experiments[2] using radium radiation instead of X-rays for the source of ionisation and giving $e = 3.4 \times 10^{-10}$.

Wilson's Method

Also in 1903, H. A. Wilson[3] modified Thomson's arrangement by placing inside the ionisation chamber two horizontal brass plates 35 mm. diameter and from 4 to 10 mm. apart, connected to a 2,000 volt battery. With no field, a negative cloud was formed by an expansion of about 30 per cent., and observation then made of the rate of fall of the top of the cloud between the plates. The same observation was made with the field on and assisting gravity to drive the drop downwards. This gave two conditions: firstly, the velocity v_1 with gravity alone (force on drop = mg), and secondly the velocity v_2 with gravity assisted by the electric force (force on drop = $mg + Fe$). The relationships are given by the equation

$$mg/(mg + Fe) = v_1/v_2 \ldots \quad (5)$$

By means of equations (1) (2) and (3), e could be found after substituting for V and D the appropriate values, which incidentally were not known very accurately under the conditions immediately after expansion. Wilson found various values of e between (2 and 4.4) $\times 10^{-10}$, the average of eleven measurements being $e = 3.1 \times 10^{-10}$.

Although Wilson's method is also subject to serious experimental uncertainties it will be noted that he observed only the uppermost and therefore least charged droplets, thus avoiding the assumption that the number of droplets is equal to the number of ions.

The Researches of R. A. Millikan

About the year 1906, R. A. Millikan, of America, conceived the idea of holding the uppermost part of the cloud stationary, with the object of observing rates of evaporation and thus making allowances for this disturbing factor in cloud methods of measurement. This idea led to his important series of oil-drop experiments, commenced about 1909.

In the meantime, determinations of the quantity e by entirely different methods gave results approaching very closely the values found in cloud chamber experiments. Rutherford and Geiger[4] in 1908 utilised the α-particles (high-speed electrons) radiated from a speck of radium to cause an impulse on the needle of a sensitive electrometer every time one of the particles entered an ionisation chamber. The total charge transferred in this way was measured, and the individual charge on each electron calculated by dividing this charge by the number of impulses. The result was $e = 4.65 \times 10^{-10}$ e.s.u.

The determination of e in 1909 by Regener[5] involved the counting of the number of scintillations produced on a diamond screen by a source of radioactive material owing to its emission of α-particles. The same material was next arranged so that the charges carried by the particles were caught in a condenser, the ultimate charge on which could be measured by very sensitive means. The quantity of electricity acquired in this way during a given time, divided by the number of scintillations recorded in the same period, evidently represented the charge on each particle, which was found to be $e = 4.79 \times 10^{-10}$ e.s.u., with a possible error of about 3 per cent. As will be seen later, these results are in remarkably close agreement with the most modern determinations.

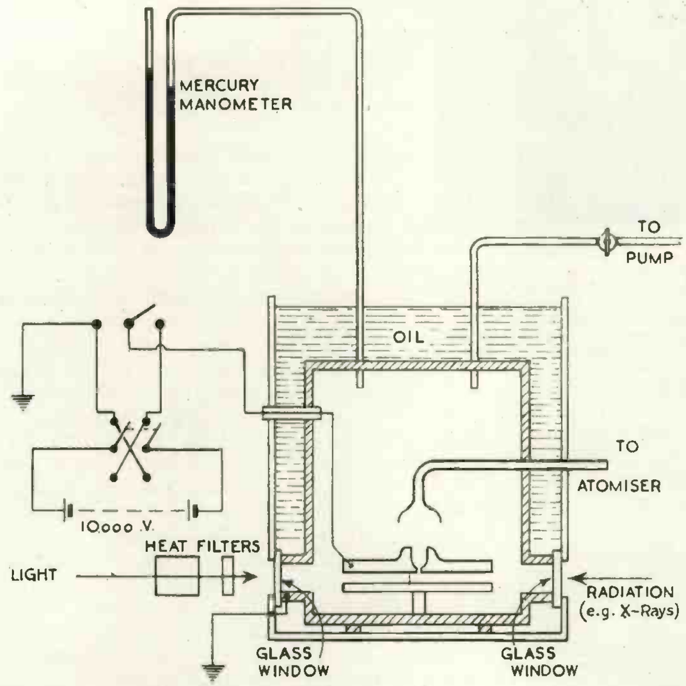


Fig. 2. The general arrangement of Millikan's final apparatus.

In the year 1910, or thereabouts, Millikan began to suspect that Stokes' theorem might not be valid for the tiny droplets used in the cloud experiments, the diameter of which was of the order of 0.0004 cm. It so happened that the validity of the theorem had also been questioned on purely theoretical grounds at about this time by Cunningham.[6] Accurate determinations of the viscosity of air had also become available, so that the possibility of more accurate results became very much improved.

The basic principle of Millikan's experiments involves the measurement of the forces on an electrified droplet of vaporised liquid maintained in suspension between two horizontal charged condenser plates. A very elementary representation of the apparatus used is given in Fig. 1. The oil, or other liquid employed, enters the chamber C in the form of a fine spray or cloud of very small droplets, each of which will have a radius of the order of two thousandths of a millimetre. The forces brought into action by the spraying operation give rise to frictional electrification of the droplets, so that each bears a definite charge of electricity. As the cloud drifts downwards under the action of gravity, one or more droplets will find access through the small hole p in plate M, and will then be under the action of the electrostatic field between the condenser plates M and N, which in this apparatus were located 16 mm. apart. With the switch S in the right-hand position, condenser plate M is connected to either the positive or negative terminal of the source of potential B, usually of about 6,000 volts, according to the position of change-over switch CS. It follows from electrostatics that under these conditions the droplet, or more strictly its electric charge, will be acted upon by a force Eq, where E is the electric field strength and q is the charge on the droplet, whose behaviour is watched through the windows w by means of a microscope having a micrometer eyepiece. According to whether the plate M is at positive or negative potential with respect to N, the direction of the force Eq on the droplet will be upward or downward respectively, so that it will either oppose or assist the gravitational force mg on the droplet, this force representing the weight w of the droplet. In the experiments it was found possible to maintain the droplet quite stationary for half an hour or more at a time. Under these conditions the necessary relation is that $Eq = w$, so that if w could be found it would be possible to calculate q directly. In practice, w is, of course, far too small to be measured accurately by direct means, but it can be determined from Stokes' theorem.

In later refinements of this experiment it was found preferable, instead of keeping the drop stationary, to measure

(*Continued on page 561*)

Plastics in the Radio Industry

II.—Manufactured Plastic Products

WE have only to examine the numerous radio components produced from plastics to appreciate their contribution to the radio world; a range of such components has therefore been compiled and is illustrated in this article.

A description of each material follows together with its physical properties. The electrical properties are omitted as they will be dealt with later.

It should be understood that the physical properties given have been determined by methods similar to those employed for metals and are extremely dependent on the exact conditions of temperature, duration of test, etc., employed. Minimum and maximum values are given to show available ranges and impact results are given as energy required to break a ½ in. square bar.

I.—Thermo-setting Resins :

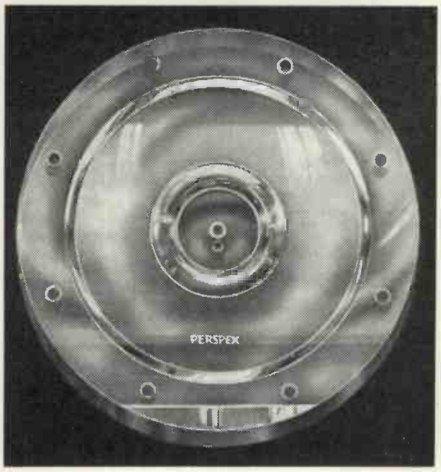
Phenol-formaldehyde, cresol-formaldehyde

Examples.—Bakelite, Catalin (Cast), Elo, Epok, Mouldrite (P.F.), Nestorite, Paxolin, Rockite (P.F.).

For moulding powders the resins are not used in their unfilled state, but with a high percentage of fillers such as wood-flour, asbestos, cotton-flock; wood-flour for cheapness, asbestos for high-temperature/low loss material and cotton-flock for shock-proof mouldings, which derive their strength from the filler. Since the base-colour is brownish and filler is always used, dark and opaque colours only are available.

The powders are moulded in steam or electrically-heated moulds under hydraulic pressure, the heating process converting them into insoluble infusible hard masses. These resins are particularly suited for large mouldings and can also be extruded

In their pure state the resins are used for lacquers and in cast form as transparent, translucent or opaque standard forms, which can be cut up into sections appropriate for machining.



Aerial Insulator. An illustration of the uses of methyl methacrylate for modern radio components. This aerial insulator for aircraft is capable of withstanding extremes of heat and cold met with under Service conditions. The disk is slightly curved, a feature which presents no difficulty in thermo-plastic working. —*Messrs. I.C.I. Plastics*

Physical Properties

Specific Gravity.—1.28-1.52. For high temperature work where special fillers are used a specific gravity of 2 is not uncommon.

Tensile Strength.—6,000-10,000 lb. per sq. inch.

Elongation at Break.—2 per cent. approximately.

Modulus of Elasticity.—7-15 × 10^5 lb. per sq. inch.

Compression Strength.—16,000 lb. per sq. inch.

Impact Strength.—0.16 to 2 foot lb.

Hardness (Brinell).—30-45.

Thermal Expansion Coefficient.—3-7 × 10^{-5} per degree centigrade.

Maximum Temperature for Continuous Resistance to Heat.—250-450° F.

Water Absorption (Immersion 24 hours). 0.1 to 1.2 per cent.

Burning Rate.—Very low.

Urea Formaldehyde

Examples.—Beetle, Mouldrite (U.F.) Rockite (U.F.).

These resins resemble the phenol-resins in their properties and method of handling, but their basic colour is white, so that they can be used for the production of light-coloured articles. The material also has a higher water absorption than the phenol type though the melamine type is much superior in this respect.

Physical Properties

Specific Gravity.—1.45-1.50.

Tensile Strength.—9,000-12,000 lb. per sq. inch.

Elongation at Break.—1 per cent.

Modulus of Elasticity.—12-15 × 10^5 lb. per sq. inch.

Compression Strength.—24,000 lb. per sq. inch.

Impact Strength.—0.14-0.16 foot lb.

Hardness (Brinell).—48-54.

Thermal Expansion.—160 × 10^{-5} per degree centigrade.

Maximum Temperature per continuous Resistance to Heat.—160° F.

Water Absorption (Immersion 24 hours). 1.2 per cent.

Burning Rate.—Very low.

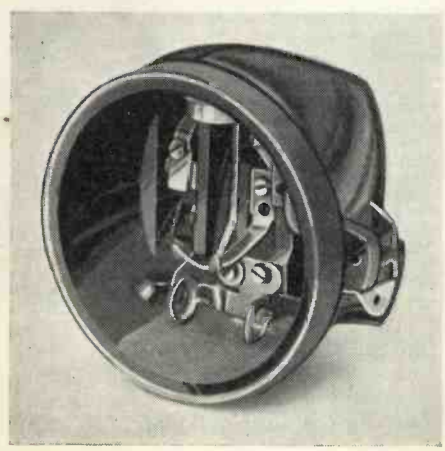
Urea formaldehyde is an ideal material for the production of radio parts such as control knobs, coloured panels, etc., and in peace-time large numbers of radio cabinets were made from this material. It is available in a wide range of most attractive colours, yet it is comparatively cheap, and is taking its place as a valuable constructional material, not only for the radio trade, but also for household furnishings. A specimen of a moulded cabinet is given in the coloured illustration on page 543.

Laminated Sheet

Phenol- Cresol- Urea- and Aniline-Formaldehyde

Examples.—Tufnol, Panilax, Delaron, Traffolyte, Micarta.

These materials are available in sheets of any thickness composed of hydraulically compressed laminations of paper or fabric coated with a soluble form of resin. The colour usually varies from yellow to brown, but boards can be finished with a decorative veneer or a coloured paper similarly treated with resin.



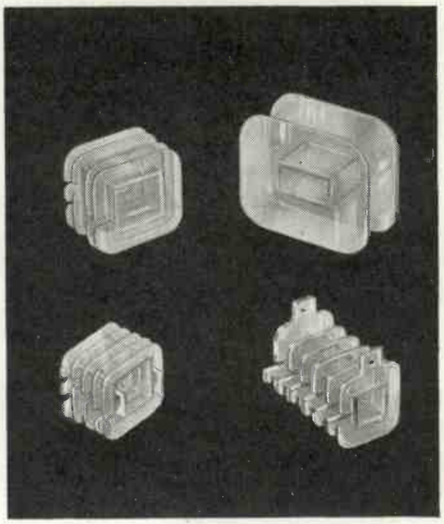
Miners' Hand Lamp. (left) A moulding which has to withstand rough usage and maintain a high standard of electrical resistance. The mountings for the lamps and switch contacts in the interior are of black cellulose acetate, like the body of the lamp. —*Messrs. Halex Ltd.*

Compression Moulding. (right) Produced from phenol formaldehyde powder with a special filler. Note the metal inserts which are moulded in the base during the manufacture. —*Messrs. de la Rue*

Physical Properties

Specific Gravity.—1.30-1.40.
Tensile Strength.—10,000-20,000 lb. per sq. inch.
Elongation at Break.—1 per cent.
Modulus of Elasticity.—4-20 $\times$ 10^5 lb. per sq. inch.
Compression Strength.—20,000-50,000 lb. per sq. inch.
Impact Strength.—0.4 to 8 foot lb.
Hardness (Brinell).—24-50.
Thermal Expansion.—1.5-3.0 $\times 10^{-5}$ per degree centigrade.
Maximum Temperature for Continuous Resistance to Heat.—250-350° F.
Water Absorption (Immersion 24 hours).—0.3-9.0 per cent.
Burning Rate.—Very low.

Laminated paper board, coated with synthetic resins of the phenol formaldehyde type is very suitable for instrument panels. Such material has good electrical properties, acts as an efficient insulator and has immense strength in thin section. It shows very little shrinkage on prolonged exposure to climatic conditions.



Low-loss coil-formers. One of the many applications of polystyrene to high-frequency work. —*Messrs. British Resin Products*

II.—Thermo-Plastic Resins

Methyl Methacrylate

Examples.—Diakon, Perspex.

This resin is particularly characterised by its water-whiteness exceedingly high transparency and high refractive index. In the powder form known as "diakon" it can be compression moulded, and, under suitable conditions, injection moulded, but its most characteristic form is in sheets which can be readily shaped by hot-pressing. It can also be obtained in rods and large masses which can be easily machined and polished, having a most brilliant appearance when finished.

Physical Properties

Specific Gravity.—1.18.
Tensile Strength.—7,000-9,000 lb. per sq. inch.
Elongation at Break.—5-15 per cent.
Modulus of Elasticity.—4.6 $\times$ 10^5 lb. per sq. inch.
Compression Strength.—11,000-13,000 lb. per sq. inch.
Impact Strength.—0.25-0.5 foot lb.
Hardness (Brinell).—18-20.
Thermal Expansion.—8.9 $\times 10^{-5}$ per degree centigrade.
Maximum Temperature for Continuous Resistance to Heat.—140-160° F.
Water Absorption (Immersion 24 hours).—0.4 per cent.
Burning Rate.—Very slow.

Polyisobutylene and Polyethylene

Examples.—Polybutene and Alkathene.

Polyisobutylene and polyethylene are wax-like solids which are just coming on to the market as insulating materials. They are tough, extremely flexible, of low specific gravity and resistant to all solvents except hot coal-tar solvents such as toluene. Used as cable sleevings and as the dielectric medium for condensers they are becoming of increasing importance to the radio and electrical engineer.

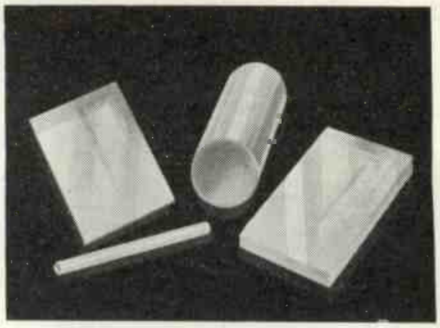
Physical Properties

Specific Gravity.—0.95-0.93.
Tensile Strength.—2,000 lb. per sq. in.
Elongation at Break.—Very large.
Modulus of Elasticity.—Low.
Compression Strength.—Flows.
Impact Strength.—Very high.
Hardness (Brinell).—1.0-2.0.
Thermal Expansion.—7 $\times 10^{-5}$ per degree centigrade.
Maximum Temperature for Continuous Resistance to Heat.—180° F.
Water Absorption (Immersion 24 hours).—Nil.
Burning Rate.—Slow.

Polyvinyl Chloride and Copolymers

Examples. — Welvic, B.X.P.'s. "P.V.C.," Chlorovene.

These resins are white powders which can be moulded by heat and pressure into transparent sheets or extruded in the form of rods and tubes though very special precautions have to be taken particularly in the case of polyvinyl chloride as it requires stabilisation against heat. The chloride—acetate copolymer has a lower softening point and can be injection-moulded. So far the sheet material is not of very high clarity and is yellowish in colour, but it is extremely tough and has a high modulus of elasticity.

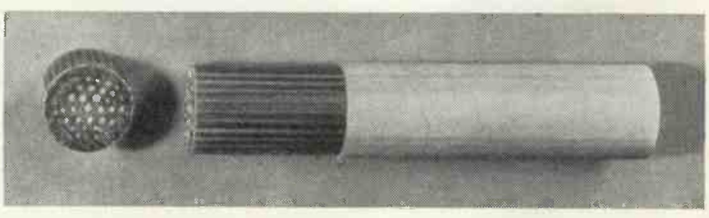


"Alkathene" tube and sheet. Illustrating the stock forms in which this material can be obtained. It is wax-like in appearance, but is exceedingly tough and has valuable electrical properties. —*Messrs. I.C.I. Plastics*

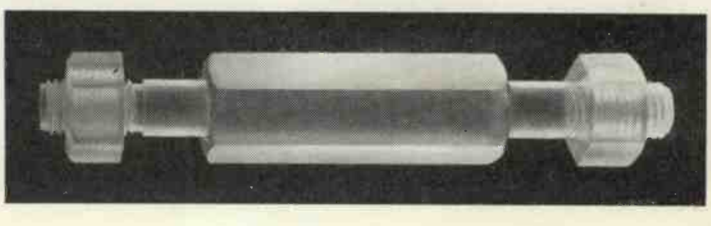
A most important characteristic of these compounds is their ability to form, by the addition of plasticisers, tough rubber-like materials which can be extruded at high speeds either as sleevings or as a direct covering to cables. These sleevings or coverings are very resistant to abrasion and do not undergo any atmospheric oxidation. The soft material can also be rolled out into very thin sheet, which can be slit and wound into rolls of any width for insulation and other purposes.

Physical Properties

Specific Gravity.—1.2-1.6.
Tensile Strength.—1,000-9,000 lb. per sq. in. depending on degree of plasticisation.
Elongation at Break.—2-500 per cent. depending on degree of plasticisation.
Modulus of Elasticity.—5-6 $\times$ 10^5 for hard polyvinyl chloride sheet. 3.5-4 $\times$ 10^5 for hard copolymer sheet.
Compression Strength.— —.
Impact Strength.—0.6-1.2 for hard copolymer.
Hardness (Brinell).—2-50 depending on degree of plasticisation.
Thermal Expansion.—3 $\times 10^{-5}$ per degree centigrade.
Maximum Temperature for Continuous Resistance to Heat.—150° F.
Water Absorption (Immersion 24 hours).—0.2 per cent.
Burning Rate.—Nil.



Distrene with Mica filler. Rod of distrene with mica dust introduced to improve the electrical properties. The pattern visible at the end of the rod is not due to agglomeration but to orientation of the particles. *Messrs. B.X. Plastics*



Bolt and nut machined from Distrene. This specimen is intended to show the ease with which the material can be worked by the usual mechanical processes. There is no tendency to chipping on the edge of the thread. *Messrs. B.X. Plastics*

Polystyrene

Examples.—Distrene (Regd.) Bakelite grade of Polystyrene.

Polystyrene is a hard glass clear resin, water-white and having a very characteristic tinkle when lightly struck.

It can be compression-moulded into sheets and blocks, extruded in the form of rods and tubes and is particularly suitable for injection moulding. Normally it is rather brittle and though, when strain-free, blocks can be readily machined it cannot be handled in very thin sheets, but by a special process it can be stretched into thin films and threads of considerable toughness and of great technical importance for high frequency insulation.

It is supplied "filled" with mica when a higher softening-point material is required.

Physical Properties

Specific Gravity.—1.05-1.07.
Tensile Strength.—5,500-8,500 lb. per sq. inch.
Elongation at Break.—1.0 per cent.
Modulus of Elasticity.—4.6-5.1 × 10^5 lb. per sq. inch.
Compression Strength.—13,000-13,500 lb. per sq. inch.
Impact Strength.—0.2-0.5 foot lb.
Hardness (Brinell).—20-30.
Thermal Expansion.—7-8 × 10^{-5} per degree centigrade.
Maximum Temperature for Continuous Resistance to Heat.—140° F.
Water Absorption (Immersion 24 hours). 0.0 per cent.
Burning Rate.—Slow.

Cellulose Nitrate

Example.—Xylonite.

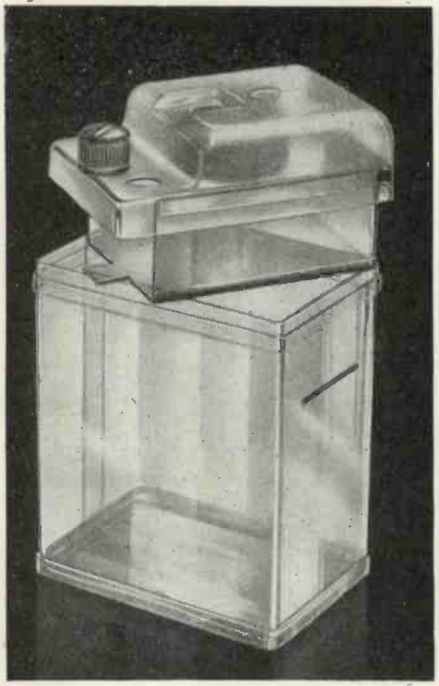
This plastic is made by a process involving the use of a solvent, by means of which the plasticiser, camphor, is incorporated into the cellulose nitrate and by the application of what is known as the "celluloid" technique, sheets of any thickness from .005" upwards can be cut from a block. It is available in any colour, from transparent to opaque and in a variety of decorative configurations, geometrical as well as haphazard, examples of the latter being cloudy amber or tortoiseshell. It is also extruded on a large scale in the form of rigid rods and tubes, but it is not suitable for compression or injection moulding from powder as it is not stable at temperatures high enough to give the required flow.

It is not particularly easy to ignite but once on fire burns with great rapidity. If it were not for this it would be one of the best all-round plastics available.

It can be cast in the form of film and is, as is well known, the basis of ciné film, which is very tough and durable.

Physical Properties

Specific Gravity.—1.35-1.60.
Tensile Strength.—5,000-10,000 lb. per sq. inch.
Elongation at Break.—10-40 per cent.



Accumulator case. Xylonite, or cellulose nitrate is one of the oldest of the plastic materials, and its resistance to dilute sulphuric acid makes it particularly adaptable to battery cases. Note the anti-spill device assembled from cemented sheets of the material. —*Messrs. Halex Ltd.*

Modulus of Elasticity.—2.4 × 10^5 lb. per sq. inch.
Compression Strength.—Nil.
Impact Strength.—0.25-1.0 foot lb.
Hardness (Brinell).—8-11.
Thermal Expansion Coefficient.—12-16 × 10^{-5} per degree centigrade.
Maximum Temperature for Continuous Resistance to Heat.—140° F.
Water Absorption (Immersion 24 hours). 1.0-3.0 per cent.
Burning Rate.—Very high.

Cellulose Acetate

Examples. — Erinofort, Celastoid, Bexoid, Cellomold.

Cellulose acetate resembles cellulose nitrate in every respect save that it can be made virtually non-inflammable, requires plasticisers other than camphor, is not quite so tough and is more affected by water, which leaches out plasticiser and tends to cause some deformation. Its stability to heat permits it to be both compression and injection moulded. It is particularly suited for the latter process when appropriately plasticised. Cellulose acetate moulding powders not only inject well, but are cheap and tough.

Like cellulose nitrate it can be made into film and in the form of triacetate has interesting electrical possibilities.

In many respects it is one of the most versatile plastics.

Physical Properties

Specific Gravity.—1.27-1.80.
Tensile Strength.—3,000-5,000 lb. per sq. inch.
Elongation at Break.—20-55 per cent.
Modulus of Elasticity.—1-4 × 10^5 per sq. inch.
Compression Strength.—11,000-27,000 lb. per sq. inch.
Impact Strength.—0.9-4.0 foot lb.
Hardness (Brinell).—8-15.
Thermal Expansion.—14-16 × 10^{-5} per degree centigrade.
Maximum Temperature for Continuous Resistance to Heat.—140-180° F.
Water Absorption (Immersion 24 hours). 1.5-3.0 per cent.
Burning Rate.—Slow.

Ethyl-Cellulose

Examples.—Ethyl-cellulose Plastic.

Like cellulose acetate, ethyl cellulose sheet can be made by the "celluloid" technique and is thus available in any thickness of sheet. It is tougher than cellulose acetate and is outstanding for its resistance to very low temperatures at which it does not become brittle. It is somewhat less rigid than the nitro and acetate.

It can be heavily plasticised to give soft extrusion materials resembling soft polyvinyl chloride and is remarkable for its compatibility with waxes, rubber and hydrocarbons.

An illustration of both hard and soft tubes is given in the colour plate.

Physical Properties

Specific Gravity.—1.10-1.20.
Tensile Strength.—4,000-8,000 lb. per sq. in.
Elongation at Break.—30-50 per cent.
Modulus of Elasticity.—2.5-3.0 × 10^5.
Compressive Strength.—10,000-12,000 lb. per sq. in.
Impact Strength.—0.6-1.8 ft. lb.
Hardness (Brinell).—5-10.
Thermal Expansion.—10-14 × 10^{-5} per degree centigrade.
Maximum Temperature for Continuous Resistance to Heat.—140-180° F.
Water Absorption (Immersion 24 hours). —1.5-2.5 per cent.
Burning Rate.—Slow.

In the table of Plastics in last month's issue an obvious omission occurred in the 'Bakelite' column. This product, as is well known, is available in laminated form and a dot should be added in the appropriate column.

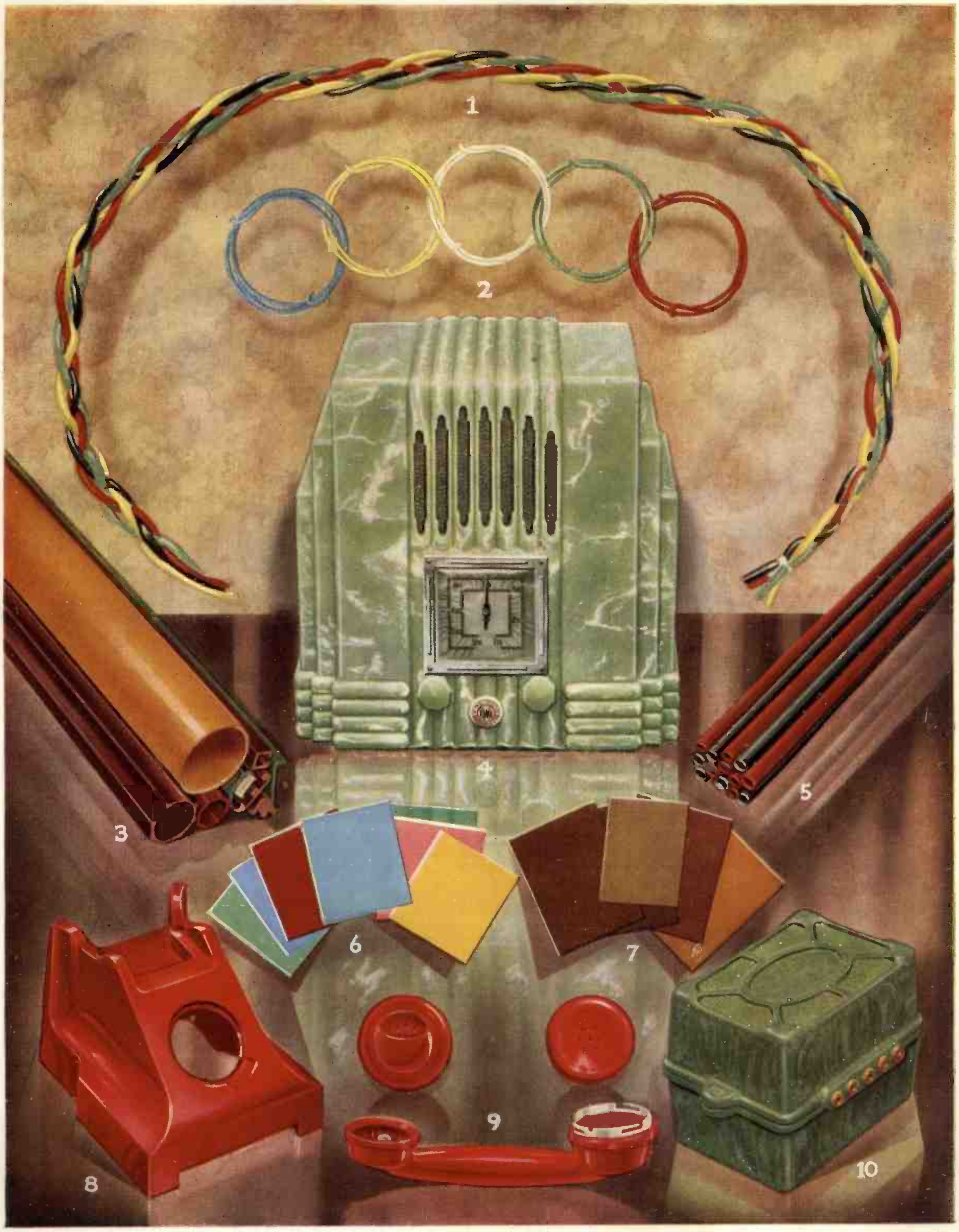
KEY TO COLOUR PLATE

1. Plait of coloured flexible insulating sleeving (ethyl cellulose and polyvinyl chloride)—*B. X. Plastics.*
2. Wire coated with "Welvic" insulation—*I. C. I. Plastics.*
3. "Rockite" extrusions, typical of the variety of shapes which can be produced by the extrusion process—*F. A. Hughes.*
4. Radio receiver cabinet moulded in "Beetle" (urea formaldehyde)—*Brit. Industr. Plastics.*
5. Specimens of rigid tubing in ethyl cellulose and copolymer—*B. X. Plastics.*
6. Sheets of "Bexoid" showing some of the colours obtainable. The red sheet is transparent—*B. X. Plastics.*
7. Samples of Bakelite sheet—laminated paper and fabric (phenol formaldehyde)—*Bakelite, Ltd.*

8 & 9. Mouldings for hand telephone set in "Diakon"—*de la Rue.*

10. Transformer case in "Mouldrite" (phenol formaldehyde)—*I.C.I. Plastics.*

BRITISH PLASTIC PRODUCTS



for description see opposite page)

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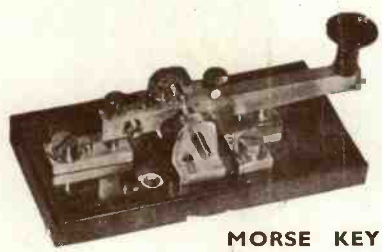
HEAVY DUTY model in solid lacquered brass on wood base 17/6.

SPECIAL model with heavy contacts back and front, lacquered brass, wood base 28/-. (*As illustrated.*)



MORSE KEY
Special Model

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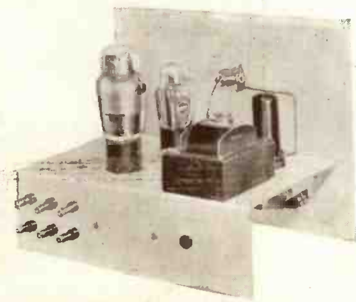

AUDIO OSCILLATOR

* * *

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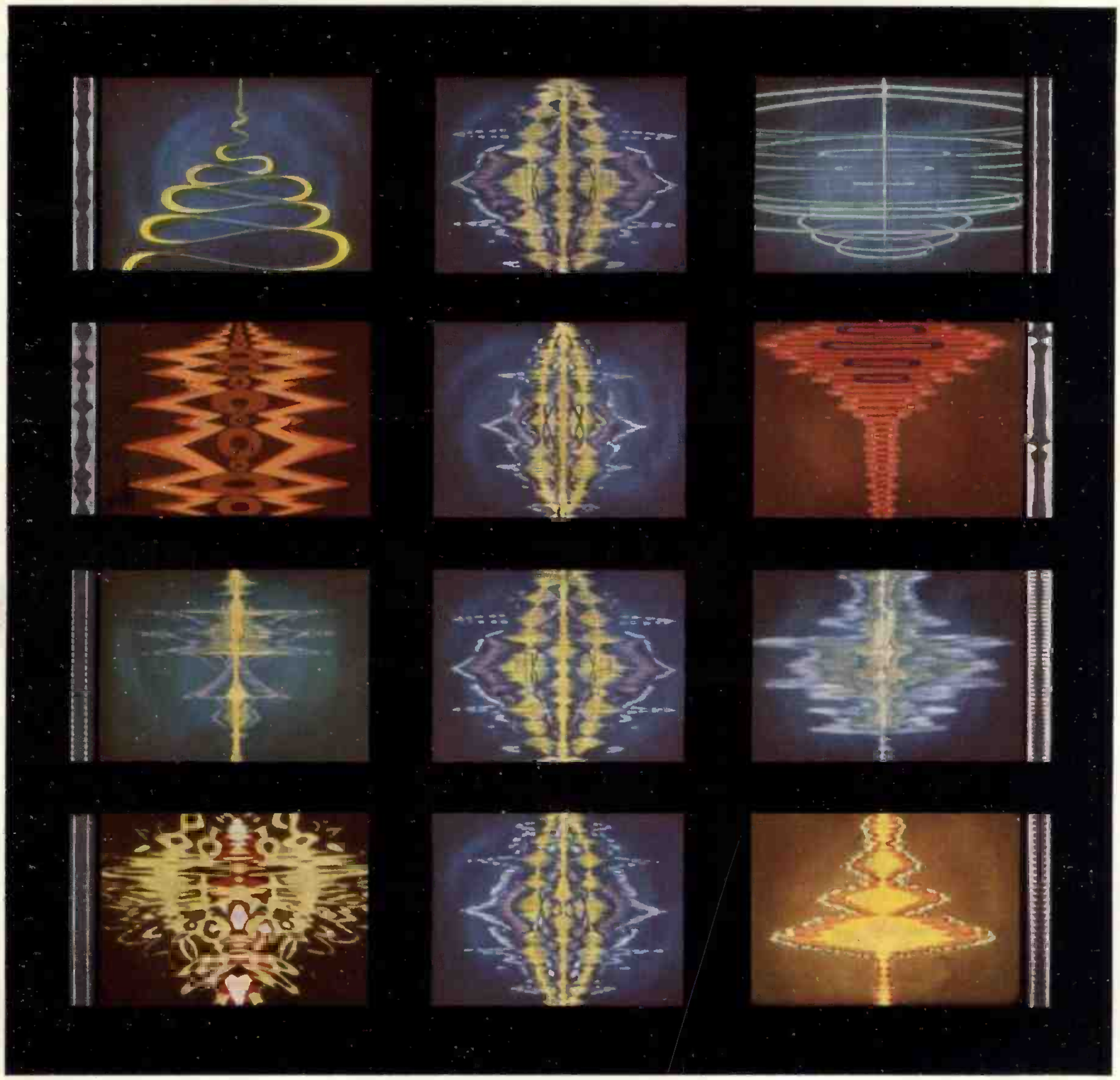
Sound in Colour

"Sound-pictures" with a true scientific basis



The successful production "Fantasia," described by Walt Disney as "an artist's adventure in colour," is a unique combination of sound and colour designed to give a fresh interpretation to well-known musical works.

In the part of the film from which the above "sound-pictures" are taken, the sound track is rendered visible on the screen and the patterns formed when various orchestral instruments are played have been elaborated with the fanciful results shown.

The actual sound track is mounted at the edge of the frames for comparison, the various instruments being :—

Harp	Harp
Kettle-drum	Bassoon
Violin	Flute
Cymbals	Trumpet

The centre strip shows four successive frames of a violin note, giving a resemblance to a vibrating string.

(By kind permission of Walt Disney-Mickey Mouse Ltd.)

Colour in Sound

A Study from the Psychological View-point

By E. L. TRIST, M.A. (Psychologist, Mill Hill Hospital)

ELECTRONIC techniques have opened up new possibilities in the investigation and control of colour-sound associations. An art of colour music, hitherto utopian, may now be realisable, and Disney's "*Fantasia*" is, for instance, one approach to such an art. Large scale exploitation has already been made of the perfected methods which now exist for the simultaneous recording and projection of colour and sound, but in most of these adventures proper use has not been made of the psychological facts which are known about colour-sound association. On the other hand, psychologists have not yet made sufficient use of modern techniques in the investigation of this field.

Long before a science of psychology existed, the phenomena of so called "coloured hearing" attracted attention. Goethe published on the subject as early as 1810. Later Sir Francis Galton included it in his inquiries into imagery. It is indisputable that in certain individuals vivid sensations of colour are aroused by sounds, especially by musical sounds. Such a colour-sound association is an example of *synæsthesia,* the term commonly applied to the interaction of the senses. A synæsthetic experience occurs whenever the physical stimulation of one sense arouses not only its own appropriate sensation, but also sensory phenomena appropriate to other senses for which no external physical stimulus is at the time present. These additional phenomena may be anything from vague associations to actual sensations. Now earlier writers regarded coloured hearing as a rather rare and abnormal phenomenon. Pronounced synæsthesia, it is true, occurs in only nine to fifteen per cent. of people, but a further fifty or sixty per cent. associate sound and colour to some degree. In only a small minority is the tendency almost or completely non-existent. The tendency to synæsthetic association of colour and sound may therefore be regarded as a normal human trait shared to some extent by most of us. Examination of this natural tendency gives the best approach to colour-sound problems in general.

Before this is made, however, a few words must be said regarding colour and sound experiences as such. Psychologically, colour has three dimensions : *brightness, hue* (*i.e.,* green, red, etc.,) and *saturation* (*i.e.,* degree of greenness, redness, etc,). Brightness and hue as functions of wave-length are shown in Fig. 1. Though from one point of view saturation is a relative matter, some hues, such as red, are absolutely more saturated than others. As regards sound, there are again at least three psychological dimensions : *pitch, loudness and timbre.* Timbre is the only one of these terms requiring special definition ; it refers to the distinctive quality of different musical instruments and is a function of overtones.

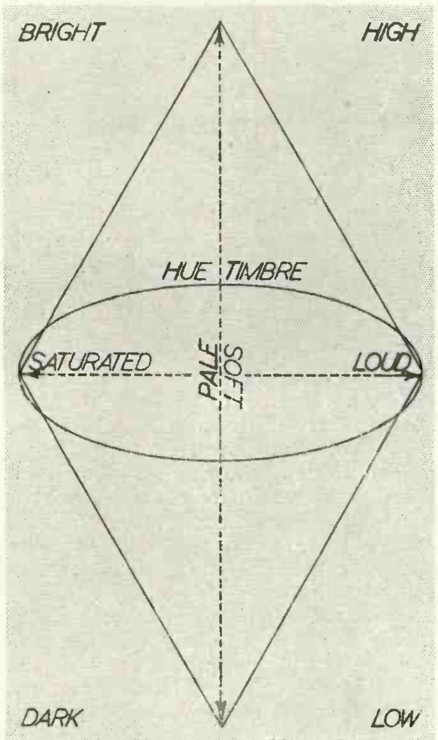


Diagram showing analogy between colour and sound attributes—Fig. 2.

Certain equations are obviously suggested between these dimensions :

Dimension	*Equivalence*
Brightness—Pitch	Up and down scales
Saturation—Loudness	Intensity factors
Hue—Timbre	Qualitative features

A simple way of representing these relationships is as functions of a double cone, as shown in Fig. 2.

The pitch-brightness equation locates the one point on which there is general agreement, for the great majority of people associate tones of high pitch with a high degree of visual brightness and lower tones with lower brightness values. Some writers even include brightness among the basic dimensions of auditory sensation ; 70% of Mudge's[1] and 87% of Sabaneev's[2] subjects report the association, which may be regarded as the major exception to Galton's famous remark that one can never get two synæsthetics to agree. The commonest variety of brightness-pitch synæsthesia is that in which the brightness correspondences remain achromatic, *i.e.,* shades of grey with black at one extreme and white at the other, but in some individuals there are hue as well as brightness correspondences. In these cases the absolutely bright colours such as yellow and green are usually related to the higher notes, blue and red corresponding with the lower. Sometimes, however, particular hues are related to particular registers, and with other individuals only the middle ranges have hue, the extremes being achromatic.

The second equation again locates a point of considerable though less general agreement. Quite common is the experience that the clearness and intensity of the visual sensation increases with the loudness of the tone. For those with achromatic correspondences, it is a question of clearness, but for those with chromatic sensations, the saturation changes — in diminuendo hues become more pale, in crescendo more vivid. But with other individuals, there is a complete change of hue with increase of loudness, cases being reported where all loud tones are seen as red, softer tones as blue. Others again feel bright colours, such as yellow, as appropriate for loud tones.

The third equation introduces a field of rather different phenomena. So far brightness and saturation have been the organising principles, with hue not always appearing. Now, however, hue becomes the dominant feature. There is a large group of people (nineteen per cent. of Sabaneev's subjects) whose colour-sound synæsthesia is built round the fact that they think of different musical instruments in terms of different colours. Some composers belong to this type, there being evidence that those who do use visual colour cues in orchestrating their work. Vernon,[3] on the other hand, regards hue-timbre association as the synæsthesia of the non-musician. At any rate, its existence denotes that "tone-colour" is more than a metaphor—is often a visual fact. The idiosyncracy of the individual steps into the picture here in a bewildering fashion, for the variety of colours associated with a given instrument is very great. A table is given overleaf.

In most of these associations richness of tone is somehow related to absolute chromatic value, brightness and saturation playing subsidiary rôles.

The reporting of such data will not have much value until there is more exact specification of the colour qualities.

Colour-Key Associations

Apart altogether from types of synæsthesia based on the elementary dimensions of colour and sound experience, there is another more sophisti-

Trumpet	Scarlet	Yellow	White
Trombone	Yellow	Brown	Dark red
Flute	Light blue	White	Pale grey
Clarinet	Pale yellow	Light green	Silver
Oboe	Green	Blue	Ochre
Bassoon	Basket	Brown	Burnt sienna
Violin	Blue	Violet	Saffron
Cello	Brown	Red	Amber
Snare drum	Grey	Yellowy	Brick
Bass drum	Black	Dull red	Dark brown

Table giving typical colour sensations associated with various instruments.

cated kind. It depends on the association of a definite colour with a particular musical key. According to Vernon, this is the synæsthesia *par excellence* of the musician; 68% of Sabaneev's musical subjects reported it. Many famous composers have been endowed with it: Beethoven, Berlioz, Chopin, Wagner, Franck, Debussy. Beethoven saw the key of B minor as black and that of B flat as the glint of steel. Rimsky Korsakov and Scriabin are perhaps the best known cases, the latter evolving an elaborate theory of the colour symphony. Some of Scriabin's key associations were: C red, D yellow, F sharp purple. Once again, there is no agreement as to which colour expresses which key. Nevertheless, Vernon has shown that in any one individual groups of musically related keys tend to go with groups of chromatically related colours.

Vernon also found that several of his subjects developed colour-key associations in the process of learning to discriminate absolute pitch. When absolute pitch is firmly established, the colour associations may sometimes fade. In some individuals, however, the appearance of a certain colour remains the first indication that a composition is being played in a particular key. Vernon's observation is among the most important made on coloured hearing; it opens the question of how far the trait is innate or how far it is something which may be developed, *i.e.,* learnt.

If we are right in thinking of colour-sound synæsthesia as dependent on a natural human potentiality, then, like other such potentialities, it should be capable of development and learning.

There is already experimental evidence on the point. Some time ago Kelley attempted to produce coloured hearing artificially in the laboratory. He failed. But more recently Howells[4] has succeeded, showing, for example, that it is possible to make a patch of red look green when a tone is played with which green has been arranged to appear constantly in previous experimental series.

Confronted with such a result, psychology must seek to discover the particular conditions under which the formation of colour-sound associations will be most readily facilitated. A pertinent subject here is that known as "the modes of appearance of colours." Colour can appear in six ways: *surface colour, i.e.,* painted wood—the colour is part of the surface of an object, is shape bounded and has microstructure; *expanse colour, i.e.,* the sky—the colour is unbounded by surface or shape and floats as a free expanse (surface colour can be seen as expanse colour if a screen with a small hole in it is held to the eye so that all one sees is a colour expanse); *bulky colour, i.e.,* a fog—this is expanse colour which has become voluminous through three dimensional space; the other modes, *transparent, lustrous, luminous,* scarcely need special definition. The important distinction is between surface and expanse colour, for the associational index of the first is as low as that of the second is high. Experiments show that colour-sound effects impossible on the basis of surface colour are readily elicited by expanse colour. Under suitable conditions, expanse colour may be made bulky, transparent, lustrous or luminous. There is little doubt that the future investigation of colour-sound synæsthesia lies in the manipulation of these qualities in relation to expanse colour.

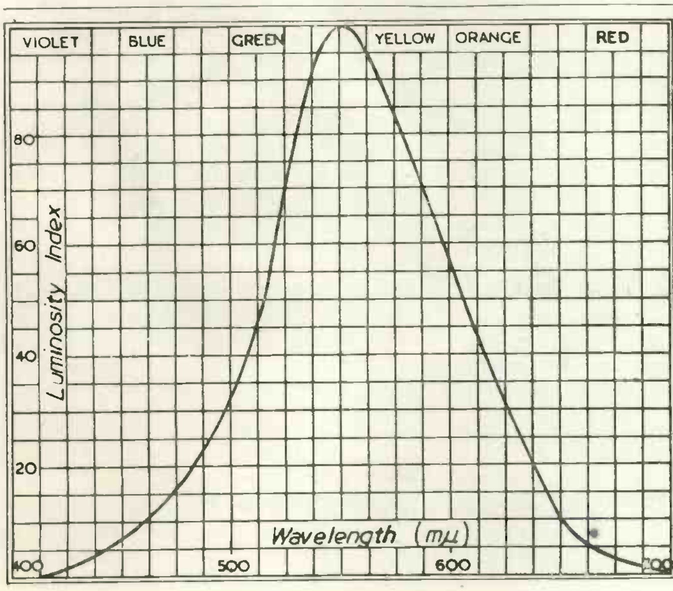


Fig. 1. Brightness as a function of wavelength.

Two conclusion arise directly out of the data which have been presented.[5]

The first depends on the immense amount of individual variation in the spontaneous colour associations. It is obvious that any instruments devised to utilise these associational tendencies must possess the utmost degree of flexibility. No single type of association can be imposed. The instrument must give free play to the individual.

The second is a corollary of what has been said about learning. Since colour association to sound is something which can be learnt as well as something which exists spontaneously, the actual learning of it by any large number of people will considerably affect the character of the predominant type of association. For if this event takes place, the process will become socialised, and socialisation involves the development of conventions, patterns and a common tradition. This would be no more than has happened in the case of music itself. The same is true of colour æsthetics. If in colour-sound association, the extent of individual differences at present overwhelms everything else in the picture, it is largely because colour-sound association has not yet been endowed with a social tradition. But the development of a tradition depends on the communication of experiences. Until the development of modern techniques there were no means through which colour-sound associations could be socially communicated.

The existence of the techniques creates the possibility of a "language." And this will be forged from interchange of experience when individuals begin to express themselves through instruments which give them free scope.

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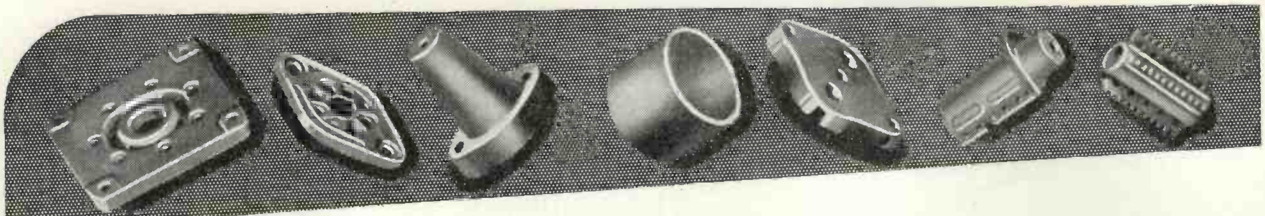
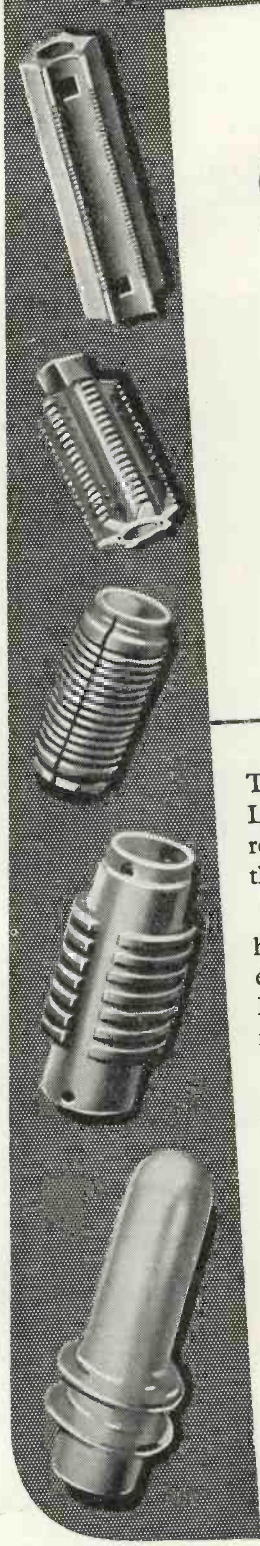
[3] Vernon, P. E., *Psyche*, 1930, 10, 4, 22.

[4] Howells, T. H., *Psychol. Bull.*, 1937, 34, 714.

[5] Karboski, O., *Psychol. Monogr.*, 1938, 50, No. 2.





A New Portable Communications Receiver

The Hallicrafters' "Sky Traveller"

A truly portable receiver of the communications type with self-contained batteries and a telescopic aerial. Provision is also made for mains operation and a charging unit is incorporated. The weight is only 18 lbs., including batteries.

Frequency Range

THIS receiver tunes from 540 to 30,500 kilocycles in four bands as follows:—

Band.	*Coverage.*
1	540 kc/s. to 1,500 kc/s.
2	1.45 Mc/s. to 4.3 Mc/s.
3	4.12 Mc/s. to 11.9 Mc/s.
4	11.26 Mc/s. to 30.5 Mc/s.

The main tuning dial is accurately calibrated in megacycles when the bandspread dial is set at "O" the position of minimum bandspread condenser capacity.

Valves

1T4 R.F. Amplifier.
1R5 1st Detector—Oscillator.
1P5GT 1st I.F. Amplifier.
1P5GT 2nd I.F. Amplifier.
1H5GT 2nd Detector—AVC—1st Stage of Audio.
3Q5GT 2nd Audio Output Stage.
1G4GT Beat Frequency Oscillator.
1G4GT Automatic Noise Limiter.
50Y6GT Rectifier.

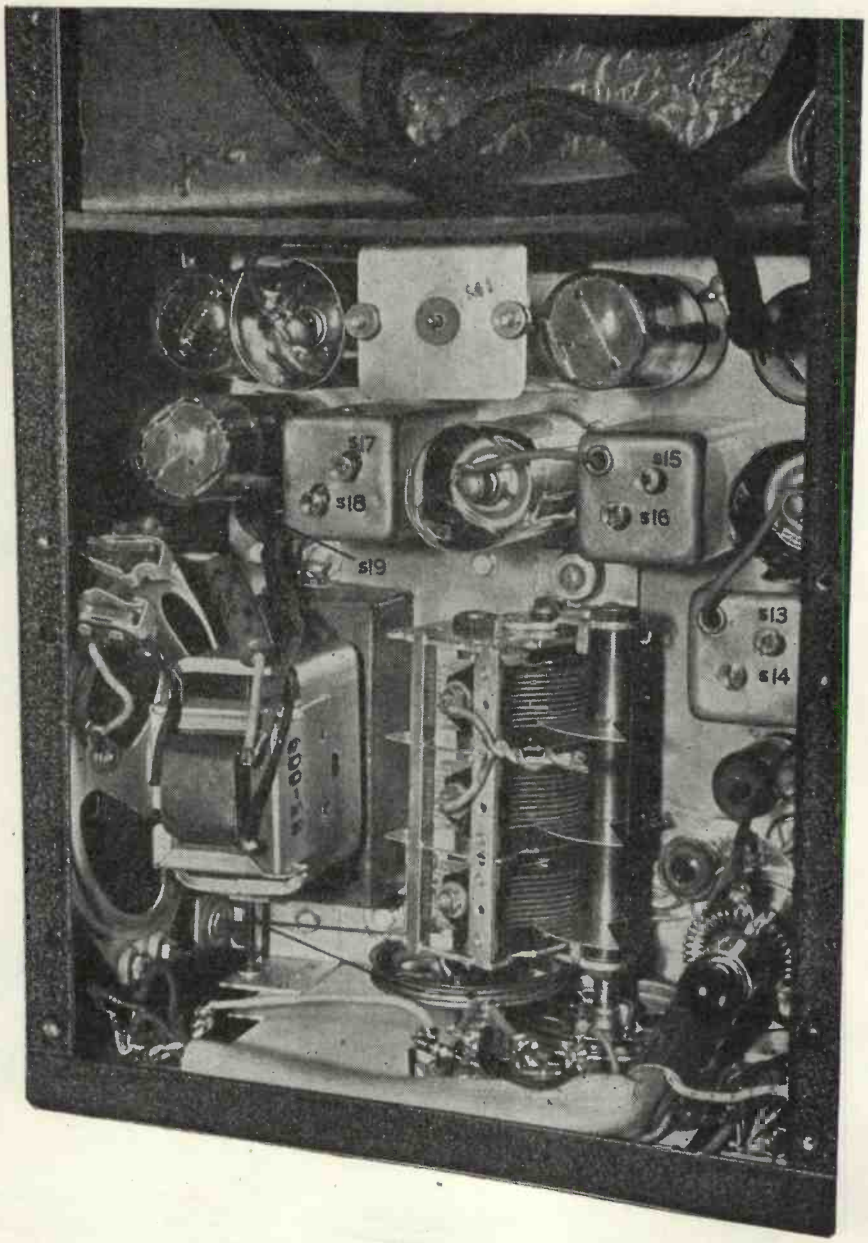
Controls

Reading from left to right, the functions of the various controls are as follows:—

The "ANL" or automatic noise limiter switch minimises ignition and similar types of interference which would otherwise be objectionable to short wave reception. With "ANL ON" filament voltage is supplied to the 1G4GT noise limiter by the 1.5 volt flashlight cell—this being its sole function. The power switch is wired also to open this circuit when in its "off" position. Since the flashlight cell is not included in the charge circuit, noise limiting should be used only when necessary regardless of the low replacement cost of the cell. For best noise limiting action use full "RF GAIN" and adjust for volume with "AF GAIN."

The A.V.C. switch is for optional use of automatic volume control. To eliminate fading it should be on when receiving phone signals and off when copying code or CW signals.

(*Continued on page* 552)



Photograph of interior of the receiver showing loudspeaker (on left) and collapsible aerial (dark knob in lower right-hand corner).

The R.F. GAIN control adjusts the sensitivity of the receiver by varying the screen voltage on the R.F. and I.F. amplifiers. Maximum sensitivity and A.V.C. action will be obtained with this control rotated as far as it will go to the right.

The BANDSPREAD TUNING knob controls the bandspread dial and its associated condenser. By setting the MAIN TUNING dial to the high frequency edges of the four amateur bands listed, the bandspread that may be expected is as follows:—

FREQUENCY RANGE. (Megacycles/sec.).		BANDSPREAD. (Dial Divisions).
(80 metre band)	4.0- 3.5	0-88
(40 ,, ,,)	7.3- 7.0	0-76
(20 ,, ,,)	14.4-14.0	0-88
(10 ,, ,,)	30.0-28.0	0-70

The STAND-BY switch removes current from the anodes and filaments of all valves with the exception of the noise limiter. When working from 115 volts A.C. or D.C., filament voltage is left on the cathode type 50Y6GT rectifier because of the time required for it to reach operating temperature.

The B.F.O. switch allows optional use of the beat frequency oscillator and is used when copying code signals. It is of additional help in locating weak phone signals by first locating their carrier. Once located, the B.F.O. is turned off to eliminate the whistle and allow reception of the modulated signal.

The neon lamp located in the centre of the tuning dial is used to indicate when the power is on. It will glow during stand-by periods as insurance against accidently leaving the S-29 turned on.

Aerial

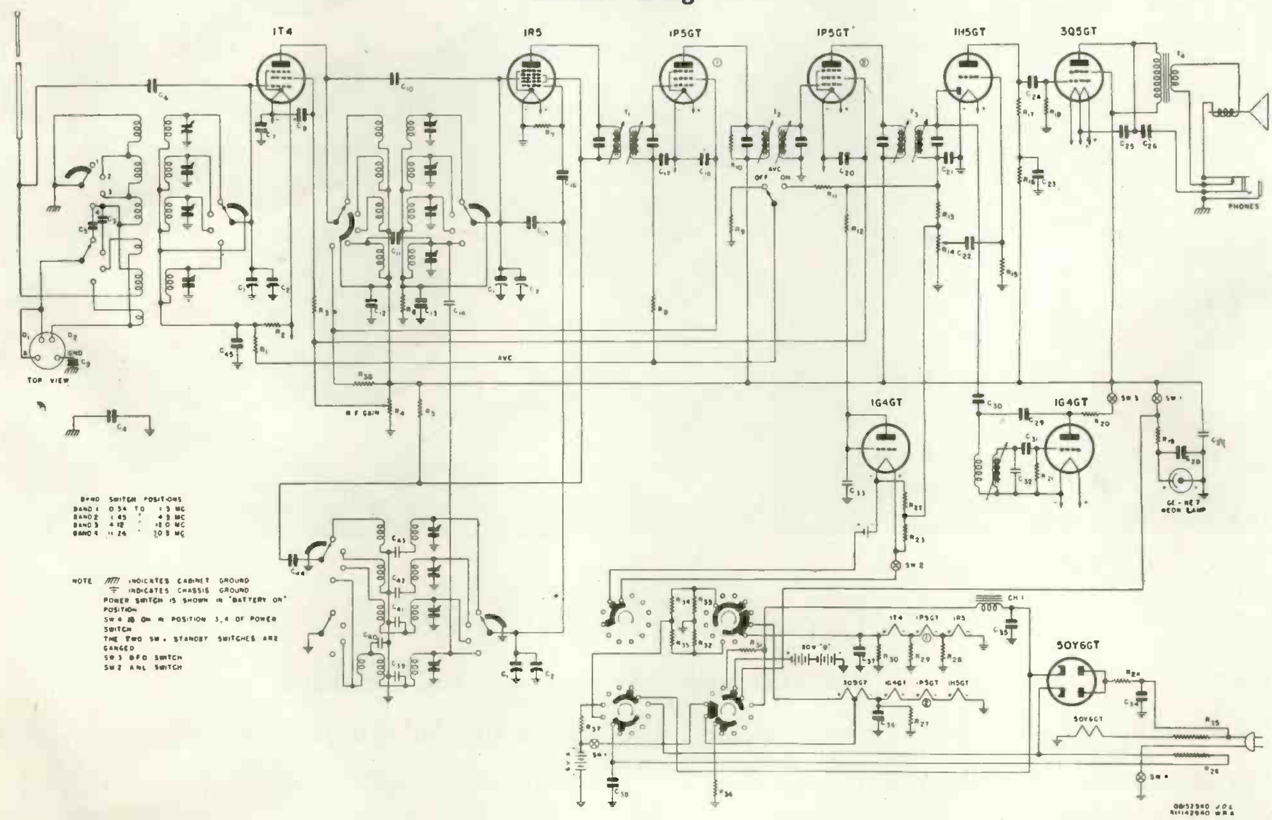
The Sky Traveller is supplied with its own telescopic aerial which is permanently connected in the circuit, and which may be extended to its full length of approximately 28 in. or compressed entirely into the cabinet. A cap is provided to shield the recessed aerial from ignition and other pickup when using a car aerial, a doublet or a long wire (inverted " L " Marconi) aerial.

If peak operation is desired on a particular band, a ½-wave doublet may be used. The flat-top length for a particular frequency may be computed by the following formula:

$$\text{Length in feet} = \frac{463}{\text{Frequency in megacycles}}$$

(*Continued on page* 554.)

Circuit Diagram



Values of Components.

Condensers	Resistors	Condensers	Resistors	Condensers	Resistors
C1 Main Tuning Gang	R1 2 meg.	16 50 mmfd.	16 100,000	31 100 mmfd.	31 9,000
2 Bandspread Gang	2 2 meg.	17 .05 mfd.	17 500,000	32 500 mmfd.	32 900
3 25 mmfd.	3 9,000	18 .01 mfd.	18 500,000	33 .05 mfd.	33 800
4 0.1 mfd.	4 500,000 (R.F. Gain)	19 .05 mfd.	19 400,000	34 .05 mfd.	34 800
5 10 mmfd.	5 5,000	20 .01 mfd.	20 50,000	35 60 mfd.	35 845
6 5 mmfd.	6 2 meg.	21 50 mmfd.	21 50,000	36 100 mfd.	36 750
7 .05 mfd.	7 100,000	22 .003 mfd.	22 300	37 60 mfd.	37 2,000
8 .01 mfd.	8 1 meg.	23 0.1 mfd.	23 1,100	38 60 mfd.	
9 15 mmfd.	9 2 meg.	24 0.01 mfd.	24 25	39 4,230 mmfd.	
10 5 mmfd.	10 40,000	25 .005 mfd.	25 450 (line cord)	40 250 mmfd.	
11 5 mmfd.	11 2 meg.	26 .01 mfd.	26 450 (line cord)	41 2,030 mmfd.	
12 .05 mfd.	12 1 meg.	27 60 mfd.	27 1,100	42 880 mmfd.	
13 .05 mfd.	13 100,000	28 .02 mfd.	28 500	43 380 mmfd.	
14 3 mmfd.	14 500,000 (A.F. Gain)	29 .01 mfd.	29 550	44 .01 mfd.	
15 2 mmfd.	15 10 meg.	30 2 mmfd.	30 600	45 .05 mfd.	

use full "RF GAIN" and adjust for volume with "AF GAIN."

Alignment Procedure

Equipment needed for aligning:

1. An all wave signal generator which will provide an accurately calibrated signal at the test frequencies indicated.
2. Output indicating rectifier type meter connected across the two lugs on the speaker transformer.
3. Non-metallic screw driver.

Setting of controls prior to alignment—IF and RF.

Power switch in BAT position. Line cord removed from outlet. BFO, ANL, AVC switches off. RF AND AF GAIN controls for maximum volume. Band switch on 1 band. Bandspread at O. Completely compress the telescopic aerial.

455 *KC-I.F. Alignment.*

Set main tuning control at 1,500 kc/sec. and tune generator to 455 kc/s.

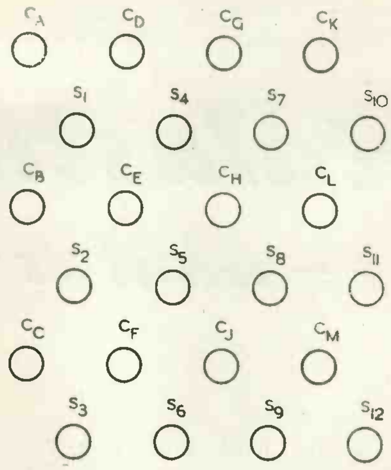


Diagram showing layout of trimmers, etc. on the underside of the chassis. The trimmers accessible from the top are marked in the photograph on page 550.

Connect low side of generator to chassis and high side to lug on rear stator section (R.F.) of main tuning condenser through a 0.1 mfd. condenser. Proceed to adjust the screw S_{13} to S_{18} inclusive, protruding from the tops of the I.F. transformers, T_1, T_2 and T_3, for maximum output.

R.F. Alignment.

Insert "long-antenna" plug, furnished with receiver, into aerial socket and connect generator as indicated in chart below. A condenser in the receiver in series with the blue lead compensates for the reduction in capacity when the aerial is folded and the covers removed: thus a dummy aerial is unnecessary.

Note.—On 3 and 4 bands, it may be necessary to "rock" the main tuning condenser to compensate for slight shifts in oscillator frequency. When adjusting the trimmers and slugs for maximum gain, the oscillator frequency is 455 kc/s. less than the signal frequency on 4 band.

Alignment Procedure.

Connect "hot" lead of signal generator to BLUE wire of aerial plug and low side of generator to BLACK wire. A dummy aerial is unnecessary.

Band.	Signal Generator Frequency and Receiver Dial Setting.	Oscillator Frequency Relative to Signal.	High Frequency End. Adjust Osc. with	High Frequency End. Adjust Trimmers for Max. Gain.		Low Frequency End. Adjust Osc. with	Low Frequency End. Adjust Slugs for Max. Gain.	
1	1.4 Mc/s.	Above	C_B	C_A	C_C			
	.6					S_2	S_1	S_3
2	4.0	Above	C_E	C_D	C_F			
	1.6					S_4	S_4	S_6
3	11.0	Above	C_H	C_G	C_J			
	5.0					S_5	S_7	S_9
4	28.0	Below	C_L	C_K	C_M			
	14.0					S_{11}	S_{10}	S_{12}

PRECISION

Notwithstanding the difficulties met with under present conditions, the Telephone Manufacturing Company, Ltd., is maintaining the well-known reliability of its condensers. These are manufactured in a modern condenser plant, and are notable for the following features :—

- Rigid construction.
- Small size and weight.
- Extreme stability.
- Low temperature co-efficient of capacity.
- High insulation resistance.
- Maintenance of initial capacitance values.
- Low power factor.
- Adequate safety factor, and
- Long life.

Only high grade materials are used, which have been proved to be suitable by chemical, physical and electrical tests, and careful supervision is given at all stages of manufacture.

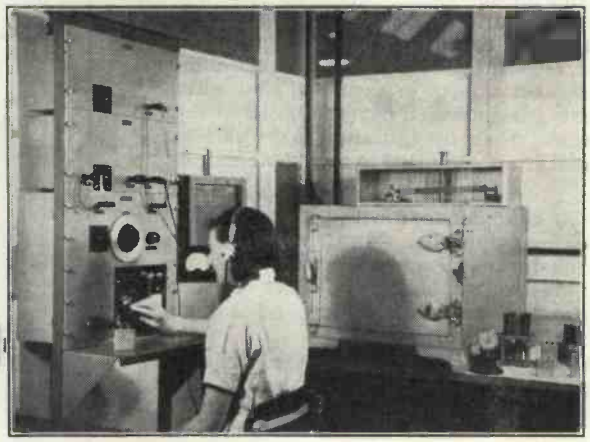
Enquiries are solicited in respect of the following types—

(a) Mica Condensers.
These are manufactured in copper or other metal cans, as required, which are marked with the actual and nominal capacities. They may be supplied and adjusted to within ½ per cent. from the nominal capacity. The temperature co-efficient is not greater than .0045 per cent. and the power factor at 1,000 cycles/second is not greater than .001.

(b) Precision Paper Condensers.
These are of the oil impregnated, oil filled, clamped paper dielectric type. The capacity is adjusted to within 2 per cent. of the nominal capacity and departures from the actual capacity due to temperature variations from 0 deg. C. to 50 deg. C. are not greater than 2 per cent. These condensers are fitted with terminals constructed from Mica-filled bakelite and having an insulation of not less than 10,000 Megohms at normal temperature and humidity.

Prompt attention given to enquiries and deliveries expedited.

PRECISION TEST OF T.M.C. CONDENSERS



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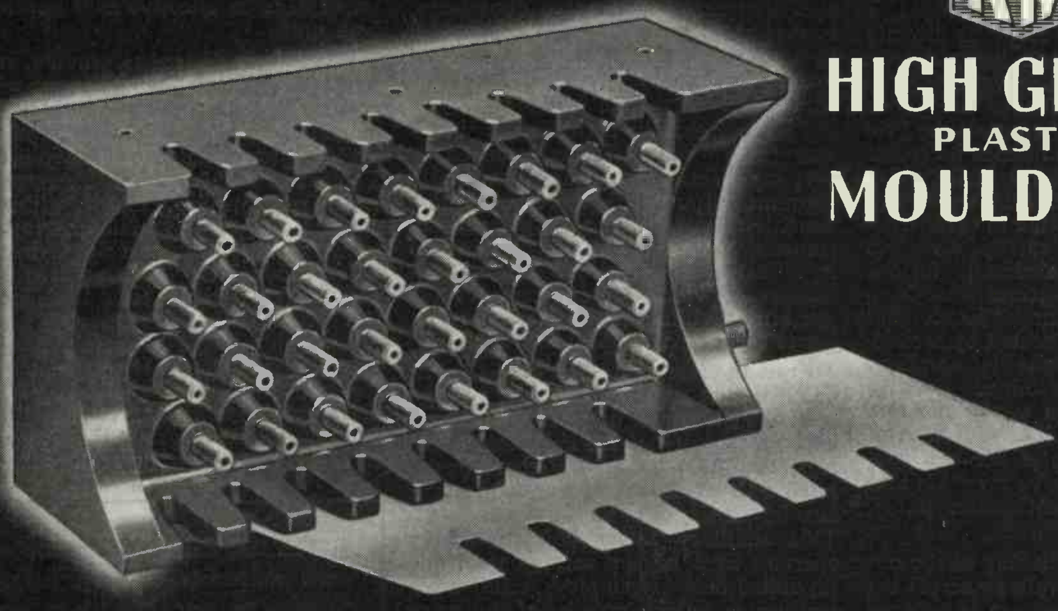


KM

HIGH GRADE PLASTIC MOULDINGS

KENT MOULDINGS

PROPRIETORS: KOLSTER-BRANDES LIMITED

FOOTSCRAY KENT

TELEPHONE FOOTSCRAY 1195

Heavy Duty Regulated H.T. Supply Unit

An economical solution to the problem of providing a larger output than can be obtained from a normal regulated power-pack has recently been evolved by the laboratories of the Radio Corporation of America.

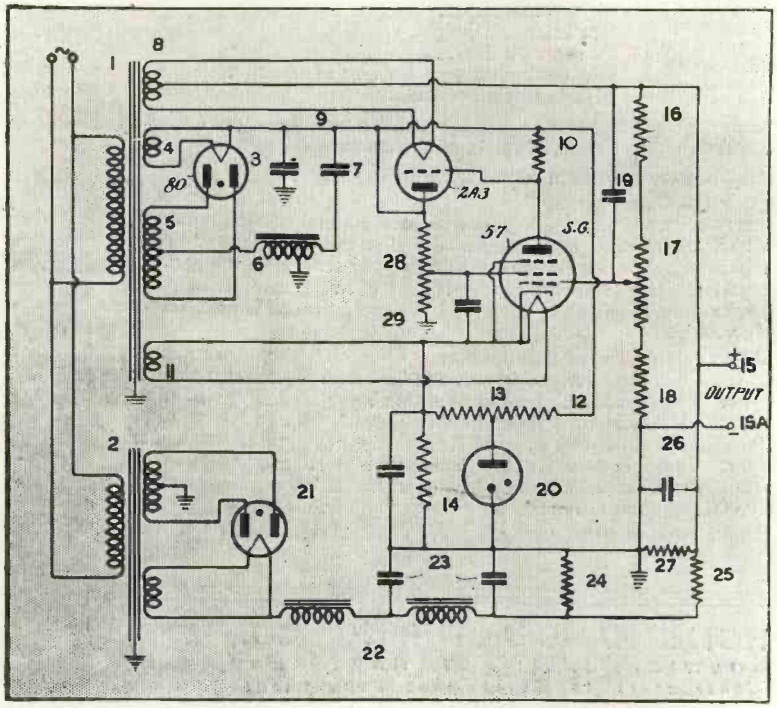
The circuit arrangement consists, in essentials, of an unregulated and a regulated H.T. supply unit connected in parallel across the A.C. supply, the unregulated unit delivering a higher voltage than the other unit. The power delivered at the common output terminals is substantially in excess of that which could be supplied by the regulated unit alone, though regulation is as efficient as if it were applied to the whole output.

The operation of the complete unit will be understood with reference to the accompanying diagram which shows transformers 1 and 2 shunted across the mains and supplying full-wave rectifiers 3 and 21 of the regulated and unregulated units respectively.

The output of rectifier 3 is partly smoothed by choke 6, centre tapped to earth, and condenser 7. Additional smoothing and voltage regulation are essential, and are provided by valves " 2A3 " and " 57," the former acting as a variable series resistor in the positive output lead, feeding current directly to the positive output terminal 15 from its centre tapped filament winding 8.

The anode of the " 2A3 " is directly connected to lead 9 and its grid to a tap on resistor 10. The voltage drop across this resistor, due to the anode current of valve " 57 " controls the grid bias of the " 2A3," and hence its resistance. The control of the series valve " 2A3 " is thus provided by the " 57 " valve, which is controlled in turn, from the potential divider 28, 29, arranged across the supply immediately following the preliminary rectifier smoothing 6, 7 already referred to. The filament of the " 57 " valve is heated by secondary 11 and its cathode is normally biased at a predetermined positive potential by connexion to the junction of resistors 13, 14, which, with resistor 12, form a potentiometer between conductor 9 and earth. Valve " 57 " is also controlled from a potentiometer 16, 17, 18 shunted across the load.

To explain the functioning of the circuit, assume that the voltage across the output terminals 15 and 15a is reduced at a particular instant, either by an increase in the load or a fall in the mains voltage. This decreases the potential drop across the resistors 16, 17, 18 and so causes a decrease in the potential applied to the grid, connected to resistance 17, of the valve " 57," thus reducing its anode current and also the voltage drop across resistor 10. The grid of the " 2A3 " valve becomes in consequence less negative, and the voltage drop across this valve diminishes, so that an increased voltage is supplied to the positive output terminal 15 compensating for the voltage reduction which occurred in the first place.



The co-operation between the " 57 " and " 2A3 " valves is characterised by very rapid action, ensuring a practically constant output voltage free of ripple. Sensitivity of the arrangement in response to ripple voltage at terminal 15 is increased by the presence of condenser 19, which largely removes the potential dividing effect of resistors 16, 17, 18 as regards ripple.

From the foregoing description it will be clear that a constant output voltage will be maintained up to the maximum current capacity of the regulated unit, *e.g.*, 100 Ma. By adding the unregulated unit as shown in the diagram, a heavier load can be accommodated. This auxiliary power unit preferably operates at a higher voltage than the regulated one. It employs a full-wave rectifier 21 (which may be of the same type as rectifier 3) having its anode and filament fed by mains transformer 2. The output of this rectifier is filtered by the usual choke-condenser combination 22, 23 and bleeder resistor 24, a voltage-dropping resistance being connected in series with the output of this unregulated unit and the common positive terminal 15 to reduce the voltage to that of the regulated unit. The regulation applied to the one regulated unit is found to be as effective as if applied to both units.

Where it is desired to provide, say, a positive 105V tap, as compared with a positive potential of 200V which is to be maintained on terminal 15, the cold-cathode glow-discharge valve 20 is used. The anode of this valve is connected between resistors 12,13 and its cathode is earthed, the valve functioning to maintain a fairly constant voltage between these two points. The required lower voltage tap is taken from the anode of the valve. Although it requires a somewhat high voltage to start this valve, this voltage is normally attainable during the " warming-up " period, and after excitation the valve maintains a substantially constant D.C. drop across its electrodes.

NOTES FROM THE INDUSTRY

Mr. J. L. Baird

Since severing his connexion with Baird Television, Ltd., Mr. J. L. Baird has been engaged on private research work, mainly on colour television. The results of this work were published in *Electronics and Television* in February this year and a coloured reproduction the following month showed the excellent detail obtained by the process.

We are now informed that Mr. Baird has accepted an appointment as consultant to Messrs. Cables & Wireless, Ltd. He will still continue his private research work, however, at his home address.

Valve Data

The engineer who has subscribed to a data service of valve information from any of the B.V.A. members may sometimes feel that he is not getting the up-to-date information that his subscription entitles him to, but every allowance must be made for the difficulties under which valve makers are working at the present. A number of newly developed valves are not available for public use, and there is little point in publishing details on a product which is unobtainable by the ordinary experimenter.

What is more important at the present time is the data on valve replacements, which will enable many sets to be kept working on substitute valves rather than be out of commission because the exact type is not procurable.

Two valuable booklets on replacement types are in preparation which will be of the greatest use to service engineers and dealers. One, published by the *Wireless Trader*, is sponsored by the B.V.A. and contains information on equivalent types of all members' valves with notes on the necessary alterations to the circuit. The other has just appeared at the time of writing and is entitled "Valve Replacement Manual" by A. C. Farnell and A. Woffenden. It is published by one of the compilers at 40 St. Paul's Street, Leeds, 1, at 5s. net. This book deals mainly with American types of valves, and gives full information on suitable equivalents for the older types, together with operating data on the whole range. Other useful information is a list of P.O. controlled valves, emergency valve replacements, frequency-changer replacements (with special notes on the Mazda AC/TP) and equivalents to the Mullard " E " series.

London readers can obtain copies from Webbs' Radio, Soho Street.

Soldering

It would be safe to say that nine out of ten users of resin-cored solder waste labour and solder by using it in the wrong way. In an interesting reference sheet on soldering, **Messrs. Multicore Solders** state that the resin-cored solder should be applied simultaneously with the iron to the work, and *not* rubbed on to the iron except when it is required to tin it. Those who say that they cannot " get on " with resin flux cores are probably to blame themselves for bad technique, as when used in the correct way there is no difficulty whatever in making good joints with cored solder.

A special feature of the " Ersin " Multicore solder is the incorporation of three separate resin cores running through the solder. Another advantage is that it is obtainable in several different S.W.G. sizes—14 to 18 for general electrical work and 22 g. or finer for instrument work. This should commend it to instrument and precision apparatus makers, since it avoids waste and makes for neater work. Various mixtures of tin and lead are recommended for particular jobs—lamp caps, for example, require a low tin content; pure tin can also be supplied.

Readers are recommended to write to Messrs. Multicore Solders at Bush House, W.C.2, for a copy of the leaflet referred to.

Metal Coating

For some reason the American valve manufacturers have never taken kindly to metal sprayed coating for valves and have even preferred to supply separate " form-fitting tube shields " for the glass bulb types. Metal coating in this country, on the other hand, has become a necessary process in valve manufacture, and after the teething troubles had been overcome no complaints were made about the quality of the coating or its adherence. Few engineers not connected with the valve industry realise that the metal is sprayed on as simply as spraying paint. The metal is fed into the spray pistol in the form of wire, granulations, or powder, and after being melted is blown on to the glass by a jet of compressed air. The use of powdered metal in a spray pistol has several advantages over the other forms in that it gives a finer and more homogeneous coating. It is not necessary to use the pure metal—brass or bronze will spray equally well—and the surface does not need special preparation unless it is of metal.

Messrs. Schori Metallising Process, Ltd., makers of the Schori Spray Pistol, state that they have successfully sprayed nearly all the thermo-plastic materials in addition to the metals and alloys, and we hope to be able to publish further details of this work later. In the meantime, they will be pleased to answer questions on the Schori process from their works at N. Circular Road, N.W.10.

Oscillograph Manual

Messrs. A. C. Cossor have issued a revised manual for their double-beam oscillograph Type 339, which is some 16 pp. larger (in spite of paper shortage!) This is much more than an instruction booklet and contains comlete operating notes and technique for nearly all oscillographic measurements.

Although supplies of the instrument itself are limited to priority orders, the book is available to interested readers at a cost of 3s. net, plus postage, and is excellent value for the money.

Students who cannot afford a more expensive treatise will find all they require of introduction to oscillograph technique and should make a point of procuring a copy.

Review of Progress in Electronics—*concluded from page* 539

its upward movement due to the field and its downward movement or drift due to gravity only, *i.e.*, with the field off, corresponding to the left-hand position of switch *S*, and to allow the drop to pick up radiation from a convenient source of some radioactive substance, or from X-rays. Experiments of this kind, with numerous modifications and different arrangements, showed that the electric charge acquired by the drop was always an integral multiple of a certain value of charge, so that for all observations, $q = ne$, where e is a constant and n is always an integer. It was accordingly demonstrated that the charge e represented the smallest possible unit of electricity—the charge carried by one electron.

Work with this apparatus revealed various sources of error, and improvements were carried out from time to time as indicated by experience in actual measurements as well as theoretical considerations. The final apparatus is shown in simplified form in Fig. 2. The inner vessel is of brass, and designed for working at pressures up to 15 atmospheres, so as to observe the effects of pressure on the test results. The absence of disturbing convection currents in the air between the condenser plates is ensured by filtering the heat rays from the light source by a water cell 80 cm. in length and a cupric chloride cell. Thermal stability is further ensured by immersing the whole vessel in an oil bath of 40 litres capacity. During observations the temperature remained constant within about 0.02° C. The atomiser for producing the cloud is blown by a puff of carefully dried and dust-free air. Only two windows are shown in the drawing, but there are three in the apparatus; one for admitting light, one for the entry of radiation when required and one for observation of the droplets by means of a short-focus telescope having a scale on the eyepiece for the measurement of their speeds.

After a total of some ten years of research, Millikan gave as his final result

$$e = (4.770 \pm 0.005)\ 10^{-10} \text{ e.s.u.}$$

In electromagnetic units this becomes

$$e = (1{,}500 \pm 0.0017)\ 10^{-20} \text{ e.m.u.},$$

which means that in practical engineering units the charge on a single electron (omitting the experimental tolerance) is 1.59×10^{-19} coulomb. Thus it is seen that a current of one ampere flowing for one second represents the movement of no less than 6¼ million million million electrons. From the established fact that $e/m = 1.76 \times 10^7$ in electromagnetic units it is also easy to calculate that the mass of an electron is approximately 9×10^{-28} gram.

Considerations of this kind lead to the view that our knowledge of the nature of an electron is fairly complete whereas in fact we are still a long way from this goal. While it is convenient to regard the electron as a simple point charge of electricity, and although this view fits in with certain experimental facts, such as relate to photoelectric effects, for example, there are other phenomena requiring altogether different views which have greatly widened the horizon of electron physics. As in the past, we may confidently expect that this widening of the subject will bring progress also in the numerous applications of electronics.

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1 *Proc. Camb. Phil. Soc.*, 9, 1897, p. 244.
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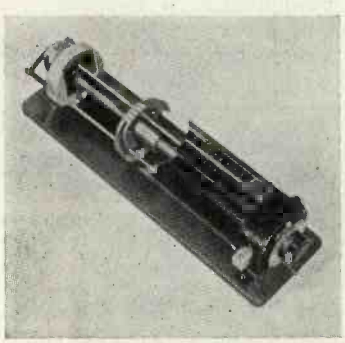
This concludes the series of articles on Electronics contributed by Mr. Windred. Readers will regret to hear that he has not been in good health lately and will join with us in wishing him a speedy recovery. We are looking forward to publishing further articles under his name during the coming months.—Ed.

A New U.H.F. Oscillator

THE August issue of the General Radio Experimenter contains an account of the new General Radio U.H.F. Oscillator, Type 757A, of which a sectioned photograph appears below.

The oscillator can be set by means of a single crank control to any frequency between 150 and 600 Mc/sec. (200 cm. to 50 cm. in air). The dial at the end of the cylindrical housing and the counter on the left of the housing (seen at the lower end in the photograph) indicate the approximate wavelength in centimetres and the reading can be converted into frequency by means of the calibration scale on the top of the case.



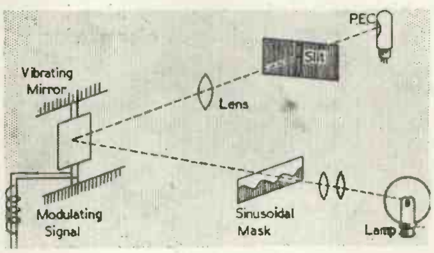
Full particulars and terms of sale can be obtained from Messrs. Claude Lyons, of Tottenham Court Road, W.1, who are the agents in this country for General Radio products.

ABSTRACTS OF ELECTRONIC LITERATURE

Transmission

New System of Frequency-Modulation
(S. Sabaroff)

The scheme suggested is an electro-optical one for producing the required pre-distortion of the modulating signal and a schematic diagram is shown below.



The image of a sinusoidal mask is, by means of a mirror, allowed to impinge on a slit. The light passing through the slit energises a photo-electric cell. Vibrating the mirror on its axis in accordance with a modulating signal will cause to be delivered from the photo-electric cell a voltage which is a sinusoidal function of the modulating signal.

Disregarding amplitude, the photo-electric cell output variation is given by cos $(a + x)$, where a is a constant of mask position and x is expressed as an angular variation of the sinusoidal image on the slit. Positioning the resting point of the mirror so as to make a equal zero will make the photo-electric cell output proportional to cos (x). Making a equal to − 90 degrees will make the photo-electric cell output proportional to sin (x). Since cos (x) and sin (x) are used simultaneously, it will be necessary to use the described arrangement in duplicate form. It is anticipated that it will be possible to obtain at least a 25 cycle displacement of the sinusoidal image, thus allowing a phase shift of 9,000 degrees at the lowest modulating frequency.

—*Communications,* Vol. 21, No. 9, September, 1941, page 8.

Thermionic Tubes

Silver Magnesium Alloy as a secondary electron emitting material
(V. K. Zworykin, J. E. Ruedy and E. W. Pike)

The wide use of secondary electron emission electrodes as a means of obtaining gain in thermionic vacuum tubes has been retarded by the lack of a sufficient rugged emissive material. There are many such electrodes that can be built into valves which will function satisfactorily for a few minutes or hours, but the requirements are for thousands of hours of useful life. The failure with time of these initially satisfactory emitters is usually due to a combination of effects of electron bombardment, residual gas, and temperature rise.

Details of experiments undertaken with alloy mixture together with circuit diagram for life testing are given.

It is claimed that although there are many points of both theoretical and practical interest that still need clarifying, the use of the alloy as a secondary electron emitter in certain types of thermionic valves is now feasible.

—*Jour. App. Physics,* Vol. 12, No. 9, September, 1941, page 696.

Measurements

Frequency Response Curve Tracer
(S. F. Carlisle, Jr. and A. B. Mundel)

In contrast to the usual methods, the instrument described here gives a continuous curve of the response characteristic on a standard cathode-ray oscilloscope screen. By this means the output of devices having varying output over their frequency ranges can be continuously observed with greater rapidity than by other means. The setting of a variable oscillator establishes the lowest frequency from which the audio output can sweep, and the sweep range is determined by the setting of the control valve and auxiliary circuits. Thus, the oscilloscope screen is not limited to a picture starting at zero frequency, but any portion of the audio range can be instantly segregated for examination.

A pentagrid valve (6L7) was used. In this valve a screen separates the two control grids and thus eliminates interaction between them. The range of frequency change is controlled by varying the mutual conductance of the control valve.

The instrument can be used for comparison of the product with a standard by a single switching system. One instrument has sufficient power to operate several test positions, each using a separate oscilloscope.

—*Electronics,* Vol. 14, No. 8, page 22, 1941.

Velocity Measurement of Transient Mechanical Motions
(S. Keilen)

Measurements of velocity of rapid non-recurrent mechanical motions by means of an oscillograph are described, one by modifying the optical system of the oscillator and the other by employing a slotted disk mounted on mechanism under test. These offer practical means of time-distance relation measurement of small devices, such as spring actuated levers, cam mechanism triggers, etc., whose performance would be affected due to the additional load required to operate auxiliary measuring instruments.

—*Jour. App. Phys.,* Vol. 12, No. 8, August, 1941, page 634.

Electrolytic Condenser Test Set
(F. A. Boyer)

A simple capacity bridge which can

ABSTRACTS (*contd.*)

be used for checking electrolytic condensers and measuring the capacity of paper condensers. It is not intended to give precision readings of capacity, but tells immediately whether a condenser is good or faulty.

The basic circuit is a bridge of standard form, and the use of a magic eye valve dispenses with the use of an oscillator.

Details of the set, together with instructions how to use with a leakage indicator described in a previous issue, are given.

—*Wireless World*, Vol. 47, No. 10, October, 1941, page 254.

Electro-Medical

Crystal Elements
(*A. L. Williams and A. W. Duffield*)

Some difficulties which were present in Rochelle salt crystal have been practically overcome through the introduction of the "Bimorph" crystal element which consists of two plates of Rochelle salt cemented together in such a manner, that, upon the application of an electrical charge, one plate expands while the other contracts causing a bending or twisting of the whole unit. To insure maximum protection against deterioration under unusually dry or damp conditions of use, the assembled crystal element is finally coated with a specially prepared moisture proof material.

Worthy of special mention is the direct inking oscillograph which is of use in the medical field for electrocardiographic and electroencephalographic studies. The crystal element drives a pen of low inertia and high stiffness which traces an inked record on a moving paper chart. The deflections of the pen are directly proportional to the electrical potentials applied across the crystal element. Two types of pens are normally available, one responding to frequencies up to 60 c.p.s. and the other up to 120 c.p.s. A thermostatically-controlled heater provides stabilisation.

—*Communications*, Vol. 21, No. 8, August, 1941, page 8.

Synchronised Voltages for Bioelectric Research
(*H. Goldberg*)

The circuit used was designed for work which required the simultaneous recording of two action potentials. These are amplified by two identical d.c. amplifiers and impressed on two cathode-ray tubes mounted side by side. It was necessary that the records allow time comparisons of events and this made the requirements for the stimulator and sweep circuit more exacting than for a system involving the recording of a single action potential alone. The arrangement can be extended for use with three channels and a three trace cathode-ray tube for recording three events simultaneously. The apparatus is battery operated.

—*Electronics*, Vol. 14, No. 8, 1941, page 30.

PATENTS RECORD

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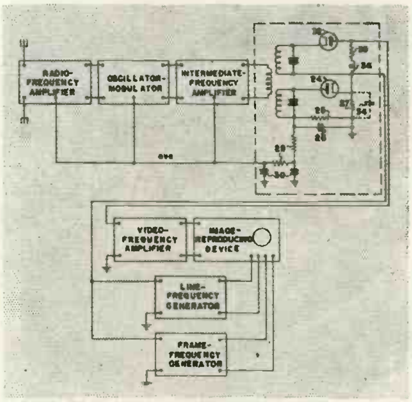
TELEVISION

Improvements in Television Receivers

This invention relates to television receiving apparatus and is especially directed to the provision of an improved system for detecting a television signal-carrier wave to derive its light-modulation components, for black-level setting of these components, and for automatic amplification control.



The I.F. amplifier is coupled to two diodes 24 and 32, through tuned transformers. The load circuit of 24 has a time constant greater than the line synchronising pulse period (25 and 26) and a short time constant circuit (27 and 34). The input circuit of the line and frame scanners are connected across 27. The negative end of 25 is connected through the filter 29 and 30 to the a.v.c. line to maintain the signal carrier amplitude constant independently of the light-modulation component. The diode 32 provides a v.f. component stabilised with respect to black level.

—*Hazeltine Corporation.* (*Assignees of R. L. Freeman*). *Patent No.* 538,103.

THERMIONIC DEVICES

A valve in which a magnetic field extends axially in the direction of the electrodes and adapted to prevent or reduce undesirable effects due to secondary electrons, while exciting no appreciable influence on the primary electrons. The field is produced by means of two magnetised plates arranged at the ends of the electrode system consisting entirely or partly of a magnetic material.

—*Mullard Radio Valve Co., Ltd. Patent No.* 538,201.

A stage for modulating an ultra short wave by a wide frequency band by a balanced thermionic amplifying stage in which the input voltage of the carrier frequency is applied between the cathodes. The modulating frequencies are applied to the controlling grids in parallel, means being provided for neutrodyning the interelectrode capacities of the valves so as to obtain a low effective capacity in the anode circuit.

—*Standard Telephones and Cables, Ltd.* (*Assignees of Le Material Telephonique Societe Annonyme*). *Patent No.* 538,026.

The object of the invention is to obtain an increase in the amplification of an amplifying circuit employing a discharge tube. A circuit is described in which an impedance is inserted which is connected to the auxiliary cathode and part of the amplified alternating voltage produced across the self impedance is supplied in a regenerative sense to the control grid.

—*Philips Lamps, Ltd. Patent No.* 537,900.

Photo-cells Utilising Electron Multiplication

A photo-cell comprising a spherical light-sensitive cathode and an electrode which is located outside the path of the light rays, and which together with the cathode constitutes an electronic lens to direct an electron beam to a secondary emission electrode. The electronic lens electrode adjoins the cathode to constitute the anode of the photoelectric system. This is so shaped that only the electron beam from that part of the cathode which is directly illuminated is led to a secondary emission electrode.

—*Mullard Radio Valve Co., Ltd. Patent No.* 538,321.

CIRCUITS

Rectangular Pulse Generator

A circuit arrangement for generating periodic electrical pulses having rectangular wave form. This comprises a relaxation oscillator provided with a series connected resistance-capacity combination which determines period of repetition of the pulses. The relaxation oscillator consists of a thermionic valve arranged to have a steep anode current—grid voltage characteristic and a small anode saturation current which controls the initiation and/or termination of the pulses.

—*Standard Telephones and Cables, Ltd., R. M. Barnard and W. Kram. Patent No.* 538,221.

INDUSTRY

Ceramic Manufacture

This invention relates to ceramic resistors and their manufacture, and is particularly applicable to those for use in lightning arrestors and electrical discharge devices. These resistors are manufactured from a mixture containing kaolin, finely ground carborundum and free carbon or substitutes.

—*I. Ernst Rosenthal. Patent No.* 538,331.

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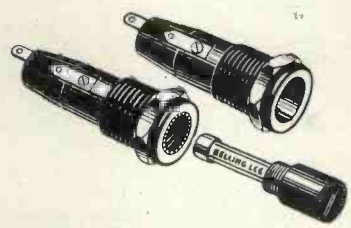

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