Electronic Engineering

INCORPORATING ELECTRONICS, TELEVISION AND SHORT WAVE WORLD

PRINCIPAL CONTENTS

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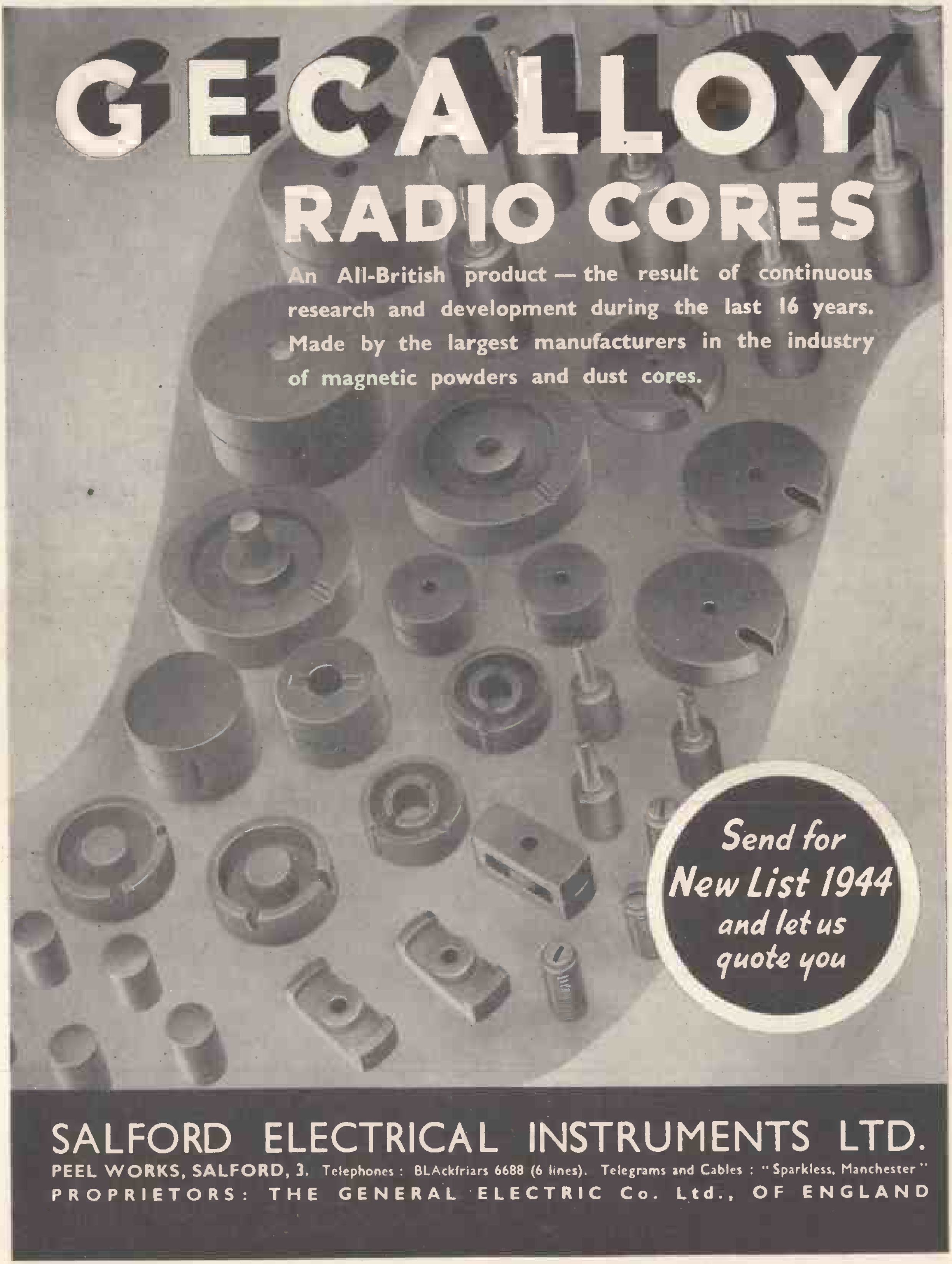
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Popular Science

ONE of the late STEPHEN LEACOCK's sketches describes his experience with the local newspaper reporter :

. . . " What did you say the lecture was about ? "

" It was called ' The Triumphal Progress of Science.' "

" On Science, eh ? " he said, writing rapidly as he spoke.

" Yes," I answered, " on Science."

" And now," he went on, " what was the principal idea of your address ? "

" I was speaking of our advanced knowledge of radiating emanations and the light it throws on the atomic structure."

. . . And the next morning as I was borne away from that city in the train I read his report in the paper :

" The distinguished visitor," so ran the report, " gave an interesting talk on Christian Science before a capacity audience. He discussed very fully the structure of anatomy which, he said, had emanated out of radio." . . .

This reporter still lives. Perhaps he does not give quite such a travesty, but there is still sufficient misrepresentation of scientific matters in the lay Press nowadays to amuse or exasperate the technical reader according to his mood.

For some reason scientific accuracy seems incompatible with the demands (or the supposed demands) of the non-technical reader. It is assumed that he requires " human interest," or excitement, or a novel angle—all things which detract from the presentation of scientific facts in a straightforward and well-balanced way. Even in more sober accounts of developments there is a disregard for accuracy of detail which would earn the sack for any technical writer of a report.

Why not rate the intelligence of the average reader a little higher than the impression given by some articles on scientific matters ? Why is every ray a death ray, or an electronic device a magic eye or an Aladdin's lamp ?

There is no reason why science should not be made interesting in itself—we know many scientists past and present who had the gift of making abstruse subjects of absorbing interest to the lay mind, and without the use of exaggerated terms.

With one or two notable exceptions, there is no scientific writer of repute associated with the daily Press. True, there are not many who combine the requisite knowledge of the subject with the gift of making it " understanded of the people," but such men are worth hunting for if science is to be properly appreciated.

There is no lack of information—the true scientist is only too pleased to give information about his work, even though he may not be skilled in presenting it attractively. Any reluctance on his part is usually born of previous experience in distortion of the facts or publicity of the wrong type.

What is wanted by science and industry is a writer who can be described by that expressive French phrase *vulgarisateur scientifique*, and whose information is above reproach technically and available to any paper who will use it.

Until men of this type can be found there is no reason why the reporting staff of any paper should not avail themselves of the advice of various scientific bodies or independent experts even on the most trivial matters instead of putting pseudo-scientific nonsense into print.

Electronic Sorting Machines

THE photograph above shows a large installation of 32 bean-sorting machines, each one equipped with an electronic sorting apparatus.

The American Electric Sorting Machine Company, designers and manufacturers of these machines, have evolved two different types of sorter—the so-called "dark trip" machine, and the "bichromatic" machine.

The dark trip type is generally used in sorting peanuts and beans, the sorting being accomplished by light reflected from the material to the photo-cell. This trips a relay circuit when a dark-coloured bean or other object passes the light beam. By means of a variable control it is possible to set the ejecting mechanism for any desired degree of "off-colour."

The bichromatic machine is sensitive to shades of colour and can be set to separate any given colour or number of colours from either end of the spectrum.

In sorting lemons, citrus, or coffee beans it is thus possible to grade light green from dark green or light brown from dark brown in one handling and without the operator touching the product.

—Michael Lorant.

Geiger Müller Counters

And Their Applications to Cosmic-Ray Research

By DR. L. JÁNOSSY*

I. Problems of Cosmic-Ray Research

IN the following we shall give a brief account of the types of experiments in which Geiger Müller counters (GM) are employed. It is not intended to give a detailed account of cosmic-ray problems, as this has been dealt with in ELECTRONIC ENGINEERING for April, 1944.

a. Ionisation Chamber

Cosmic rays were discovered in the course of measurements on the electrical conductivity of gases. These experiments were carried out by means of ionisation chambers, like most of the early investigations on cosmic rays.

The ionisation chamber proved to be very useful, especially as some of the models proved to be extremely stable and reliable. The ionisation chamber technique has, however, great disadvantages. Firstly, an ionisation chamber is sensitive to rays from all directions. The ionisation current observed is therefore a measure of the integrated intensity and it is not possible to obtain reliable information about the radiation intensity in given directions. Attempts to obtain the intensity in certain directions by shielding an ionisation chamber must fail, because of the large penetrating power of the cosmic rays. It is found, for example, that about 30 per cent. of the radiation at sea level is capable of penetrating a lead absorber 1 m. thick.

Secondly, an ionisation chamber shows a certain amount of background, *i.e.*, the ionisation current is only partly due to cosmic rays while the rest is due to the radioactivity of the surroundings and the radioactive contamination of the chamber walls. The effect of the radioactivity of the surroundings can be got rid of by shielding the chamber with 5 to 10 cm. of lead; the background due to the contamination of the walls is, however, most troublesome as it cannot be assessed accurately.

* The Physical Laboratories, The University, Manchester.

b. The GM Counter

A single GM counter, when used to record cosmic-ray intensity, shares all the disadvantages of the ionisation chamber besides the additional disadvantage of covering a small area only. The number of pulses recorded by a single counter is subject to larger statistical fluctuations than the current in an ionisation chamber as the latter is due to the passage of a larger number of single particles.

The great importance of GM counters arises, however, from the fact that they can be used in coincidence.[1] It was found that two counters placed above each other show simultaneous pulses. Such coincidences occur too frequently to be accidental and they must be attributed to single particles traversing both counters.

The coincidence method has proved to be very effective in the investigation of cosmic rays. In particular, the difficulties arising in connexion with the ionisation chamber which were described above can be overcome when using coincidences arrangements.

(1) The radiation intensity in given directions can be determined directly by using a counter telescope (Fig. 1). Coincidences between the counters 1 and 2 are mainly due to particles traversing both counters. Therefore, the rate of coincidences observed is a measure of the intensity of incident particles in the directions subtended by the two counters.

Measurements carried out with arrangement of the type shown in Fig. 1 revealed that the intensity in a direction inclined by α to the vertical is proportional to $\cos^2\alpha$.

The arrangement shown in Fig. 1 was improved by Johnson[2] whose arrangement is shown schematically in Fig. 2. The counter M is surrounded by a number of counters 1, 2 . . . 6, 1′, 2′ . . . 6′. The counters 1,M,1′ are placed in one plane, similarly the counters 2,M,2′, etc. Coincidences between these groups of three are recorded simultaneously. Thus the

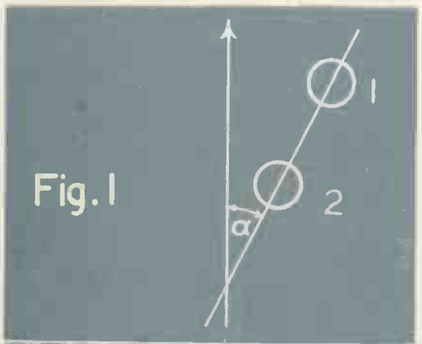


Fig. 1

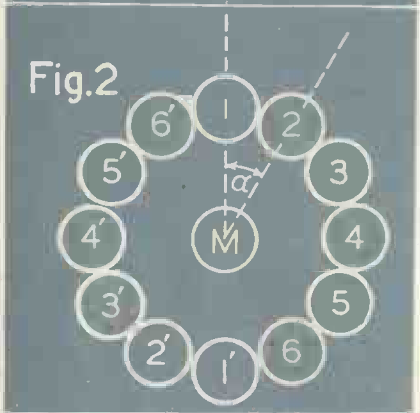


Fig. 2

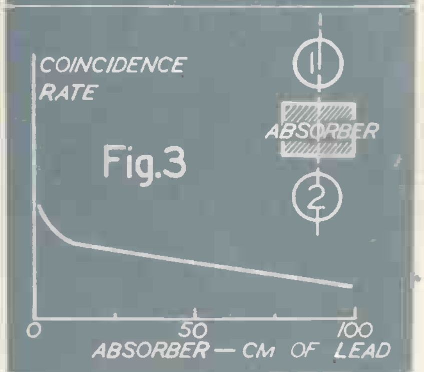


Fig. 3

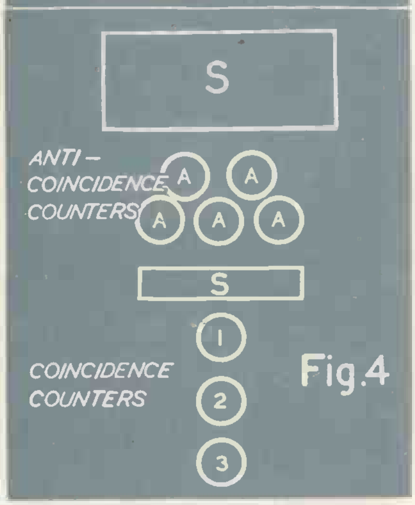


Fig. 4

coincidences 1,M,1′ give the vertical intensity, the counters 2,M,2′ the intensity in a direction inclined by α, etc. Therefore the intensities in a number of directions are recorded simultaneously. Moreover, in order to compensate for small differences in the geometry or efficiency of the counters the arrangement is turned every hour by an angle α round the counter M and thus the intensity in any direction is measured by any of the counters in turn.

(2) The background of the coincidence rate is merely due to accidental coincidences, that is, due to the accidental overlapping of independent discharges. The rate of accidental coincidences depends on the resolving power of the coincidence arrangement. Take, for instance, two counters with the single rates N_1 and N_2, the rate of accidental coincidences can be shown to be

$$A_{12}=2N_1N_2t_0$$

where the arrangement is assumed to resolve only pulses with a time interval exceeding t_0. In practice the rate of accidental coincidences can always be made insignificant.

The radioactivity of the surroundings does not contribute to the coincidence rate as α- or β-rays cannot penetrate the walls of the counters while γ-rays produce too few ions to be recorded by more than one counter in succession. Most of the coincidences recorded by a coincidence arrangement can therefore be attributed to cosmic rays.

c. Some Applications

a. The following further applications of coincidence arrangements shall be mentioned.

(1) Consider a vertical coincidence arrangement, Fig. 3 (inset). By placing material of varying thickness between the counters the absorption of cosmic rays can be measured. In Fig. 3 the rate of coincidences is plotted against thickness of lead between the counters. It is seen that the first 10 cm. of lead absorbs a great deal, but the radiation penetrating 10 cm. of lead is absorbed only slowly in greater thicknesses.

(2) It was noticed by Rossi[3] that three counters placed in a triangle give rise to triple coincidences although no single particle can be expected to traverse all the counters. Such coincidences are caused by showers of particles. The existence of showers of particles was proved later directly by cloud chamber photographs (Blackett and Occhialini[4]).

d. Anti-Coincidences

The seemingly insoluble problem of detecting non-ionising rays with counters can be solved by using "anti-coincidences." The procedure is illustrated by the arrangement of Fig. 4. The arrangement consists of an ordinary coincidence arrangement 1,2,3, and a group of counters A which is placed close above the coincidence system. The counters A are connected in parallel and they cover the whole of the solid angle subtended by the coincidence arrangement below. Coincidences 1,2,3 which are not accompanied by the discharge of any of the counters A are called anti-coincidences.

Anti-coincidences can be caused by a number of processes. The most interesting process is, however, the following. A non-ionising particle falls on the absorber s which is placed between the anti-coincidence counters A and the coincidence system. The non-ionising particle does not discharge the counters A but it may give rise to an ionising secondary in s. This discharges the counters below and thus causes an anti-coincidence. Thus non-ionising radiation can be detected by means of anti-coincidences.

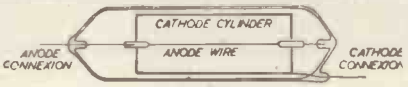


Fig. 5. Geiger Müller counter.

Fig. 6. Resistance quenching (slow counter).

By placing absorbers S above the anti-coincidence counters A one can absorb the non-ionising radiation. Plotting the rate of anti-coincidences against the thickness of S one obtains the absorption function of the non-ionising radiation.

The above method was used for the investigation of the photon component of cosmic rays. The existence of a weak penetrating non-ionising component could also be established with the help of anti-coincidence arrangements.[5]

e. Experimental Requirements

It is seen from the experiments described above that a coincidence arrangement has to fulfil the following requirements.

(1) The number of accidental coincidences must be reduced and therefore the resolving time t_0 must be as small as possible. Under ordinary circumstances a resolving time of the order of 10^{-4} sec. is found to be suitable; for special purposes the resolving time has to be reduced down to 10^{-7} sec. Shorter resolving times seem to be impracticable as counter-discharges seem to set in with irregular delays after the passage of the particle. These delays are larger than 10^{-7} sec., and therefore an arrangement with $t_0 < 10^{-7}$ sec. may not record all genuine coincidences.

(2) It is important that the counters have a high efficiency. This is especially important for counters used in anti-coincidence. An ionising particle leaking through a counter due to lack of efficiency might be mistaken for a non-ionising particle.

It is found that fast counters (compare below) have an efficiency exceeding 99 per cent.

II. Mechanism of the GM Counter

General Description

The GM counter is an improved version of Geiger's point counter.[6] The GM counter consists of a cylindrical cathode surrounding a thin central wire which acts as anode. The electrodes are usually sealed into a glass tube, and the counter is filled with some gas to a pressure of about 1/7 of an atmosphere. A schematic drawing of the counter is shown in Fig. 5. A potential difference of the order of 1,000 volts is applied between the electrodes. It is found that under suitable conditions ionising particles crossing the sensitive volume of the counter give rise to electrical discharges. The discharges arising from the passage of particles must be quenched. The electric pulses produced by the discharges can be recorded and thus the number of particles crossing the counter can be counted.

The Mechanism of the Counter Discharge

Particles crossing the sensitive volume of a GM counter will give rise to positive ions and free electrons. The electrons are attracted to the anode wire. In the vicinity of the anode the potential gradient is so large that the electrons in this region give rise to secondary ionisation. More electrons are liberated in this process and an electric discharge results.

The positive ions produced in the discharge are accumulating round the wire because of their small mobility. The positive space charge which results reduces the field-strength until the secondary ionisation ceases and the discharge is stopped.

The positive ions are eventually driven to the cathode and neutralised, and thus the counter becomes ready for the next discharge.

The above mechanism for the counter discharge was suggested by Montgomery and Montgomery[7] and is in accordance with the experiments of Ramsay[8] on the mechanism of the counter discharge.

Slow and Fast Counters

For most counters the actual discharge mechanism is more complicated than described above. The complications arise from the fact that the positive ions are likely to emit secondary electrons on impact with the cathode, and these electrons give rise to secondary discharges. Due to these secondary electrons multiple discharges may arise or even an oscillating discharge may set in. In practice one has to find means to prevent secondary discharges taking place.

Secondary discharges can be extinguished by an external resistance as shown in Fig. 6. The current flowing during the discharge produces a voltage drop across R. For a sufficiently high resistance this voltage drop reduces the voltage across the counter below the value required to maintain the discharge and thus the discharge is extinguished.

All the early counters were used with resistance quenching. This method is, however, very unsatisfactory. Firstly, the resistance quenching is not very reliable and oscillations may set in occasionally. Secondly, to quench the discharge, resistances of the order of 10^9 ohm have to be used. The capacity of a counter together with the capacity of the coupling unit leading to the recorder cannot be less than about 20 $\mu\mu$F. Therefore the time constant of the quenching circuit is of the order of

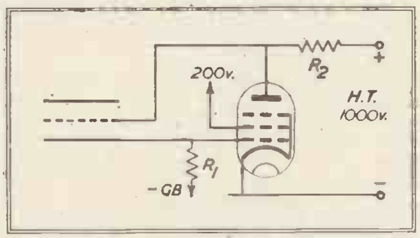


Fig. 7. Neher Harper circuit for extinction of counter discharge.

$$t \approx 20\times10^{-12}\text{F}.10^9\text{ohm} = 0.02 \text{ sec.}$$

The counter is ineffective for a period of the order of t after each pulse. This time is very long and it results in serious loss of efficiency. Because of its slow recovery the resistance-quenched counters are called slow counters.

Neher Harper Circuit

The secondary discharges can be extinguished quickly, using a circuit devised by Neher and Harper.[9] The circuit diagram is shown in Fig. 7. The counter voltage is applied through a resistance R_2 and is cut off again by a pentode immediately after a discharge has started. The recovery time of the outside electrical circuit can be made short and therefore the ineffective time can be reduced.

The counter H.T. of the order of 1,000 volts has to be applied to the plate of a pentode, but this does not cause any difficulties.

Fast Counters

It was found by Trost[10] that counters filled with a mixture of a gas and an organic vapour show excellent qualities. The best results were obtained with ethyl alcohol though other vapours can also be used.

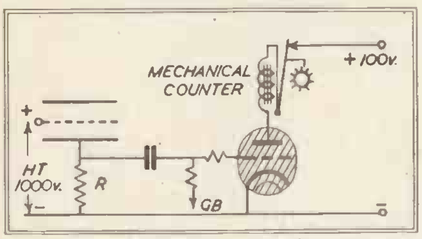
The alcohol counter is self-quenching, that is, no secondary discharges set in after the first discharge has been terminated by the space charge. The alcohol counter can therefore be used with small anode resistance and its recovery depends only on the time required for the positive space charge to disperse. This time is of the order of 10^{-4} sec.

III. The Recording of Counter Pulses

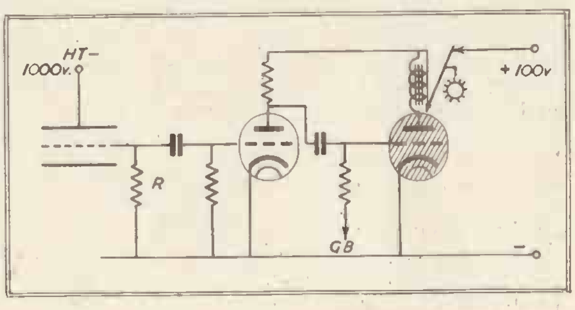
a. Single Pulses

The electric pulses accompanying the discharges of a GM counter can be amplified and recorded mechanically. Simple circuits are shown in Fig. 8 and Fig. 9. In the circuit of Fig. 8 the cylinder of the counter is earthed through a resistance R while a positive H.T. is applied to the anode. Discharges of the counter produce positive voltage pulses on the cathode. These pulses are fed through a condenser to the grid of a gas-filled relay. The relay operates in its anode circuit a mechanical counter. Each counter discharge sets off the gas-filled relay; the discharges of the relay are broken mechanically by a switch attached to the mechanical counter. Thus the mechanical counter is made to record the counter pulses.

A rather more reliable circuit is shown in Fig. 9. In this arrangement the counter anode is earthed and a negative H.T. is applied to the counter cathode. The negative pulses arising at the anode are fed to the grid of a triode or pentode. The am-



Figs. 8 and 9. Recording of single pulses.



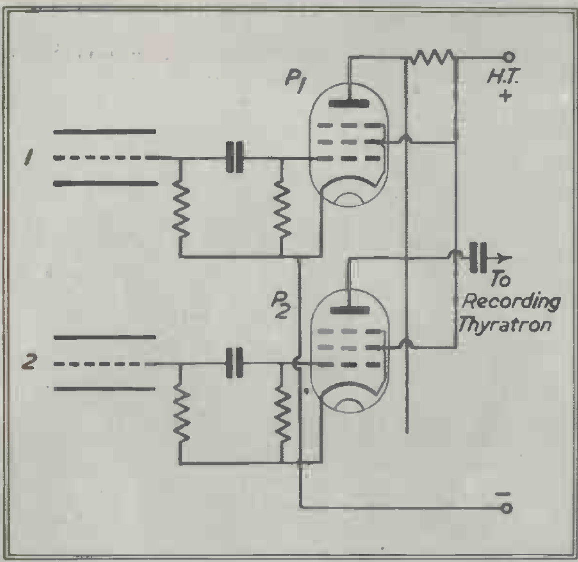


Fig. 10. Rossi circuit for coincidence counting.

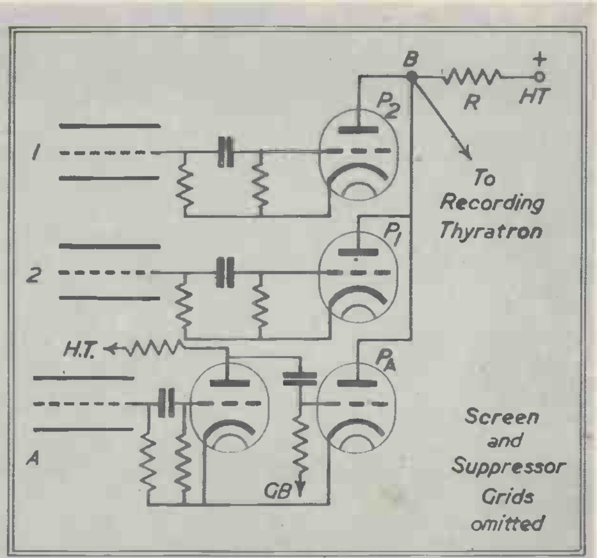


Fig. 11. Anti-coincidence recorder.

plified and reversed pulses obtained at the plate of the pentode are fed to a gas-filled relay and mechanical recorder as in the circuit above.

b. Counting of Coincidences

The discharges caused by one particle passing through two counters are for all practical purposes simultaneous. The problem arises therefore to select discharges which take place simultaneously in two GM counters. A circuit selecting coincidences was designed by Rossi.[11]

Rossi's circuit is shown in Fig. 10. The counters 1 and 2 are coupled to the grids of the pentodes P_1 and P_2. The pentodes are fed through a common anode resistance R. Both pentodes carry current in the initial state.

The resistance R is chosen large compared with the impedance of the pentodes. Most of the potential drop occurs, therefore, along the resistor R and the plates of the pentodes are kept at potentials only slightly above earth potential.

Whenever a (negative) pulse is received from one counter the anode current of the corresponding pentode is cut off for a short time. If the current is cut off in one of the pentodes only, then the plate voltage of the pentodes is still kept low by the current of the other pentode. Whenever the current is cut off in both pentodes simultaneously, the voltage drop across R is cut off altogether and the plate voltage rises to the value of the external voltage.

Taking output pulses from the plates of the pentodes, small pulses will be received whenever one of the counters discharges, while large pulses are obtained for coincident discharges.

A suitably biased gas-filled relay can be made to respond only to the large pulses which are due to coincidences of the counters.

The Rossi circuit (Fig. 10) can also be used to record coincidences between more than two counters. Each counter has to be connected to a separate pentode. It is easily seen that, due to the common resistance R, large pulses can result only if *all* of the pentodes receive pulses simultaneously.

c. Recording of Anti-Coincidences

Anti-coincidences can be recorded, for instance, by a circuit as shown in Fig. 11. The pulse of the anti-coincidence counter is reversed by an extra stage. The pentode P_A is fed through the load resistance R which also feeds the coincidence pentodes P_1 and P_2. The anode current of the pentode P_A is cut off by a negative bias and current flows only after pulses received from the anti-coincidence counter A.

An anti-coincidence consists of the discharge of the counters 1 and 2 not accompanied by the discharge of the counter A. An anti-coincidence gives rise to a large pulse at the point B just as in the case of the Rossi circuit. But coincidences 1,2,A give rise to small pulses only, as such a coincidences cut off the pentodes P_1 and P_2 but switch on the pentode P_A. The current through the pentode P_A keeps the voltage low in the point B.

The anti-coincidence circuit shown in Fig. 11 has a disadvantage. If the anti-coincidence pulse arrives with a small delay then the current in P_A is switched on too late, and the voltage pulse in B is not quenched effectively by the anti-coincidence counter. This difficulty can be overcome by delaying the coincidence pulse and broadening the anti-coincidence pulse. A circuit using this principle was described by Rossi and co-workers.[12]

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The Photopulse

By E. LLOYD THOMAS, B.Sc.(Hons.), A.C.G.I.*

Describing a simple and flexible stroboscopic light generator suitable for general experimental and production test purposes.

THE essential features of a stroboscopic light generator differ according to whether the instrument is to be used for speed measurement or motion study. For either purpose some light source is required that will deliver pulses of light of adequate intensity at a rate which, though controllable, must be free from spontaneous fluctuations. For speed measurement the frequency control must be accurately calibrated, but this is not so necessary for motion study. Experience indicates, however, that for the latter purpose the pulse ratio† should not exceed two or three per cent., or the movement may be blurred instead of sharply defined. The requirements for speed measurement are less exacting in this respect.

Although commercial general purpose stroboscopic light generators have been available for some time, there exists a considerable demand for a simple instrument of moderate performance. It is the purpose of this article to describe such an instrument, which was developed to meet the needs of general experimental work and production testing.

The Basic System

The system finally adopted for this instrument, after a consideration of the various mechanical and electrical methods of producing a pulsating light source, is entirely electronic. From the basic circuit shown in Fig. 1 it will be seen that the pulse generator consists of a single valve connected as a blocking-grid oscillator and coupled to a gas-discharge lamp.

The action of the circuit is developed in Fig. 2, and may be followed by considering what happens when the H.T. supply is switched on. The transformer is connected so that as the anode current begins to rise, the e.m.f. induced in its secondary tends to drive the grid of the valve positive with respect to its cathode. This accelerates the increase of the anode current, which, since the action is cumulative, rises sharply to a maximum value that is limited only by the total D.C. resistance of the anode circuit and the value of the H.T. supply. Meanwhile, the positive excursion of the grid potential is limited by the fall in the input resistance of the valve which accompanies it, and the resulting flow of grid current charges the capacitor *C*. The sudden pulse of anode current sets up a train of damped oscillations in the transformer, so that, after the current has reached its peak value, the e.m.f. begins to decrease. As it does so the grid is driven rapidly negative, well beyond cut-off, and the anode current drops back again to zero. Now, providing the time constant of *C* with the resistance of the grid leak *R* is large enough, the oscillations in the transformer will

* The Plessey Co., Ltd.

† The pulse ratio is the ratio of the duration of each pulse to the repetition period, and is most conveniently expressed as a percentage.

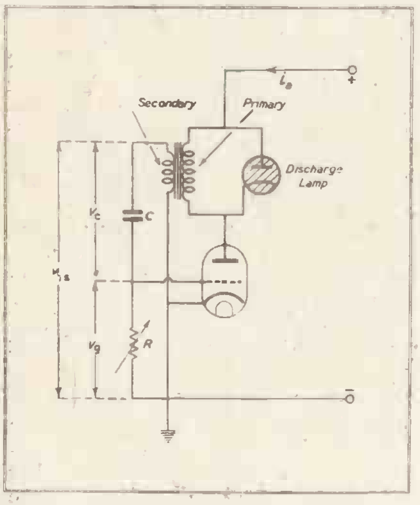

Fig. 1 (left). The basis of the instrument is a blocking-grid oscillator coupled to a gas-discharge lamp.

Fig. 4 (right). The complete instrument, showing the lamp arm extended.

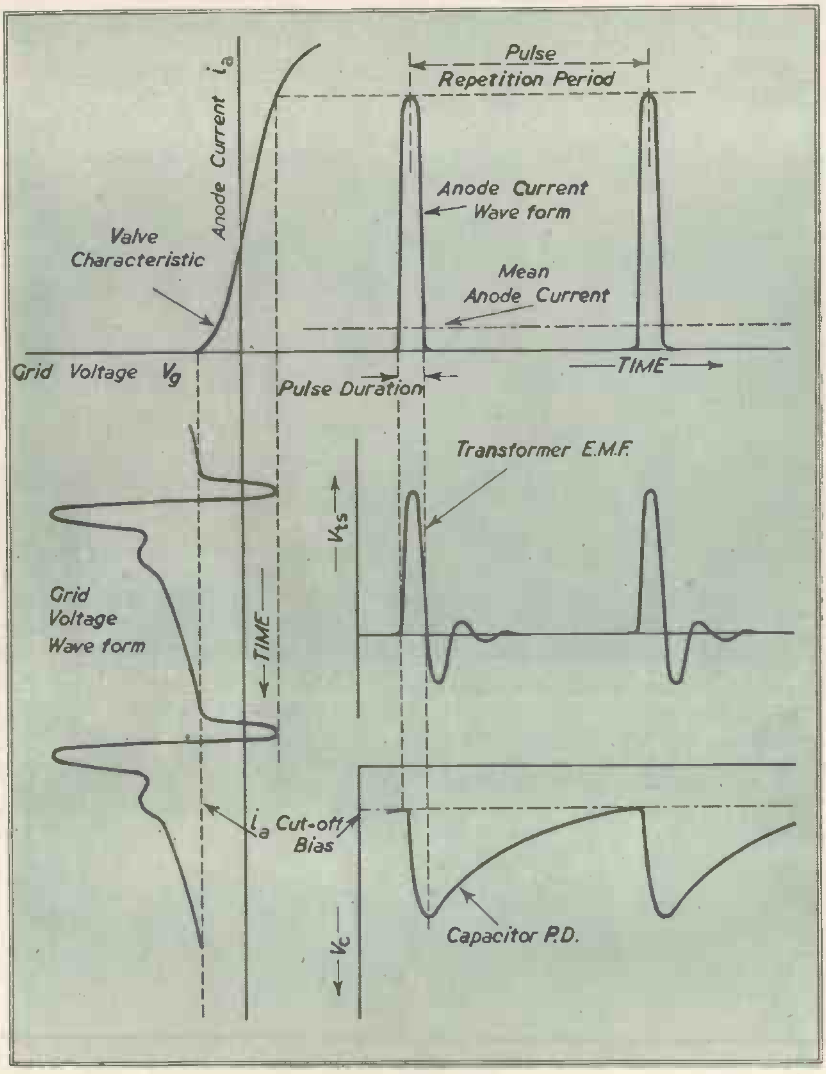

Fig. 2. Theoretical waveforms of current and voltages developed by the circuit of Fig. 1, and drawn with an exaggerated pulse ratio for the sake of clarity. The grid voltage is the sum of the P.D's across the transformer secondary and the capacitor.

die away more rapidly than the large negative bias on the valve, which will remain in a non-conducting state while the charge on C leaks away through R. After this interval, when the grid voltage has fallen to the cut-off point, the cycle will be repeated and the valve will pass another pulse of current.

Each pulse cycle is made up, therefore, of two distinct parts: a short active period, followed by a much longer interval of quiescence. While the pulse duration is determined partly by the characteristics of the transformer and partly by the time constant due to the capacitor charging through the input resistance of the valve, the pulse frequency* is controlled mainly by the time constant of the same capacitor discharging through the grid leak.

If the circuit constants are suitably chosen the pulse is very sudden, and a large e.m.f.—of the order of several hundred volts—is induced in the anode winding of the transformer. Since the discharge lamp is connected in parallel with this winding, the P.D. developed across it each time a pulse occurs causes it to emit a momentary flash of light.

* The pulse frequency is the number of pulses occurring each second.

Design Considerations

Although special grid-controlled lamps have been developed for this kind of work they are not generally available at the present time. Accordingly, a simple cold-cathode "neon" lamp is used in the present instrument, preliminary experiments having shown that this would give sufficient light for the majority of purposes. Since the amount of light emitted by this type of lamp depends on the average value of the current, the effective illumination for a given pulse frequency can be increased by:

1. Reducing the total resistance of the valve anode circuit.
2. Raising the H.T. supply.
3. Increasing the pulse ratio.

The requirements of both grid and anode circuits are satisfied by choosing a valve which combines a short grid base and sharp cut-off with a low D.C. anode resistance, and operating it with as high an anode voltage as is practicable. In this way peak anode currents as high as 0.5 ampere can be obtained with a small receiving type valve. Since the pulse ratio is so small the average current is only a few milliamperes, and no trouble has been experienced with valve failure on this account. The brightness of the lamp can, of course, be increased still further by connecting more than one valve in parallel.

A consideration of the grid circuit conditions shows that the pulse duration cannot be much less than one half of the period of damped oscillations in the transformer. This means that the natural frequency of the transformer must be at least twenty-five times the pulse frequency if the pulse ratio is not to exceed 2 per cent. If, for example, the transformer construction follows normal A.F. practice, its natural frequency will not be less than 5 kc/s. and the circuit will operate satisfactorily up to a frequency of about 200 c/s. There is no difficulty in working at much higher frequencies if the transformer is suitably designed.

The pulse duration will only approach this minimum value, however, if the charging time constant of the grid capacitor is comparatively small. Otherwise this capacitor will take an appreciable time to charge during the active part of each cycle, and the pulse duration will be increased. In order to secure maximum illumination it is advisable, therefore, first to choose a value for C that will make the pulse duration as large as can be tolerated, and then to adjust R to give the desired frequency.

The basic circuit of Fig. 1 has one disadvantage when it is intended to make the pulse frequency continuously variable. If this is brought about in the most convenient way, by making the value of C fixed and that of R variable, then the pulse duration remains constant while the frequency changes, and the brightness of the lamp becomes directly proportional to the frequency. Fortunately this effect, which makes the illumination fall off at low frequencies, can be compensated for very simply by feeding the H.T. supply to the system through an RC combination similar to an ordinary decoupling circuit. This causes the effective anode voltage on the valve to be inversely proportional to the average value of the anode current, so that an increase in pulse frequency brings about a decrease in pulse amplitude. By choosing suitable values for the components of this feed circuit the average anode current, and hence the brightness of the lamp, can be made practically independent of frequency.

A Practical Instrument

Fig. 3 shows the circuit of a practical instrument based on the system of Fig. 1. This instrument, which has been called the "Photopulse," is intended for speed measurement and, in particular, for examining the movement of small mechanical and electro-mechanical devices. The circuit is mains driven and employs only one valve, apart from the lamp. With the component values given, the frequency range is from 25 to 400 c/s., corresponding to speeds between 1,500 and 24,000 r.p.m. in two ranges. The power consumption is only 20 watts.

The transformer T_1 is wound on a small core intended for an A.F. coupling transformer, and has a turns ratio (anode winding/grid winding) of 3. The purpose of the resistor R_1 is to improve the shape of the pulse at low frequencies by increasing the damping. The power transformer (T_2) has two secondary windings which provide 4 volts A.C. for the valve heater and the pilot lamps, and 350 volts A.C. for the voltage doubler circuit.

The instrument has two main controls, marked "Frequency" and "Range" respectively. The former determines the setting of the variable grid resistor R_4, and gives a continuous variation of the frequency in each range. The latter is a three-position switch that selects the frequency range and controls the power supply; the change from one range to the other being effected by altering the value of the grid capacitor.

Since the pulse frequency is liable to be affected slightly by mains voltage and thermal fluctuations, provision is made for adjusting the scale calibration to the mains frequency at one point in each range. For this purpose the lamp housing of the instrument encloses a steel reed which is caused to vibrate at twice mains frequency, *i.e.*, 100 c/s., by a small electromagnet connected across the valve heater supply. The frequency control is first set to 100 c/s. in the lower range, and the preset resistor R_3 adjusted until the reed, which is painted white and illuminated by the lamp, appears stationary. This procedure is then repeated at 100 c/s. in the second range by adjusting R_2.

The synchronising control R_6 enables the frequency of the pulse generator to be locked to that of an external system if a suitable control voltage is applied to the terminals marked "Sync."

Construction

The arrangement of the components is not critical, but the pulse transformer T_1 should be mounted in such a position relative to the power transformer that the coupling between them is a minimum. Otherwise it is possible that the pulse generator might "lock" at the mains frequency or some multiple of it.

No special components are necessary, but it is advisable to use a wire-wound variable resistor of large diameter and reliable construction for the frequency control in order to minimise erratic frequency variations and to maintain an accurate calibration.

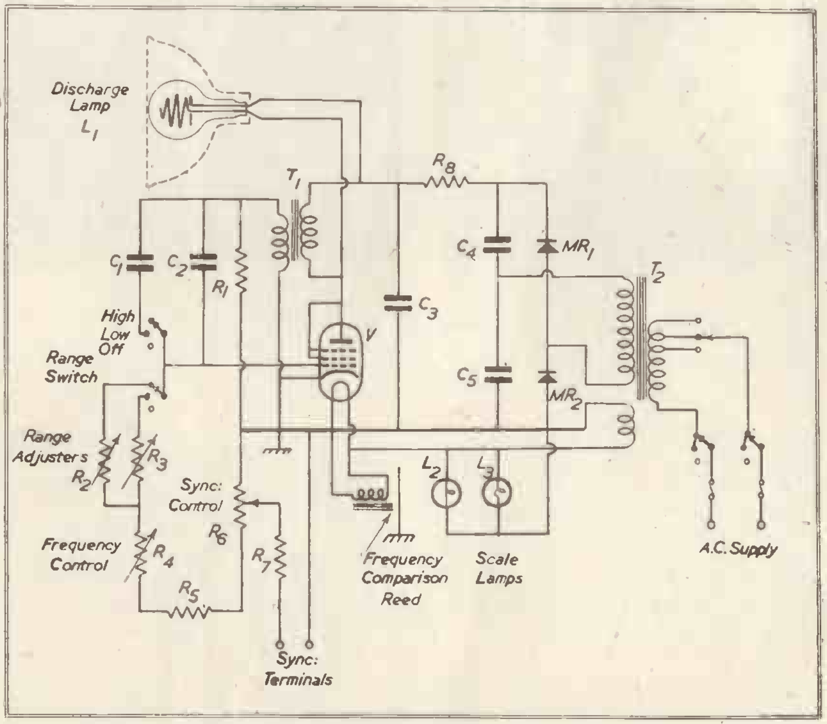

Fig. 3. Circuit diagram of complete instrument covering the frequency ranges 25-100 c/s. and 100-400 c/s.

Component Values

R_1.	1,000 ohms.	R_5.	5,000 ohms.	C_1.	0.75 μF.
R_2.	250 ohms max.	R_6.	100 ohms max.	C_2.	0.25 μF.
R_3.	" "	R_7.	"	C_3.	1.0 μF, 1,000 V wkg.
R_4.	20,000 ohms log. law.	R_8.	30,000 ohms, 5 watt.	C_4.	0.5 μF, 750 V wkg.
				C_5.	" " "

V : Mazda SP 41.
MR.1 and MR.2 : Each two Westinghouse H.50's in series.
L.1 : Osram "Osglim," without ballast resistance.
L.2 and L.3 : Each 6.2 V, 0.3 A.

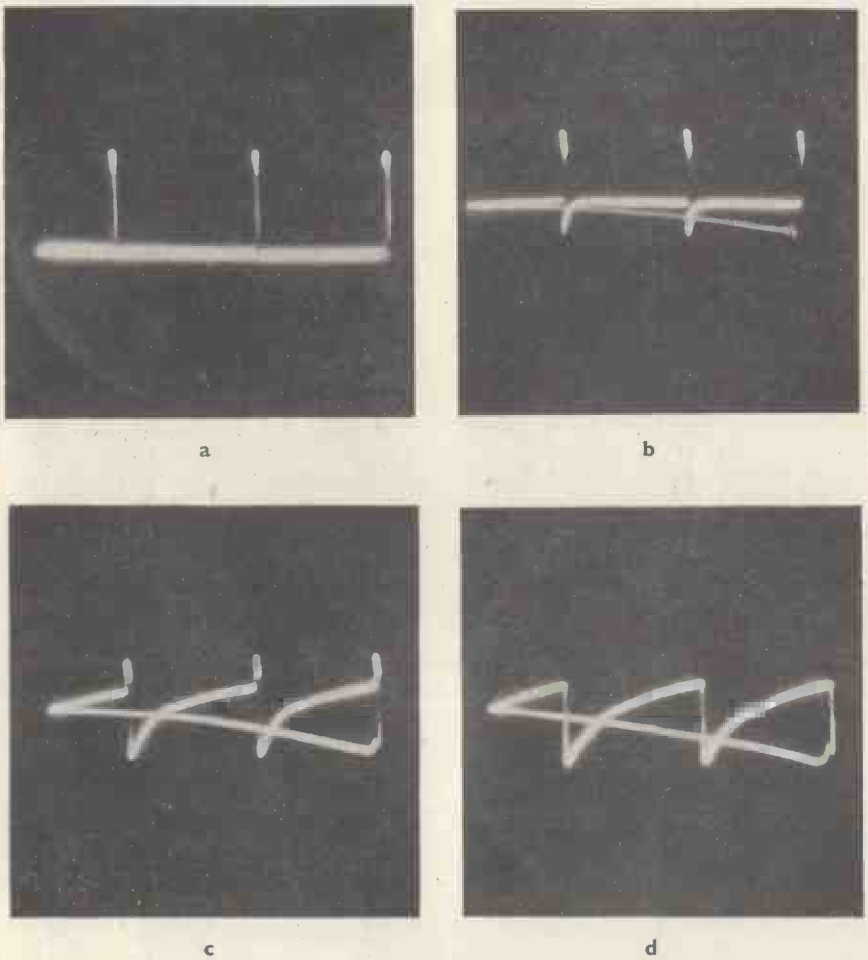

Fig. 5. Oscillograms of waveforms developed by the circuit of Fig. 3.

(a) Valve anode current, pulse frequency: 200 c/s.
(b) Voltage across discharge lamp „ 60 c/s.
(c) Valve grid voltage, pulse frequency: 300 c/s.
(d) Voltage across grid capacitor „ 200 c/s.

Operation and Performance

In the form just described the Photopulse can be used to illuminate an object either directly or as a silhouette. For silhouette working, which requires a light source with a large uniformly luminous area placed behind the object, a ground glass diffusing disk can be clipped over the reflector.

For speed measurement it is only necessary to illuminate some distinguishing feature (preferably a spot of white paint) on the rotating object, and, starting at a low frequency, advance the frequency control. The correct setting of the control is the highest that gives only one stationary spot.

The silhouette method is preferable for studying the behaviour of certain types of mechanism, such as electrical contacts making and breaking regularly at high speed. If the frequency control is adjusted so that the movement is almost, but not completely, arrested, then the contacts will appear to open and close with such deliberation that any irregularity can be detected immediately.

Synchronisation should be effected by turning the synchronising control right back, setting the pulse frequency to a value slightly lower than the control frequency, and then advancing the synchronising control again until synchronism is obtained. If the controls are handled in this way, the pulse generator will pull into step from 5 per cent. off frequency with a control voltage of about 3 volts peak across the synchronising terminals.

Four oscillograms of waveforms developed by the circuit of Fig. 3 are reproduced in Fig. 5. The pulse ratio varies between three and slightly less than one per cent., according to the frequency. Owing to the comparatively heavy damping and the small pulse ratio the transients in the actual grid voltage waveform are not so conspicuous as in the theoretical curve of Fig. 2, which was drawn for light damping and an exaggerated pulse ratio to illustrate the action of the circuit.

As an example of the versatility of this instrument it may be mentioned that, in addition to the applications already referred to, it has been used with success for investigating contact bounce in high speed relays and the formation of standing waves on loudspeaker cones.

Acknowledgment

In conclusion, the writer wishes to thank the management of the Plessey Co., Ltd., for permission to publish this article.

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[2] H. E. Kallmann, "Stroboscopic Light Source," *Proc.I.R.E.*, Vol. 27, No. 11, p. 690, November, 1939.

Profit and Loss

There is a fetish in some of the Departments about making profits. Surely the purpose of a policy like this is not to make a profit. The Ministry of Supply provides an illustration of how this fetish is growing. Valves were imported from America and cost 9d. each, but the Minister of Supply insisted on charging 11s. each. The manufacturer puts them into his sets and sells them back to the Government. The Minister of Supply put that down as profit. Their purpose should be to reduce the costs of production as low as possible in the interests of the radio industry after the war. There is another case in which the Government pays 6¾d. for a certain type of valve for which they receive 35s., and then pride themselves that they are making a profit. That is reducing business to sheer nonsense. The Government should endeavour to spread costs over industry as far as possible, but should not set out to make profits and then boast that they are paying their way and making profits.—*Mr. A. Edwards—House of Commons, January* 31, 1944 (*Hansard*).

Dust-Free Electronic Equipment

By C. G. VOKES, A.M.I.Mech.E.*

THE circumstances and conditions of our modern industrial urban civilisation loads the atmosphere with dirt and grime; this same civilisation demands better living and working conditions, and has resulted in air-conditioning ceasing to be a luxury and becoming a general demand. Filters for air purification are now commonplace not only in hospitals and similar institutions, but in large residential buildings, places of amusement and in some private residences; also in industrial buildings, sometimes for the welfare of the workers, but more often on account of the nature of the processes being carried out and the delicacy of the apparatus and machinery concerned.

The time has come when more attention must be given to the protection of electrical equipment from dirt. A notable example of air filtration where electrical apparatus is employed is in automatic telephone exchanges, it being essential that the delicate gear should not become dust laden. In the case of electric motors and generators, the consequences of working under bad air conditions are well known, but they can be overcome by fitting suitable filters. Fig. 1 shows a filter fitted to a machine having the air intake at the top of the endshield. A similar filter adapted for an intake at the side of the endshield appears in Fig. 2; this also shows the multi-vee formation of the fabric filter element. This type of construction gives in a compact space a very large area of filtering surface and consequently a low air velocity through the material. The largest dust particles are prevented from reaching the element by means of a louvred inlet panel. Using a dry filter of this kind, instead of the oil-wetted viscous type, there is no danger of oil being thrown into the windings and it is practically self-cleaning under the action of vibration.

It has been found imperative to provide air filters in the large assemblies of electronic apparatus used for war purposes, not only when operating under desert conditions, but also when working in more normal circumstances, and experience points to

(*Continued on p.* 416)

* Managing Director, Vokes, Ltd., Guildford.

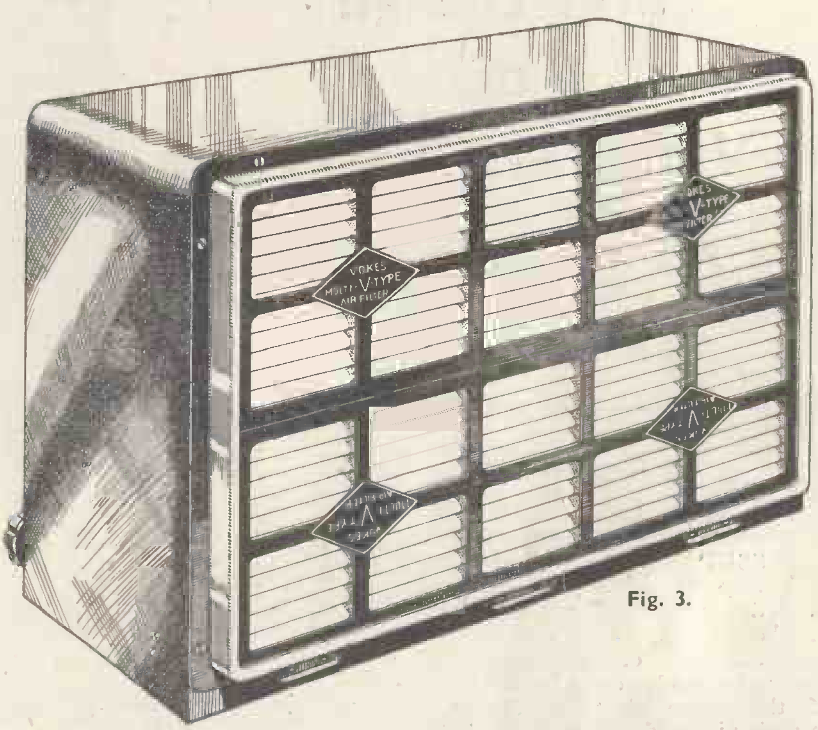

Fig. 3.

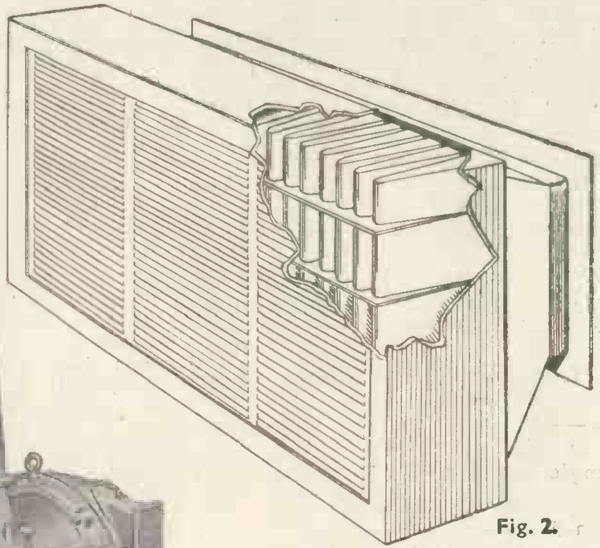

Fig. 2.

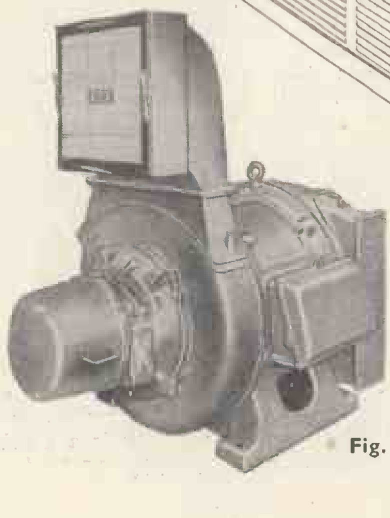

Fig. 1.

The Principles and Design of Valve Oscillators

Part II—Frequency Stability

By A. C. LYNCH, M.A.,*
and
J. R. TILLMAN, Ph.D.*

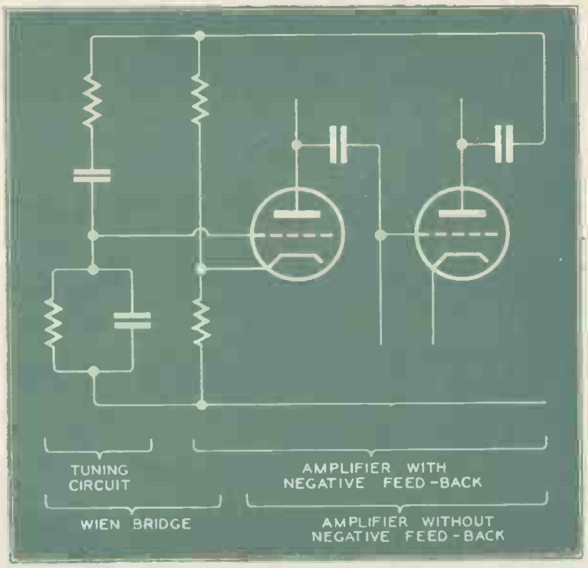

Fig. 4. Alternative interpretations of oscillator circuit.

5. Conditions for Good Stability of Frequency

ASSUME a tuning circuit of very good stability—a condition not often realised except in the case of a crystal. Then the stability of oscillator frequency depends on the constancy of the phase shift in the driving circuit, and on the association of large phase shift in the tuning circuit with small change of frequency. The latter property is characteristic of a circuit of high "Q" (Q being the ratio of the reactance of the inductor or capacitor to the total series resistance).

To find the nature of this relationship, consider a parallel resonant circuit composed of pure capacitance C and inductance L, the resistance R of the inductor being such that $Q = \frac{\omega L}{R}$ is constant.

Then the impedance of the circuit $= \frac{R + j\omega L}{1 - \omega^2 LC + j\omega CR}$ and the phase angle ϕ of this impedance is given by

$$\tan\phi = \frac{\omega L(1-\omega^2 LC) - \omega CR^2}{R(1-\omega^2 LC) + \omega^2 LCR}$$

$$= Q(1-\omega^2 LC) - \frac{\omega^2 LC}{Q} \quad \ldots\ldots\ldots \ (1)$$

Hence
$$\frac{d\phi}{d\omega} = \frac{\dfrac{d\tan\phi}{d\omega}}{\dfrac{d\tan\phi}{d\phi}} = \frac{2\omega LC\left(Q + \dfrac{1}{Q}\right)}{1 + \tan^2\phi}$$

If Q is large, this becomes

$$\frac{d\phi}{d\omega} \doteqdot -\frac{2\omega LCQ}{1 + Q^2(1-\omega^2 LC)^2}$$

Then, if $\omega^2 LC = 1$, so that $\tan\phi \doteqdot 0$,

$$\frac{d\phi}{d\omega} \doteqdot -2\omega LCQ = -\frac{2Q}{\omega}$$

or

$$\frac{d\phi}{df} \doteqdot -\frac{2Q}{f}$$

This relation leads to several important conclusions. It shows the desirability of using high-Q circuits for stable oscillators of the inductance-capacitance type, and it is one of the two reasons for the excellent stability of a crystal oscillator—the crystal has a very high equivalent Q, and also can be arranged to have a low temperature coefficient. For investigations into the relative merits of various driving circuits, tuning circuits of low Q should be used, so that frequency changes of the type now being discussed will outweigh those due to thermal and mechanical effects; and in any claim for the stability of a driving circuit the Q of the tuning circuit used should be stated.

In resistance-capacitance tuning circuits the value of $d\phi/df$ corresponds to a Q of the order of ½, and frequency stability is therefore difficult to obtain. There are certain oscillators in which the tuning circuit is a nearly-balanced Wien bridge,[5] or a twin-T network,[6] which has very similar properties. These circuits can be regarded as applying negative feed-back to the amplifier, as may readily be seen in the case of the Wien bridge (*see* Fig. 4). This feed-back reduces the driving-circuit phase shift to a small fraction of what it would otherwise be. The magnitude of the negative feed-back is increased as the balanced condition is approached, assuming the amplifier gain to be simultaneously increased so as to maintain the oscillation. Such oscillators can be made very stable; their disadvantage is the need for a driving circuit of very high gain to overcome the large attenuation in the tuning circuit.

The phase-shift in the driving circuit should preferably be small, as $\frac{d\phi}{df}$ is at a maximum when $\phi = 0$. If, for example, $\phi = \pi/4$, that is, $\tan\phi = 1$, and Q is large, then from equation (1)

$$Q(1-\omega^2 LC) \doteqdot 1$$

and hence $\frac{d\phi}{df} = -\frac{Q}{f}$; which is only half its optimum value. This apparently trivial warning is ignored in one otherwise excellent circuit,[7] in which ϕ tends towards $\pi/2$.

When the condition $\phi = 0$ is satisfied, the oscillation frequency is the same as the natural frequency of the tuning circuit. It is sometimes stated—wrongly—that the frequency is then

* Post Office Research Station.

independent of the properties of the driving circuit, and therefore stable.[8] It is true, however, that this condition gives the minimum frequency change for a given alteration of phase shift in the driving circuit. It is also true that this condition makes the frequency nearly independent of the resistance of an LC tuning circuit, which changes rapidly with temperature; this useful property appears to have been overlooked hitherto.

Alteration of the phase-shift in the driving circuit can arise in at least three ways: mechanical instability, causing changes in stray capacitance; change in valve capacitances; and changes in the magnitudes of harmonics produced by overloading. The last is usually the most important, and is discussed in the next section of this article.

Mechanical instability can cause frequency changes even when there is no apparent vibration, and a very rigid construction is desirable. (In a certain oscillator assembled on a steel panel with stiff wiring, changes of the order of 20 parts per million were stopped by tying certain of the wires, even including valve cathode leads, to insulating supports.)

The change of input capacitance of a valve not only produces harmonic as a result of change of capacitance within each cycle, as discussed above; it also causes a change of frequency if supply voltages vary, since the mean tuning capacitance then alters. As before, the grid-to-cathode capacitance is the least stable. Frequency changes arising directly from this cause can be prevented by stabilisation of power supplies.

6. Effect on Stability of Harmonic Production

The overloading of a valve in the driving circuit produces harmonics which are fed into the tuning circuit. The harmonics are transmitted with a phase shift different from that of the fundamental—the difference is usually nearly $\pi/2$—and are also attenuated. Harmonic components, therefore, return to the overloaded valve, and there intermodulate with the fundamental.

To find the nature of this effect, consider the simple case of a non-linear element whose characteristic is given by $V = aV_0 + bV_0^2$ where V_0 and V are the input and output voltages respectively. Let a potential E sin ωt be applied to this element. Then the resulting output

$$= aE \sin \omega t + bE^2 \sin^2 \omega t$$

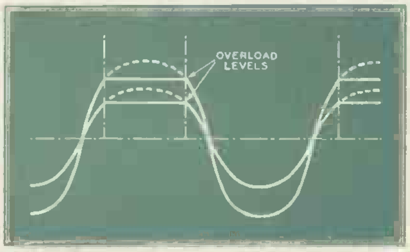

Fig. 5. Output waves of overloaded feed-back amplifier at two overload levels.

$$= E \left\{ a \sin \omega t + \frac{bE}{2}(1 - \cos 2\omega t) \right\} \quad .. (2)$$

Since harmonics are subjected to a phase shift of nearly $\pi/2$, and the direct-current component is blocked at some stage, the wave returning to the non-linear element is approximately of the form

$$E \left\{ c \sin \omega t - d \cos (2\omega t + \pi/2) \right\}$$

$$i.e., \quad E \left\{ c \sin \omega t + d \sin 2\omega t \right\}$$

where d/c depends on the relative attenuations of the frequencies in the tuning circuit and also on the non-linearity b/a. This gives rise to an output

$$aE(c \sin \omega t + d \sin 2\omega t)$$
$$+ bE^2(c^2 \sin^2 \omega t + 2cd \sin \omega t \sin 2\omega t + d^2 \sin^2 2\omega t) \quad \ldots\ldots (3)$$

of which one term can be reduced to

$$bE^2.cd(\cos \omega t - \cos 3\omega t)$$

That is, it contains a term of fundamental frequency but of phase $\pi/2$ different from that of the original input wave.[9]

The complete effect of the repeated circulation of the signal round the network is the sum of a rapidly converging series, and the expressions (2) and (3) are the sums of one and two terms respectively. Further terms are of no interest—they do not affect the fact that an out-of-phase signal of fundamental frequency is present.

The amplitude of this out-of-phase signal depends on the extent of the overloading of the valve. When this signal is combined with the original wave, the phase shift of the resultant wave depends on the overloading; and, since this shift must be compensated in the tuning circuit, the oscillation frequency also depends on the extent of the overloading.

The presence of harmonics is thus not in itself a cause of frequency instability, which arises only when the magnitude of the out-of-phase modulation product changes; that is, only if the level or the phase of the harmonics changes relative to the fundamental, and not always then. There are at least three directions in which increased stability can be sought: the reduction of the harmonic to a small value, its stabilisation at some definite value, and the shifting of its phase, relative to the fundamental, to a value of either zero or π. The two latter possibilities, although both easy to realise in practice, have been ignored in previous accounts of oscillator theory; and published calculations[10] of the relation between stability and harmonic content, although generally accepted, do not apply to oscillators in which these latter devices are used. The false step in these calculations appears to be the assumption that the valve characteristic remains the same when, for some unspecified reason, the oscillation amplitude varies.

Four examples of stabilised systems follow.

A group of tuned circuits may be used to reject harmonics.[11] This method, however, is cumbersome and scarcely applicable to variable-frequency oscillators.

The gain of the driving circuit may be so controlled that the amplitude of the oscillation remains small and constant, and no valve generates appreciable harmonics. There are two convenient methods available. One[12] is the same as a conventional A.V.C. circuit: a signal derived from the amplifier is rectified, smoothed, and used to control the gain of a valve in the amplifier circuit. The other method uses a bridge or potentiometer circuit[13] in which the resistance of one arm depends on the current flowing in it. The circuit can be so adjusted that the out-of-balance signal is of very constant amplitude. Both circuits act as limiters without manufacturing appreciable harmonics, and the harmonic content will in any case be fairly constant. Some care is necessary in oscillators of wide frequency-range to prevent "hunting" at a low frequency determined by the time-constant of the A.V.C. circuit or thermal element.

A driving circuit whose gain is stabilised by negative feed-back has the property that the relative intensities of the harmonics remain constant when the supply voltage changes. This is because, in any oscillator, the extent of limiting action required is determined solely by the amplifier gain and the tuning circuit loss. If the gain is stabilised, so also is the loss required in the limiter. The waveform produced by the limiter under conditions of large feed-back is a sine-wave whose peaks, at one or both limits of the amplitude, are replaced by straight lines at certain limiting values (Fig. 5). When the limiting action is at one peak only, there is a unique relation between the harmonic content and the limiter loss (*i.e.*, the ratio of fundamental output to fundamental input). When the supply voltage changes, the amplitude becomes that corresponding to the new cut-off point, but the shape of the wave remains the same. This is not true of amplifiers in which the gain depends on the supply voltage, since a change in gain requires a change in the output-to-input ratio of the limiter—that is, in the shape of the output wave.

The use of a second tuned circuit[14] subjects harmonics to an additional phase shift of nearly $\pi/2$. They therefore return to the overloaded valve with a total phase shift of nearly π, and any fundamental component generated by intermodulation is in opposite phase to the original wave and thus harmless. The second circuit is preferably of low Q, and, if so, need not be accurately matched to the main one.

Of these four systems, stabilisation of the level of harmonic is much the simplest. An example of its use is in a carrier frequency oscillator designed at the Post Office Research Station, which is based on a two-stage pentode amplifier whose gain is 52 db without negative feed-back and 30 db with it. The output is coupled through a suitable resistance to the tuning circuit; five combinations of dust-cored coil (of Q about 50) and coupling resistor are used for the frequency range 9 kc/s to 1.1 Mc/s. By means of two potentiometers, each essentially capacitive, the tuning circuit is connected to the input of the amplifier, and a fraction of the signal at this point (where it contains about 0.3 per cent. harmonic), by way of another valve, to the output stages. The stability of frequency is about 1 per million per 1 per cent. change of supply voltage for the lowest octave and about 5 per million per 1 per cent. change at higher frequencies, so that stabilisation of power supplies is unnecessary. Experiments with a similar driving circuit and a tuning circuit having Q = 150 have shown that at 200 kc/s a frequency stability of 10 parts per million, from all causes, can be maintained over several hours.

In such an oscillator, the frequency changes caused by the driving circuit are unimportant compared with those due to thermal and mechanical effects in the tuning circuits. When advances in the design of tuning circuits justify it, it will be necessary to consider the relative practical merits of this system and of bridge-stabilisation (the second system described). Until then, bridge-stabilisation, although now coming into considerable use, is probably a needless complication except for oscillators of the highest precision—a class limited at present to crystal and tuning-fork oscillators.

(*To be continued.*)

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Dust-Free Electronic Equipment (*continued from p.* 413).

the desirability of providing such protection for even small units of this nature. Electronic test gear employed in industry, such as loss-factor, capacity bridges and voltage testing instruments used in the manufacture of radio condensers, and a multitude of other industrial instruments would all benefit by the adoption of air filtration.

The back panel of an ordinary domestic radio receiver is frequently only a pressed card containing ventilating slots and other apertures; when this is removed for the purpose of making some adjustment or replacement it is found that dust, fluff and cobwebs are very much in evidence. Apart from hampering servicing this is a sharp reminder of the possibilities of indifferent working due to surface leakage, bridged condenser plates, and so on. The panel can be conveniently, and certainly beneficially, replaced by a filter. A typical 3-valve all mains receiving set is shown equipped in this manner in Fig. 3. In this example the filter is held in place by a dished, rectangular rim, screwed to the cabinet. The fabric filtering element is of the multi-vee pattern having the advantages already mentioned, the material

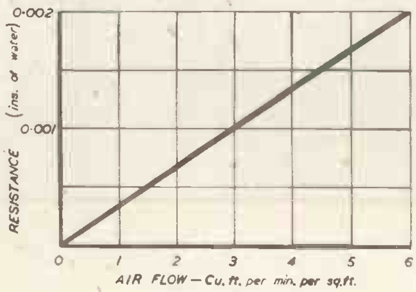


Fig. 4.

being pressed cotton fibre between two layers of gauze-like material.

Tests on receiving sets so equipped have shown that restriction of the convection currents responsible for cooling is not, as sometimes believed, excessive, and no adverse effects due to temperature increases have been detected in the course of many hours running. Temperatures at various points within the cabinet have been recorded both when employing the standard back panel and with a filter fitted. They were found to be only a few degrees higher with the filter in use, and the temperature of the "hot spot" on the top of the cabinet was increased by little more than 2° C. Temperature increases of this order are unlikely to prove a disadvantage with normal radio equipment. This is a small price to pay for achieving dust-free conditions within the apparatus.

Manufacturers of electronic equipment are experimenting with air filters and are also studying the effect of deliberately introducing quantities of dust into their apparatus. The extra cost of production involved by fitting a filter will be relatively small in the case of all but the very cheapest of equipment, and it is probable that customers, once having realised the advantages, will expect this refinement.

The electronic engineer will readily think of instances where air filters can be added to advantage; as a guide to those who may wish to make their own convection cooling flow calculations the curve of Fig. 4 is given. This shows the pressure drop through the filter material for given air flows in the case of the filtering material already referred to for use with radio receivers. With such material a filtering efficiency of 98 per cent. of all air-borne foreign matter can be obtained for particles down to a few microns in diameter.

Aerial-Coupling Circuits

A Series of Data Sheets

Part II.—Series-Capacitance Aerial Coupling

By S. W. AMOS, B.Sc.(Hons.), Grad.I.E.E.

THE circuit for series-capacitance aerial coupling is given in Fig. 1(a) and the electrical equivalent of it is given in Fig. 1(b), in which the aerial-earth system has been replaced by an equivalent generator as explained in Part I. The derivations of expressions for the reflected capacitance, voltage gain and selectivity factor for this particular circuit are given in the appendices at the end of this article, and readers who are interested in the mathematics of this subject are referred to them. The final results, which describe completely the performance of this circuit, are given below. The expression for reflected capacitance is given first since it is necessary to know this before the voltage gain can be calculated.

(1) Reflected capacitance =

$$\Delta C_2 = \frac{cC_1}{c+C_1},$$

(2) Voltage gain $= \dfrac{V_2}{V_1}$

$$= \frac{\dfrac{L_2}{C_2}}{R_2\left(j\omega L_2 + \dfrac{1}{j\omega C'}\right) + (r+R_2)\left(j\omega L_2 + \dfrac{1}{j\omega C_2}\right)},$$

(in which $C' = \dfrac{cC_1}{c+C_1}$

and $C_2 = \dfrac{1}{\omega^2 L_2} - \Delta C_2$)

(3) Selectivity factor

$$= \frac{R_2}{R_2 + \omega^4 L_2^2 C'^2 (r+R_2)}$$

Reflected Capacitance ΔC_2

The mistuning effect of this particular type of aerial-coupling circuit is such as to add in parallel with C_2 a capacitance ΔC_2, equal in value to the aerial capacitance c and the series capacitance C_1 in series. This correction, ΔC_2, therefore, has a maximum value of c (200 pF) realised when C_1 approaches infinity, but for very small values of C_1 the correction ΔC_2 is approximately equal to the value of C_1. These points are illustrated in Fig. 2, which indicates the value of ΔC_2 for any value of C_1. This curve was prepared from Expression 6 of Appendix I, c being put equal to 200 pF. It will be noted that the value of ΔC_2 is independent of frequency. This is in general not true for other types of aerial coupling and makes ganging of tuned circuits particularly simple in this case. Unfortunately, unless C_1 is very small, when $\Delta C_2 \approx C_1$, the calibration of the tuning condenser will depend very largely on the value of the aerial capacitance and so will be different for every different aerial used. One effect of the reflected capacitance is to restrict the frequency range of the secondary tuned circuit. The extent of this restriction will be apparent from Fig. 4.

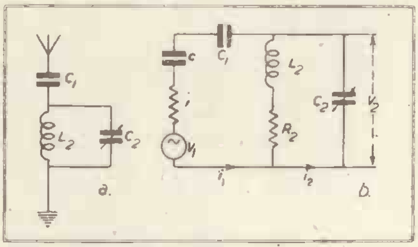


Fig. 1. (a) Series-capacitance aerial coupling and (b) its equivalent circuit.

Voltage Gain

The expression given above for V_2/V_1 gives the voltage gain of the aerial-coupling circuit in terms of the circuit constants and this expression is plotted in Fig. 3, which shows how the voltage gain of this aerial-coupling circuit varies with frequency for various values of series capacitance C_1. To illustrate the method of calculation a typical result will be evaluated.

Example

Consider the frequency for which $\omega = 6 \times 10^6$ rads/sec. and suppose $C_1 = 50$ pF. Then $C' = \dfrac{cC_1}{c+C_1} = 40$ pF.

With no aerial coupling C_2 would be given by

$$\frac{1}{\omega^2 L_2} = \frac{1}{36 \times 10^{12} \times 157 \times 10^{-6}} = 177 \text{ pF}.$$

But as the aerial-coupling circuit contributes 40 pF towards this, the actual value of C_2 will be only 137 pF. The reactances of L_2, C' and C_2 at this frequency are as follows :—

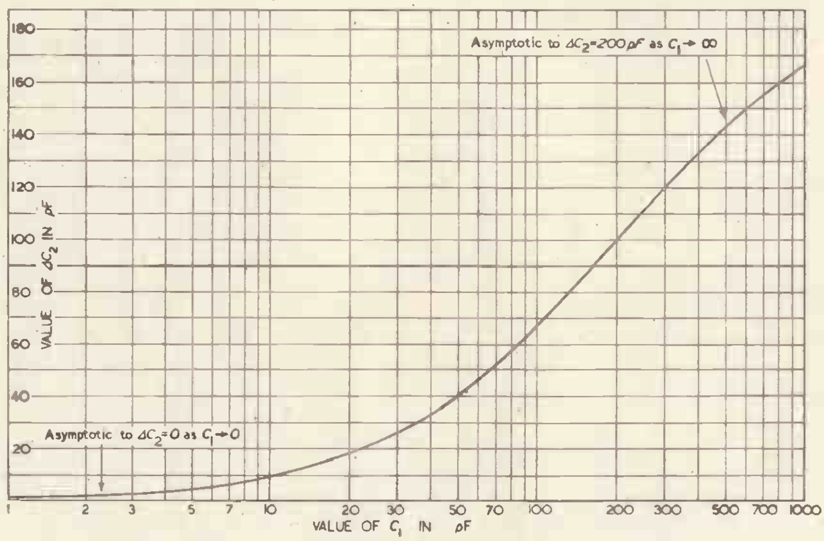


Fig. 2. Variation of reflected capacitance with series capacitance.

The Voltage Gain of the Aerial-Coupling Circuit

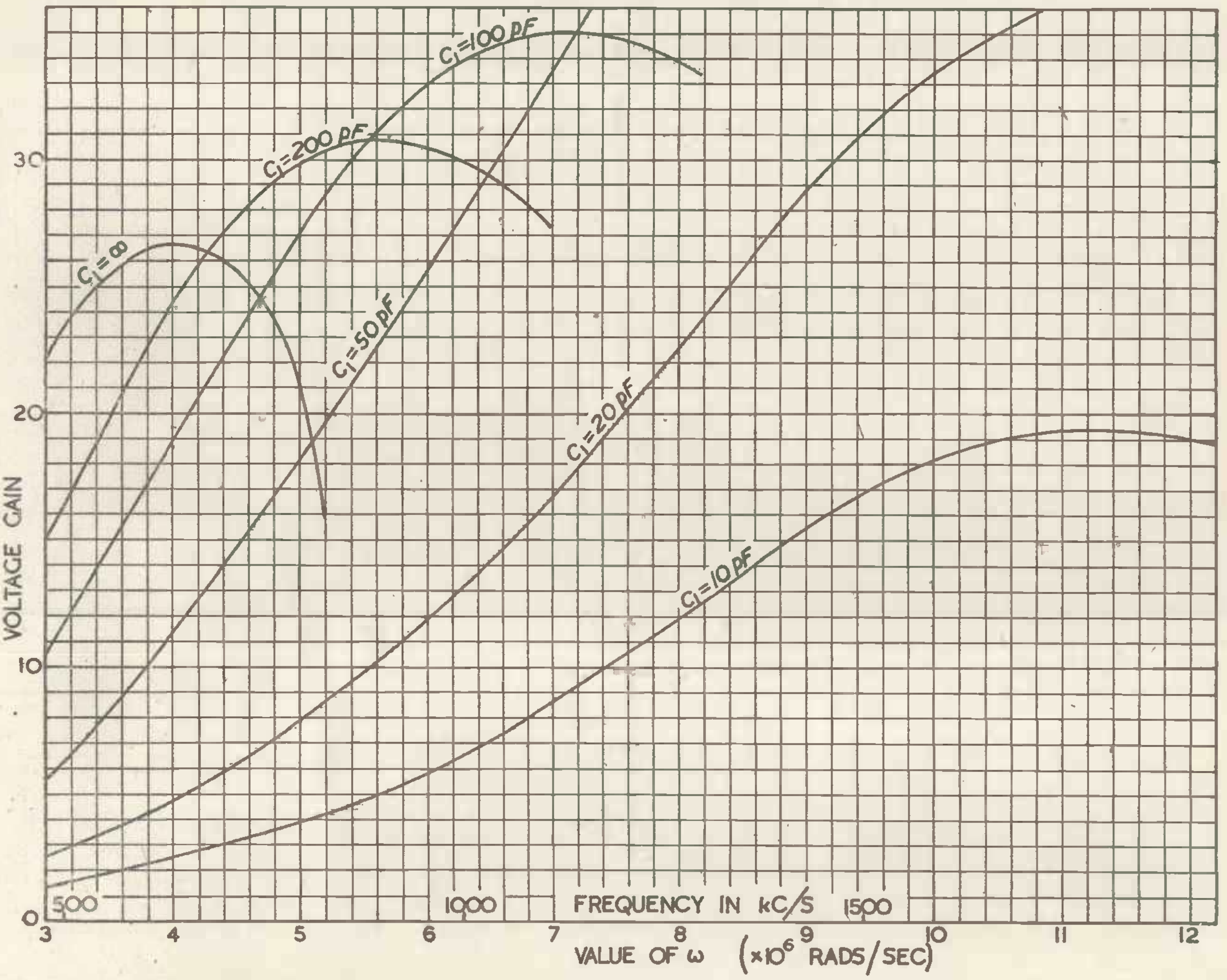


Fig. 3.

$$\omega L_2 = 6\times10^6\times157\times10^{-6} = 942 \text{ ohms}$$

$$\frac{1}{\omega C'} = \frac{1}{6\times10^6\times40\times10^{-12}} = 4{,}167 \text{ ohms}$$

$$\frac{1}{\omega C_2} = \frac{1}{6\times10^6\times137\times10^{-12}} = 1{,}217 \text{ ohms}$$

From Table 1, given on p. 419, R_2 is 9.42 ohms at $\omega=6\times10^6$ rads/sec.

$$\therefore \frac{V_2}{V_1} = \frac{\dfrac{157\times10^{-6}}{137\times10^{-12}}}{9.42(942-4{,}167)+49.42(942-1{,}217)}$$

$$= \frac{157\times10^6}{137\times44{,}000} = 26.04$$

In a similar way the value of V_2/V_1 can be calculated at other frequencies and for other values of C_1. The results are plotted in Fig. 3. From a knowledge of these values of V_2/V_1 it is a comparatively simple matter to calculate the corresponding values of the voltage gain factor. The voltage gain factor was defined in Part I as being equal to $2V_2/QV_1$. Since Q has been assumed equal to 100 at all frequencies, then if the voltage gain factor is expressed as a percentage it is clearly equal to $2V_2/V_1$, *i.e.*, twice the numerical value of the voltage gain. The variation of voltage gain factor with frequency for various values of C_1 is given by the dotted curves in Fig. 4. In Fig. 4 the projection of each curve on the horizontal axis measures the frequency range given by the value of C_1 for the curve in question. In calculating the high frequency extremes of each waveband the capacitance in the tuned circuit was assumed to be 30 pF. This is intended to include the minimum capacitance of the tuning condenser and all strays.

Selectivity Factor

Example

As a numerical example, consider the frequency for which $\omega=7\times10^6$ rads/sec. and let $C_1=50$ pF. C' is then $\frac{200\times50}{200+50}=40$ pF and R_2 from Table 1 is 10.99 ohms. Hence the selectivity factor is given by :—

$$\frac{10.99}{10.99+7^4\times10^{24}\times157^2\times10^{-12}\times40^2\times10^{-24}\times50.0}$$

$$=\frac{10.99}{10.99+4.83}$$

$$=.695 \text{ or } 69.5 \text{ per cent.}$$

Selectivity and Voltage Gain Factors

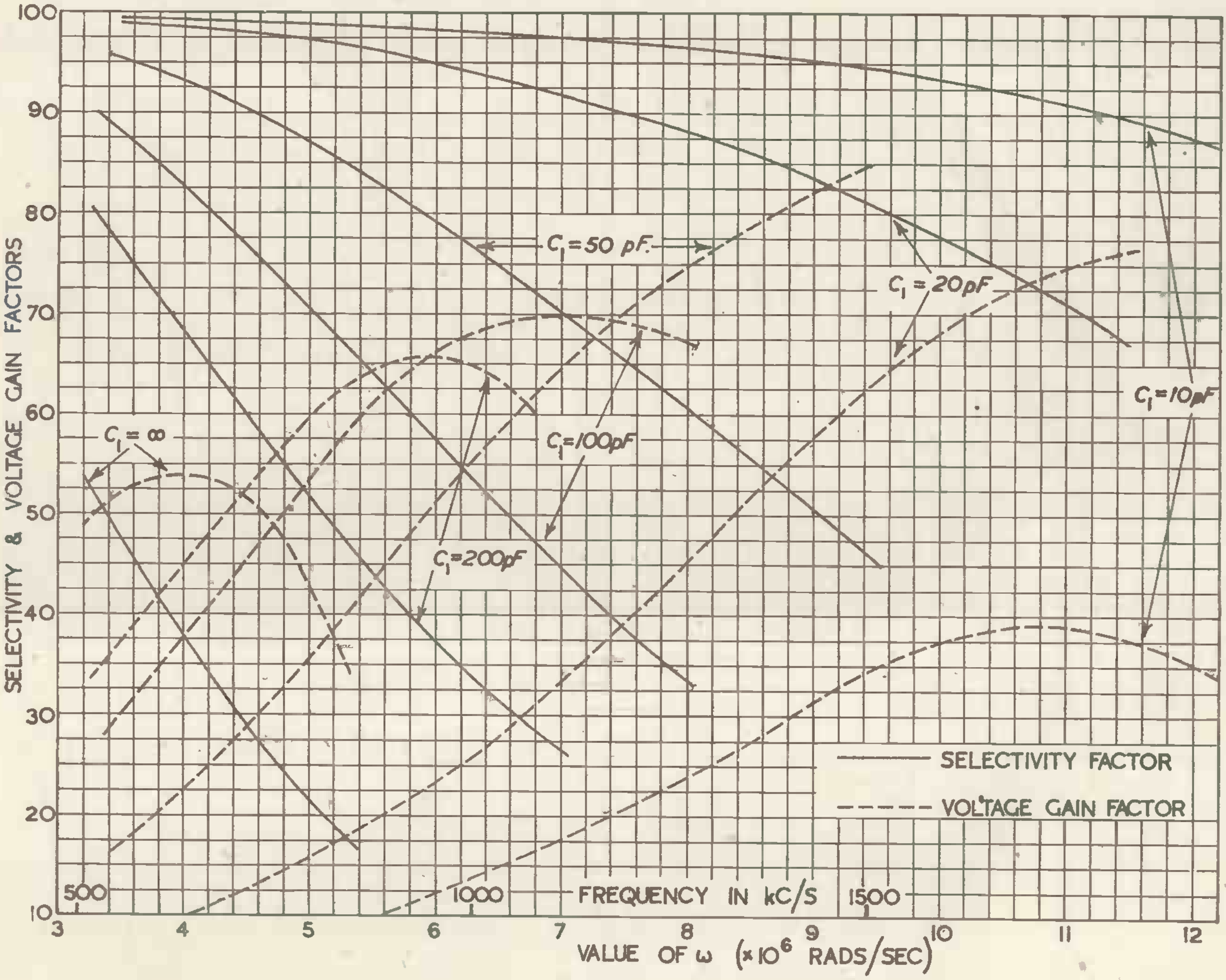


Fig. 4.

In a similar way the selectivity factor may be calculated for other frequencies and other values of C_1. The results are exhibited in graphical form by the solid curves of Fig. 4. As before, the horizontal projection of each curve measures the waverange secured with that particular value of C_1. We now have a complete knowledge of this aerial-coupling circuit.

Interpretation of Results

From Fig. 4, it is possible to assess the performance of this circuit for any frequency and any value of C_1. It is at once clear that if complete coverage of the medium waveband is wanted, then we are immediately restricted to values of C_1 of less than 50 pF. The performance for this value of C_1 is fair; selectivity factor is at all frequencies greater than 47 per cent. and the voltage gain factor varies from 15 per cent. at 550 kc/s. to 85 per cent. at 1,500 kc/s. Smaller values of C_1 give better selectivity but this is necessarily secured at the expense of voltage gain.

In these days of high-slope valves it is comparatively easy to obtain high-voltage gain and so high selectivity may possibly be deemed more important than gain in an aerial-coupling circuit. Hence values of C_1 smaller than 50 pF are to be recommended, particularly as such small values tend to make the performance of the aerial-coupling circuit independable of the constants of the aerial-earth system.

If we are only interested in the performance of the circuit at one particular frequency, as when the circuit is used in a pretuned receiver or a transmitter, then it is possible to determine a value of C_1 which will give the best compromise between the two conflicting interests of gain and selectivity. At 1,700 kc/s., for example, by making C_1 equal to 20 pF we can get a selectivity factor and a voltage gain factor of 73 per cent.; at 1,200 kc/s., putting C_1 equal to 50 pF gives 67.5 per cent. of the maximum possible gain and selectivity, both very good performances. At any frequency there is one value of C_1 which will give optimum results and this occurs where the selectivity and gain curves of Fig. 4 cross.

Table 1

Value of $\omega \times 10^6$ (rads. per sec)	3	4	5	6	7	8	9	10	11	12
Value of f (kc/s.)	471	628	785	942	1099	1256	1413	1570	1727	1884
Value of R_2 (ohms) for Q = 100.	4·71	6·28	7·85	9·42	10·99	12·56	14·13	15·7	17·27	18·84

Appendix I

The Derivation of an Expression for the Reflected Capacitance $\triangle C_2$

Applying Kirchhoff's laws to Fig. 1(b)

$$V_1 = i_1 Z_p - i_2(j\omega L_2 + R_2) \quad \ldots\ldots\ldots\ldots \quad (1)$$

where $Z_p = R_p + jX_p$

$$= (r + R_2) + j\omega L_2 + \frac{1}{j\omega c} + \frac{1}{j\omega C_1}$$

and $O = i_2 Z_s - i_1(j\omega L_2 + R_2)$, ………… (2)

where $Z_s = R_s + jX_s = R_2 + j\omega L_2 + \dfrac{1}{j\omega C_2}$.

From (2) $i_1 = \dfrac{Z_s}{j\omega L_2 + R_2} i_2$.

Substituting for i_1 in (1)

$$V_1 = \frac{i_2 Z_p Z_s}{j\omega L_2 + R_2} - i_2(j\omega L_2 + R_2).$$

Now $V_2 = \dfrac{i_2}{j\omega C_2}$.

$$\text{Hence } \frac{V_2}{V_1} = \frac{\dfrac{1}{j\omega C_2}}{\dfrac{Z_p Z_s}{j\omega L_2 + R_2} - (j\omega L_2 + R_2)}$$

Neglecting R_2 in comparison with $j\omega L_2$, this gives

$$\frac{V_2}{V_1} = \frac{\dfrac{L_2}{C_2}}{Z_p Z_s + L_2^2\omega^2} = \frac{\dfrac{L_2}{C_2 Z_p}}{Z_s + \dfrac{L_2^2\omega^2}{Z_p}} = \frac{L_2}{C_2 Z_p Z} \quad \ldots\ldots \quad (3)$$

in which Z represents the impedance of the secondary circuit in the presence of the primary.

Rationalising

$$Z = Z_s + \frac{L_2^2\omega^2}{Z_p} = R_s + jX_s + \frac{L_2^2\omega^2}{R_p + jX_p}$$

$$= R_s + jX_s + \frac{L_2^2\omega^2(R_p - jX_p)}{R_p^2 + X_p^2}.$$

Neglecting resistive components in comparison with reactive ones, we have the approximate result:

$$Z = R_s + \frac{L_2^2\omega^2 R_p}{X_p^2} + jX_s - j\frac{L_2^2\omega^2 X_p}{X_p^2}.$$

At resonance the reactive terms here vanish, giving $jX_s - j\dfrac{L_2^2\omega^2}{X_p} = 0$,

i.e., $L_2^2\omega^2 = X_p X_s$ ………………………… (4)

and leaving $Z = R_s + \dfrac{L_2^2\omega^2 R_p}{X_p^2}$ …… (5)

Substituting for X_p and X_s in (4)

$$\left(\omega L_2 - \frac{1}{\omega c} - \frac{1}{\omega C_1}\right)\left(\omega L_2 - \frac{1}{\omega C_2}\right) = L_2^2\omega^2.$$

Putting $\dfrac{1}{c} + \dfrac{1}{C_1} = \dfrac{1}{C'}$, *i.e.*, $C' = \dfrac{cC_1}{c + C_1}$, and multiplying out, gives

$$-\frac{L_2}{C'} - \frac{L_2}{C_2} + \frac{1}{\omega^2 C' C_2} = 0,$$

from which

$$C_2 = \frac{1 - \omega^2 C' L_2}{\omega^2 L_2} = \frac{1}{\omega^2 L_2} - C'$$

But $\triangle C_2$ is defined as $\dfrac{1}{\omega^2 L_2} - C_2$ and is hence clearly equal to C'.

$$\therefore \triangle C_2 = C' = \frac{cC_1}{c + C_1} \quad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

Appendix III

The Selectivity Factor

Expression (5) has already shown that the resistance of the secondary circuit in the presence of the primary is greater than the normal amount R_2 by the amount $\dfrac{L_2^2\omega^2 R_p}{X_p^2}$. Substituting for R_p and X_p gives this increase of resistance as

$$\frac{L_2^2\omega^2(r + R_2)}{\left(L_2\omega - \dfrac{1}{\omega C'}\right)^2} \approx \omega^4 C'^2 L_2^2 (r + R_2)$$

provided that C_1 is small, so that $\dfrac{1}{\omega C'} \gg L_2\omega$. The selectivity factor is hence given, from the expression given in Part I, by

$$\frac{R_2}{R_2 + \omega^4 C'^2 L_2^2 (r + R_2)} \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

From this expression we can see that selectivity will decrease with increase of frequency, coupling capacitance, tuning inductance or aerial resistance. Increase of R_2, however, improves the selectivity factor, though a larger value of R_2 necessarily implies that the Q of L_2 is low even in the absence of aerial damping.

Appendix II

The Voltage Gain

Substituting in (3) the value of Z given in (5)

$$\frac{V_2}{V_1} = \frac{L_2}{C_2 Z_p\left(R_s + \dfrac{L_2^2\omega^2 R_p}{X_p^2}\right)} \approx \frac{L_2}{C_2\left(Z_p R_s + \dfrac{L_2^2\omega^2 R_p}{X_p}\right)}$$

But, from (4), $\dfrac{L_2^2\omega^2}{X_p} = X_s$. $\quad \therefore \dfrac{V_2}{V_1} = \dfrac{L_2}{C_2(Z_p R_s + R_p X_s)}$

Substituting for Z_p, R_s, R_p and X_s gives the result

$$\frac{V_2}{V_1} = \frac{\dfrac{L_2}{C_2}}{R_2\left(r + R_2 + \dfrac{1}{j\omega c} + \dfrac{1}{j\omega C_1} + j\omega L_2\right) + (r + R_2)\left(j\omega L_2 + \dfrac{1}{j\omega C_2}\right)}$$

$$\approx \frac{\dfrac{L_2}{C_2}}{R_2\left(j\omega L_2 + \dfrac{1}{j\omega C'}\right) + (r + R_2)\left(j\omega L_2 + \dfrac{1}{j\omega C_2}\right)} \quad \ldots\ldots\ldots \quad (7)$$

High Vacuum Gauges

By M. PIRANI, Dr.Phil., F.Inst.P., F.S.G.T., and R. NEUMANN, Dipl.Ing.

Part IV (conclusion)

A SPECIAL feature of the Philips gauge is that it is fitted not only with an ammeter but also with a "tuning indicator lamp," *i.e.*, a glow lamp with a short anode and a long cathode (Fig. 30). By the variations in the extension of a luminous layer extending along the cathode a qualitative indication of the pressure is obtained. The pressure range of the gauge extends from 10^{-5} to 5×10^{-3} mm. Hg.

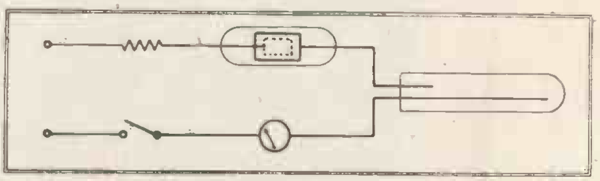


Fig. 30. Philips gauge with tuning indicator.

Fig. 31 shows the complete gauge as furnished by W. Edwards & Co., Ltd. Fig. 32 gives a calibration curve.

(e) Disordered or Partially Ordered Molecular Movements of the Gas

Of the disordered movements of the gas molecules use is made in the quartz fibre manometers described above. Also the Knudsen gauge may be considered to belong to this kind of instrument as it is based on the action of heat which in itself is characterised by disordered molecular movement.

As early as 1873 W. Crookes[79] had observed that "when a heavy metallic mass is brought near a delicately suspended light ball in a vacuum . . . if the mass is hotter than the ball it repels the ball." Thus he had found the radiometer principle and what was called later "Crookes' light mill." Here a little disk on a rotatable arm in an evacuated bulb and whose frontside is blackened turns if the latter is irradiated in the direction of the light beam. The irradiated black surface becomes warmer than the blank back not irradiated, therefore the gas molecules impinging onto the frontside are "heated," *i.e.*, they rebound with a higher velocity than that which they have in arriving. The recoil of these gas molecules explains this motion qualitatively.[80]

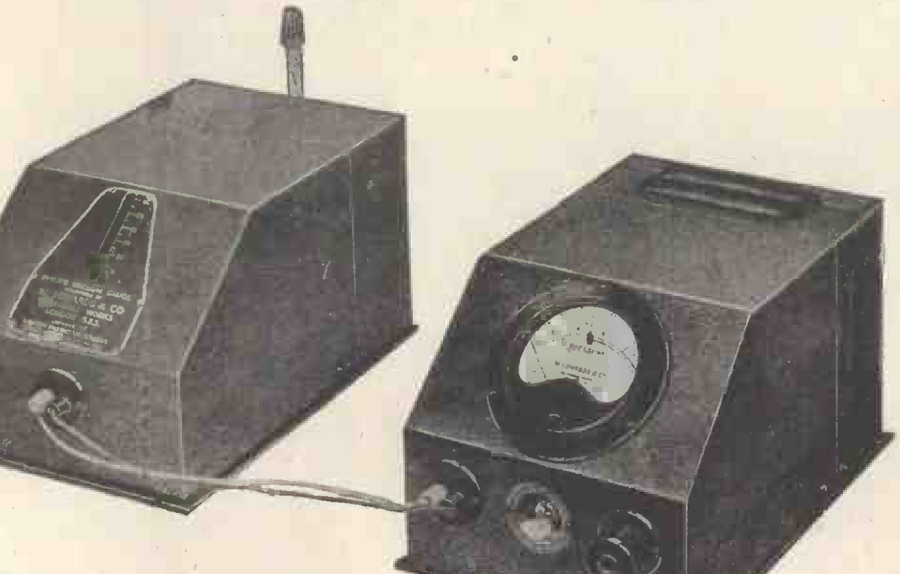


Fig. 31. Philips gauge (W. Edwards & Co.).

As a predecessor of the Knudsen gauge the "transpiration gauge" of Sutherland[81] should be mentioned. A piston inside a cylinder is driven by radiometer forces in the direction of higher to lower temperature. It is balanced by a counterpoise situated in a side chamber of the cylinder and its movement is counteracted by a quartz torsion fibre.

Dewar[82] described experiments made with a radiometer for the detection of the gaseous products produced by radioactive bodies. He used an ordinary radiometer with rotating vanes, but mentions the necessity of employing the torsion balance or bifilar suspension for quantitative measurements.

Knudsen was led to his design of a radiometer gauge by his theoretical investigations[83] on conditions of equilibrium in gases, on thermic molecular flow and on thermic molecular pressure of gases in tubes and porous bodies. His first apparatus[84] consisted of a vertical platinum strip set parallel to a platinum plate suspended by a short wire. The strip was electrically heated and its temperature determined by resistance measurement. The deflection of the suspended plate was read by means of mirror and telescope. He found the pressure of the surrounding gas to be

$$p=2K/(\sqrt{T_1/T_2}-1)$$

where K is the force exerted by each square cm. of plate and T_1 and T_2 the absolute temperatures of the two plates. By comparison with a McLeod gauge (pressure p') it was found that p'/p is unity at very low pressures, increases only slowly as long as the mean free path is large but rapidly when the pressure was increased and the mean free path therefore decreased. Then the relations between repulsive force, temperature and pressure become rather complicated.[85]

Generally speaking, the methods for the calibration of sensitive manometers[86] are either based on the expansion of gas, the pressure of which was measured with an ordinary barometer through a number of bulbs of known volume, or on the use of the relations found by Knudsen for the flow of gas at low pressures. The simple law found for the relation between pressure and repulsive force at high vacuum makes the Knudsen gauge applicable as an "absolute manometer" which usually does not require calibration with another gauge. This is a distinct difference from gauges based on conductivity or viscosity. These latter depend in their action on the so-called "accommodation coefficient" which is a measure of the extent to which the gas leaving the surface accommodates itself to the temperature of the surface.[87] This coefficient may be calculated, but only if the temperature of the gas corresponding to the average kinetic energy of the gas molecules leaving the surface is known.

As this is not commonly the case the hot wire and viscosity gauges require calibration, usually with a McLeod. Also with the Knudsen gauge comparison with a McLeod gauge is frequently used although it is not really necessary. For low temperature difference between the frame and the heating plates (say 50° C.) calculation may be used. If the temperature difference is larger the accommodation coefficient cannot be neglected any more and for this case calibration with a McLeod gauge is desirable.

The Knudsen gauge is superior to any other gauge for large systems with organic vapours where the filaments of a hot wire gauge are contaminated and alter their emissivity. This holds especially true for pressures between 10^{-5} and 10^{-6} mm. Hg.[84]

Knudsen himself describes some other types of his gauge.[89] In one type a mica sheet is suspended on a quartz fibre. On each side of the sheet a glass plate shields one half of it. The walls of the tube surrounding this arrangement are heated by warm water and the torsion of the sheet is measured by a microscope with ocular micrometer. The principle of a similar arrangement due to Angerer is shown in Fig. 33. The fixed plates are heated by electric current, the movable vane consists of mica. In another type a metal tube, one half of which is cut away, carries a thin aluminium strip the deflections of which are measured when the glass tube surrounding the metal tube is heated. Other modifications of the Knudsen gauge in its form as described by Angerer were proposed by Woodrow[90] and by Shrader and Sherwood,[91] who also describe convenient methods for measuring the temperature of the heated strips. A sturdy design was developed by DuMond and Pickles.[88]

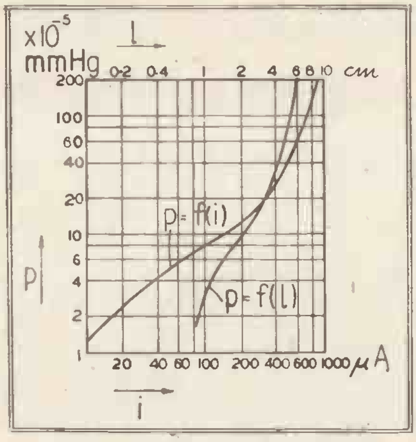
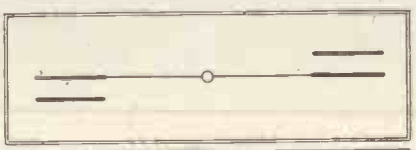


Fig. 32. Calibration curve of Philips gauge.



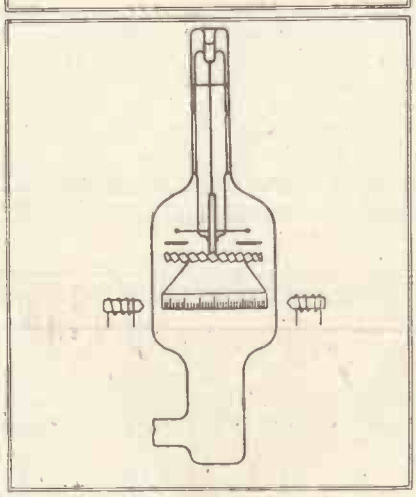


Fig. 33. (above). Knudsen gauge, principle.
Fig. 34. (below). Riegger's Knudsen gauge.

In a modification shown in Fig. 34 proposed by Riegger[92] a little winged wheel with wings inclined under 45° is suspended below a circular heating band. The scale is circular with 100 partition marks, 1·5 mm. distant, on the circumference. The movement of the wheel is damped magnetically. With 2A heating current the calibration curve is nearly linear and one scale division corresponds to 5×10^{-7} mm. Hg. Different gases require different calibration curves. In the "Molvakumeter" proposed by Gaede[68] (German Patent 648380) the torsional deflection of an oscillating system is initiated by a current impulse acting on a little magnet connected to the suspended system. Thermal molecular pressure acts as a directing force of the oscillations.

Partially ordered movement of the gas molecules is made use of in the molecular gauge of Langmuir[93] and Dushman.[94] Langmuir gives the following description of its principle: "The gauge consists of a rotating disk above which is suspended by a quartz fibre another disk carrying a mirror. The viscosity of the gas causes it to be set in motion by the lower disk and this motion produces a torque on the upper disk which can be measured in the usual way by a beam of light reflected from the mirror." A speed of 10,000 r.p.m. of the rotating disk is obtained by means of a rotating field produced outside the bulb. The torque exerted onto the upper disk was found to be proportional to the pressure inside the bulb and inversely proportional to the square root of the mol. wt. of the gas.

Fig. 35 shows the principle of the gauge. A is a Gramme ring used for producing the rotary field, B the rotor of the induction motor, C the disk directly coupled to the rotor, D the suspended disk dragged on by the viscosity of the gas, E the quartz wire with the mirror F, G the bulb encasing the movable parts and connected at H to the vacuum to be measured.

The gauge is applicable for pressures down to about 10^{-7} mm. Hg. A rather serious drawback of it is the large amount of metal and mica parts within the bulb. These are apt to occlude or absorb a hardly controllable quantity of gases which it is difficult to remove by degassing.

General Remarks

The principal systems of vacuum gauges have now been discussed. But

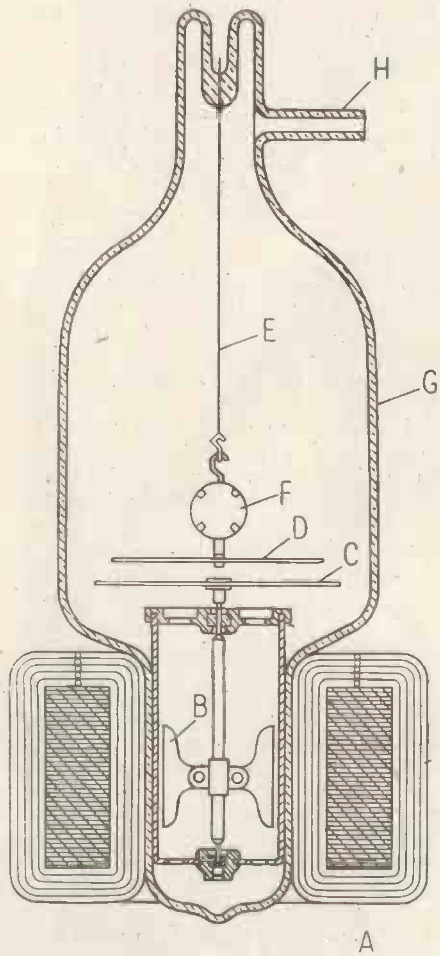


Fig. 35. Langmuir and Dushman's molecular gauge.

it might be useful to make some general remarks concerning the measurements and the materials involved. As was stated above, the development of the metal filament lamp in the first decades of this century brought with it the necessity for measuring methods and devices which could—at least to some extent—replace the rather cumbersome method of the compression gauge, a method in no way suitable for the use of recording instruments or appliances for automatic control. This necessity was accentuated when the mercury arc rectifier with metal casing was developed, and still more so when X-ray equipment, vacuum bottles, electronic devices for radio and television, vacuum-impregnated paper condensers, photocells and the like had to be produced on an ever-increasing scale.

But it was soon found that the mere measurement of pressure was not sufficient. On the one hand the dynamic state of the whole exhaust system has to be taken into consideration. Neither pressure nor the quality of the gases present is the same in all parts of the system, especially if the connecting tubing is narrow. A considerable time is required until some kind of equilibrium is obtained. Therefore the gauge should be brought as near as possible to the apparatus to be evacuated. On the other hand, the quality of the gas present or evolved and its specific properties are very important. And the same may be said of the materials used in the construction of the vacuum system, especially the glass, the metals, the special chemicals used for occluding, absorbing or adsorbing vapours and residual gases.

Some examples for corroborating these statements may not be out of place.

When giving his lecture on the hot wire gauge in 1906, Pirani showed its application in evacuating an X-ray tube by means of a rotating oil pump. A well-known physicist, when seeing the preparations for the test, warned the lecturer that he would never be able to evacuate the X-ray tube with an oil pump as oil had a vapour pressure of 0.02-0.04 mm. Hg, while the X-ray tube needed a vacuum of about 10^{-3} mm. Hg. Actually, the experiment proved successful as the oil vapours of the pump could not penetrate through the connecting tubing to the X-ray tube, since during evacuation the gas flow was in the direction from tube to pump.

As regards the quality of gases it may have been noticed that in describing the cleaning of glass containers (*see above*), alcohol was recommended for the removal of fatty residuals. Experience has shown that if benzene or petrol is used instead these substances may adhere to the glass and be cracked by heat and electron impact while alcohol is readily evaporated and sucked away by the pump.

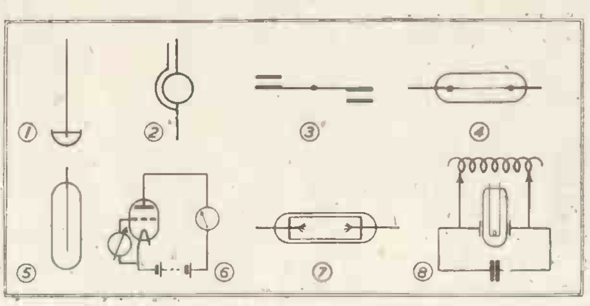
The grease solution is spread by benzene. The grease shows more adsorption on glass than benzene, but the adsorption of methylalcohol is stronger than that of grease. (Dr. H. D. Bangham, private communication.)

The cracking of hydrocarbons is frequently due to the presence of a metal heated to, say, 250-500°C., *e.g.*, Pt, Ni, Cu, Mo, W or an oxide. Not only hydrogen would be generated from the hydrocarbons—benzene vapours, oil vapours or vapours derived from a tap grease—but carbon might be deposited at some place where it can impair the exactness of vacuum measurement. So, for instance, the resistance of a hot wire gauge may be altered in an undesirable way or the electron emission of an ionisation-gauge filament may be influenced even before a visible deposition of carbon occurs. Great care, therefore, must be taken to prevent hydrocarbon from penetrating into the gauges.

These facts explain why in many cases the practical physicist in the fields of lamp and electronic valve manufacture developed and preferred relative and qualitative methods to accurate measurements with scientifically calibrated instruments. Occasionally both methods are used simultaneously as was, for instance, done in the investigations of Alterthum and Evest mentioned above.

As another example for the importance of taking into consideration the gas quality as distinct from the gas pressure the following may be mentioned. It has been observed that a few minute traces of vapour of sodium or potassium developing in the neighbourhood or on the surface of the anode of a vacuum rectifier may cause a backfire although the vacuum may be perfect as far as pressure is concerned. The sodium may

Fig. 36. Symbols for principal gauges.



be generated by electron impact from a fraction of a milligram of some sodium compound (*e.g.*, a tiny glass particle).

Not only pressure and quality of the gas play an important part in vacuum measurement but also its quantity, which may vary considerably during and after the measuring process. This quantity may be large but hidden in some way by adsorption, absorption and occlusion. It may be altered by " topophysical " or " topochemical " effects. The water skin on the inner surface of bulbs—more generally speaking on the inner surface of any glass container—and on the glass stems of lamps or valves tends to develop water vapour, carbonic acid and nitrogen when heated. This development of gases may even continue after the gases adsorbed have all been given off by slow decomposition of the glass (Langmuir). In the presence of an electron source inside the bulb the water skin may be destroyed and the vacuum diminished by the development of the gases thus set free. In the experiments of Pirani and Lax mentioned above, the water skin was destroyed by the electrolytic migration of sodium ions.

Glasses contain gases even when fused. As may be said, a glass has not an exact " frontier " towards the atmosphere surrounding it. Its surface is constituted by a frozen jelly which gradually becomes a vapour. Thus a vacuum in a glass vessel is only possible at temperatures lower than the evacuation temperature. These properties must be taken into account in so far as they counteract to some extent the disappearance of gas in electric discharges especially also in the presence of a getter. The extensive investigations of Langmuir, Dushman, Campbell, Miller and others on this subject can only be mentioned and the interested reader is referred to their publications. Similarly, the presence of metals inside or as parts of the vacuum vessels may impair the exactness of vacuum measurement. Even if their gas content is reduced as far as possible by melting *in vacuo* they still may be able to set free certain gases under special conditions as they frequently contain impurities. Thus, for instance, nickel metal may contain NiO and NiC simultaneously, and when a sheet or wire is heated to temperatures of, say, 500-800° C. *in vacuo* a very slow development of CO may result. Therefore, nickel pro-

Table 3

Historical Notes

Year	Symbol	Name	Remarks
		(A) Gas laws and barometer	
1660	①	Boyle	
1679		Mariotte	
1829	①	Arago	
1874	②	McLeod	
1890			First industrial application (carbon filament lamps)
1901	①	Rayleigh	
		(B) Phenomenology of discharges (1) Theory	
1730–1760		Gray, Du Fay and Nollet	Pencils and glow discharges
1838		Faraday	,,
1858		Plücker	,,
1868		Hittorf	,,
1870		Crookes	,,
1876		Goldstein	,,
1895		Röntgen	X-rays
1901		Townsend	
1904		Cooper Hewitt	Mercury arc rectifier
1911		Aston and Watson	
		(2) Applications	
1912	⑦	Pirani	
1924	②+⑦	Stintzing	
		(C) Heat conductivity (1) Theory	
1860		Maxwell	Heat conductivity of gases independent of pressure
1873		Crookes	" Light mill "
1875		Kundt and Warburg	Thermometer cooling
1884, 1889		Bottomley	Hot wire for heat conductivity
1888		Schleiermacher	,,
1898		Smoluchowski	Explanation of influence of low pressures
		(2) Applications	
1906	④	Pirani	10^{-4}, tantalum lamps, later rectifiers
1911	④	Hale	10^{-6}
1921	②+④	Pfund	10^{-7}
1921	④	Campbell	Gas analysis
1939	④	Melville	Microgauge for small gas quantities
		(D) Impact of molecules (1) Theory	
1909		Knudsen	
		(2) Applications	
1914	③	Knudsen	
1918	③	Shrader and Sherwood	
1920	③	Riegger	
1935	③	DuMond and Pickles	
		(E) Electron emission (1) Theory	
1903		Richardson	
1904		Wehnelt	
		(2) Applications	
1916	⑥	Buckley	Electronic valves, hot cathode rectifiers, X-ray tubes, discharge tubes, lamp bulbs
1916	⑥	Hausser-Ganswindt and Rukop	
1927	⑧	Selenyi	
1928	⑧	H. Miller, Inman	" Clean-up "
1937		Penning	" Philips " gauge
		(F) Viscosity and molecular drag (1) Theory	
1875		Kundt and Warburg	
1913		Langmuir	
		(2) Applications	
1913		Langmuir	
1914	⑤	Haber and Kerschbaum	
1915		Dushman	" Molecular " gauge
1923	⑤	A. S. Coolidge	
1925	⑤	King	

duced by the carbonyl process is not as good for vacuum work as electrolytic nickel, especially if it is remelted *in vacuo*.

All these considerations tend to show that no method of vacuum measurement can claim to have an absolute value in itself. It must have a certain objective, *e.g.*, the control of the pumping method in a lamp or a valve. But then it should also be able to make some kind of prediction as to what will happen after the bulb has been separated from the pumping system. But this is only possible if considerations as those outlined above have been taken into account. Undoubtable and exact values are only obtainable where permanent gases are concerned. Indications on vapours may be obtained with the compression gauge alone or in combination with the hot wire gauge by measuring at different compressions. But there still remains the slow after-development of gases. These may only be found by continuous measurement within the vessel itself. In a vessel cleaned by several methods perhaps no differences could be found, as, for instance, a tiny layer of fat would not be indicated by a vacuum gauge outside the vessel. Also the presence of a water skin would not be noticed. Only by those methods in which the vessel itself is used for measurement these surface films could be found with some degree of certainty.

In conclusion, a table concerning the historical development of high vacuum measurement, together with some symbolic representations of the principal designs, is given. The selection is made rather at random and the table does not claim to be complete. The symbols are given in Fig. 36 and numbered from ① to ⑧ and the respective numbers are marked on the table.

As is apparent from this table, the development of the vacuum gauge forms a good example for the mutual interaction between pure and applied science.

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CORRESPONDENCE

Photo-cell Nomenclature

DEAR SIR,—Regarding the note on Photo-cell Nomenclature in the December ELECTRONIC ENGINEERING, permit me to set forth the practice in the United States.

The emissive type is generally called a "phototube" (a vacuum tube in which one of the electrodes is irradiated for the purpose of causing electron emission from that electrode),[1] the term "cell" being restricted to cases where the electrodes are in conductive relation as in a primary cell. The trend is to use "photoelectric cell" or simply "photocell" for the solid or barrier layer (voltaic!) type[2] and "photovoltaic cell" for the one where the electrodes are immersed in an electrolyte.[3]

"Photo-e.m.f. cell" would be all right except that it is difficult to get all the periods in. The selenium cell[4] (resistance type) has been so long known by that name that it would seem difficult (should I say monstrous?) to say that it could not be termed a cell unless it were a current generator.

The names may be listed as follows:—

Type.	Name.
Emissive	Phototube (Photoelectric Tube)[1]
Solid or Barrier Layer	Photocell (Photoelectric Cell)[2]
Electrolytic	Photovoltaic Cell[3]
Resistance	Photoconductive Cell[4]

It will be seen that the terms tend to assume the shortest form.—Yours,

ALFRED S. TRASK.

Richmond, Va., U.S.A.

[1] American Standard Definitions of Electrical Terms (A.I.E.E.), 1941, p. 231.
[2] Wilson, E. D., *Electronics*, January, 1939, p. 15.
[3] Fink *et al*, *Transactions Electrochemical Society*, Vol. 79 (1941), p. 367.
[4] Shurkus, A. A., *Radio News*, July, 1944, p. 32.

Amplitude Distortion

DEAR SIR,—Mr. J. R. Hughes is quite correct in taking me to task over the use of the term "amplitude distortion." The B.S.I. glossary now substitutes the term "non-linear or harmonic distortion." There is no ambiguity in the article which refers on p. 237, Nov. 1944, to "amplitude or harmonic distortion."

I might at the same time point out that my "phase distortion" is defined by the B.S.I. glossary as "time delay distortion." The new term gives a much better and clearer discription of the effect.—Yours truly,

K. R. STURLEY.

Chelmsford.

Lissajous Figures

DEAR SIR,—I have followed with interest the series on Cathode-Ray Tube Traces by Hilary Moss. In Part I—Lissajous Figures (p. 21, June, 1944) he says: "These figures are named after Professor Lissajous, who first produced them by combining at right angles the component oscillations of two tuning forks."

"Lissajous Figures" are identical with the "Bowditch Curves" of Nathaniel Bowditch of Salem, Massachusetts, American mathematician and writer on navigation. On August 18, 1813, he communicated to the American Academy of Arts and Sciences a paper "On the Motion of a Pendulum Suspended from two Points," which was published as Memoir LII in Vol. III of the *Memoirs of the American Academy of Arts and Sciences*, 1809-1819, pp. 413-436. Bowditch's paper gives a considerable mathematical treatment of the curves and has plates showing the traces of the pendulum motion for various combinations of frequencies. Lissajous' paper carries a date of 1857.

In bringing these facts to light I do not recommend that the curves be now called "Bowditch Curves" or even "Bowditch-Lissajous Figures," since the name of Lissajous is too well established. I mention the matter merely as an historical item of possible interest to some of your readers. The instance is one of many in the history of science wherein one man's name is honestly attached to a discovery or a theory that has been anticipated by someone else. Often the originator is not widely known, publishes in a medium of limited circulation, or at a time when the idea finds no application.—Yours,

R. H. FRAZIER.

Massachusetts Institute of Technology, U.S.A.

In thanking Prof. Frazier for his note, we have suggested that the name of Lissajous was associated with the C.R. tube traces on account of their similarity with his original light spot traces. In a book on the Harmonograph mention is made of Suardi, who published a collection of harmonic traces from pendulums about the eighteenth century.—ED.

Low Frequency Amplification

Part V. The Anode Decoupling Circuit

By K. R. STURLEY, Ph.D., M.I.E.E.

THE reactance of the smoothing capacitance of the H.T. supply for a mains-operated amplifier increases with decrease of frequency and so forms a common coupling impedance for all the stages. For example, an 8 μF capacitor has a reactance of 19,900Ω at 1 c/s. Voltages may be produced in the H.T. supply by the low-frequency current components from all the stages, but the greatest is that due to the output stage because it generally has the greatest current change. These voltage components if fed back to the grid of the output valve or to the grid of a previous stage, *via* the preceding anode load connexion to the H.T. supply, can either decrease or increase the overall response at low frequencies. With RC coupling the phase of the feedback voltage is such as to cause low-frequency degeneration if fed to the grid of the output valve, or regeneration if fed to the grid of the stage before the output. Thus for a two-stage amplifier the feedback occurs to the grid of the output valve only and is degenerative, but for a three-stage amplifier it is to the grid of the stage preceding the output as well, and the effect is predominantly regenerative. In extreme cases regeneration may lead to low-frequency oscillation (about 5 to 10 c/s.) known as "motor boating." The amplifier is actually functioning as a multivibrator, the charge and discharge characteristics of the coupling capacitors and resistors determining the frequency of oscillation. If transformer coupling is employed between the stages, the phase of the feedback depends on the sign of the mutual inductance coupling between the primary and secondary. "Motor boating" in a transformer-coupled amplifier can usually be stopped by reversing the primary or secondary connexions, but this method cannot be recommended because it usually converts the feedback from regenerative to degenerative. A frequency response curve of the reversed connexion will generally show considerable and progressive attenuation of low frequencies.

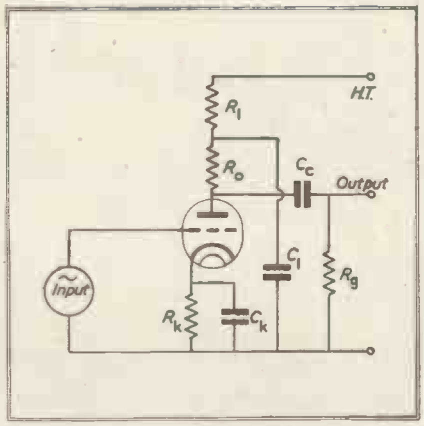


Fig. 34. A valve amplifier with anode circuit decoupling.

The simplest and most common method of reducing this form of feedback is to include a resistance-capacitance filter between the anode load resistance of each stage and its H.T. supply as shown in Fig. 34 by R_1C_1. Average values of R_1 and C_1 are 5,000Ω and 2 μF, respectively. This decoupling circuit has an effect on the overall frequency response at low frequencies because the reactance of C_1 in parallel with R_1 adds to the load resistance R_o and increases the load impedance as the frequency falls. Low-frequency amplification can therefore be raised above medium-frequency amplification. For example, the amplification at medium frequencies, where the reactance of C_c can be neglected, and that of C_k and C_1 so small that R_k and R_1 have no A.C. volts across them, is

$$A_m = \frac{\mu R_g}{R_a+R_g}\cdot\frac{R_o}{\dfrac{R_aR_g}{R_a+R_g}+R_o} \quad \ldots \; 24$$

The above expression for A_m is directly derived from Thévenin's theorem, *see* Appendix (next month). This theorem, of general application to networks having a pair of output terminals, amply repays careful study, and it is often of great assistance in simplifying valve problems. Its usefulness is well demonstrated in this analysis of the effect of the decoupling circuit. At low frequencies, assuming that the reactance of C_c is small compared with R_g and can be neglected,

$$A_l = \frac{\mu R_g}{R_a+R_g}\cdot\frac{R_o+\dfrac{R_1}{1+j\omega C_1R_1}}{\dfrac{R_aR_g}{R_a+R_g}+R_o+\dfrac{R_1}{1+j\omega C_1R_1}}$$

Replacing $\dfrac{R_aR_g}{R_a+R_g}+R_o$ by R' we have

$$\frac{A_l}{A_m} = \frac{\dfrac{R_1}{R_o}+1+j\omega C_1R_1}{\dfrac{R_1}{R'}+1+j\omega C_1R_1} = \frac{\left[\dfrac{R'}{R_1+R'}\right]\left[\dfrac{R_1}{R_o}+1+j\omega C_1R_1\right]}{1+\dfrac{j\omega C_1R_1R'}{R_1+R'}} \quad \text{or}$$

$$\left|\frac{A_l}{A_m}\right| = \sqrt{\frac{\left[\dfrac{(R_1+R_o)R'}{(R_1+R')R_o}\right]^2+\left[\dfrac{\omega C_1R_1R'}{R_1+R'}\right]^2}{1+\left[\dfrac{\omega C_1R_1R'}{R_1+R'}\right]^2}} \quad \ldots\ldots\ldots\ldots \; 25a$$

$$= \sqrt{\frac{B^2+\left(\dfrac{R''}{X_1}\right)^2}{1+\left(\dfrac{R''}{X_1}\right)^2}} \quad \ldots\ldots\ldots\ldots \; 25b$$

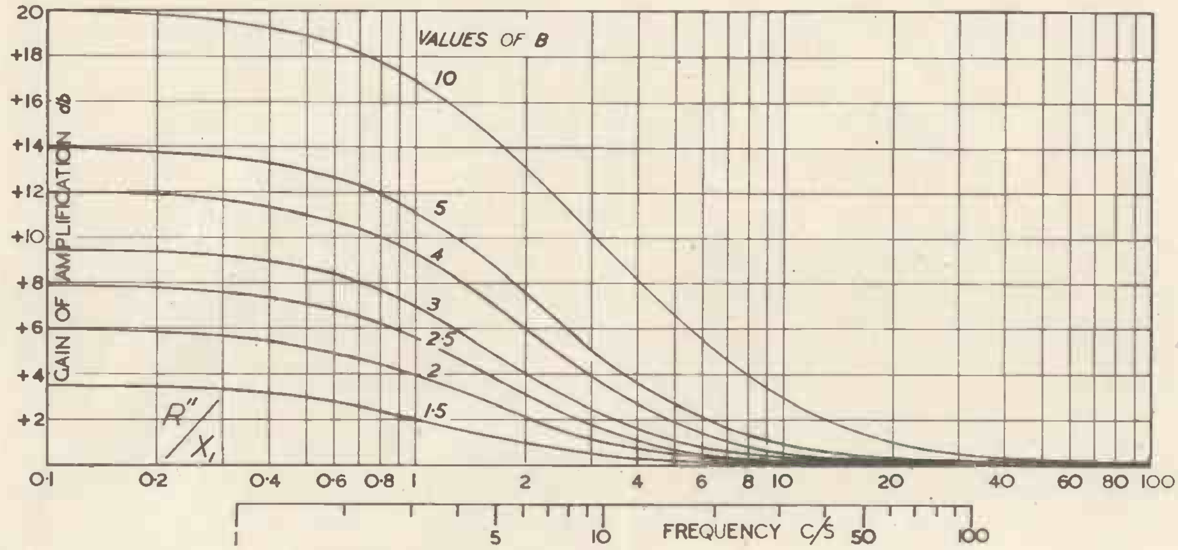


Fig. 35. Frequency response curves for the anode decoupling circuit.

where $B=\dfrac{(R_1+R_o)R'}{(R_1+R')R_o}$ and $\dfrac{R''}{X_1}=\dfrac{R'R_1}{X_1(R_1+R')}=\dfrac{\omega C_1R_1R'}{R_1+R'}$

i.e., low-frequency increase in amplification is

$$+20\log_{10}\left|\frac{A_1}{A_m}\right|=+10\log_{10}\frac{B^2+\left[\dfrac{R''}{X_1}\right]^2}{1+\left[\dfrac{R''}{X_1}\right]^2}\text{ db} \quad \ldots\ldots 26$$

Expression 26 is identical in form to the Expression 22 (Part IV) for the low-frequency decrease of amplification due to the cathode self-bias circuit; the only difference is in sign, which is positive (representing a gain in amplification). The frequency response is plotted in Fig. 35 against a horizontal logarithmic scale of R''/X_1 for the same selected values of B as were used for the cathode self-bias curves of Fig. 30. As R''/X_1 decreases (decreasing frequency) the gain in amplification approaches the value which is realised when $C_1=0$, and this value is:—

$$+20\log_{10}B=+20\log_{10}\frac{(R_1+R_o)\left(\dfrac{R_aR_g}{R_a+R_g}+R_o\right)}{R_o\left(R_1+\dfrac{R_aR_g}{R_a+R_g}+R_o\right)}$$

As a rule with a triode valve $R_a \ll R_g$ and $+20\log_{10}B$

$$\approx +20\log_{10}\frac{(R_1+R_o)(R_a+R_o)}{R_o(R_1+R_a+R_o)}=+20\log_{10}\frac{\left(1+\dfrac{R_1}{R_o}\right)}{\left(1+\dfrac{R_1}{R_a+R_o}\right)}$$

Phase angle displacement is obtained by rationalising

$$\frac{A_1}{A_m}=\frac{B+j\dfrac{R''}{X_1}}{1+j\dfrac{R''}{X_1}}=\frac{\left(B+j\dfrac{R''}{X_1}\right)\left(1-j\dfrac{R''}{X_1}\right)}{1+\left[\dfrac{R''}{X_1}\right]^2}=\frac{B+\left(\dfrac{R''}{X_1}\right)^2+j(1-B)\dfrac{R''}{X_1}}{1+\left[\dfrac{R''}{X_1}\right]^2} \quad \ldots\ldots 27$$

from which

$$\phi_1=\tan^{-1}\frac{-(B-1)\dfrac{R''}{X_1}}{B+\left(\dfrac{R''}{X_1}\right)^2} \quad \ldots\ldots 28$$

In Fig. 36 curves of ϕ_1 are shown against a horizontal logarithmic scale of R''/X_1 for the selected values of B. The angle ϕ_1 is negative, and for equal values of R''/X_1 and R_k/C_k and the same values of B it is numerically equal to the positive phase-angle displacement due to the cathode self-bias circuit. Hence both attenuation and phase characteristics of the decoupling circuit are the reverse of those of the cathode self-bias circuit, and it is possible to choose values which will enable the former to cancel both types of distortion from the latter. The conditions for exact compensation are that the values of B and those of R_k/X_k and R''/X_1 should be equal. Equal values of B give

$$1+\frac{R_k(1+\mu)}{R_a+R'_o}=\frac{(R_1+R_o)R'}{(R_1+R')R_o}=\frac{(R_1+R_o)\left[\dfrac{R_aR_g}{R_a+R_g}+R_o\right]}{\left(R_1+R_o+\dfrac{R_aR_g}{R_a+R_g}\right)R_o} \quad \ldots 29a$$

and this ensures that the maximum loss for the cathode circuit is exactly equal to the maximum gain of the anode circuit. The second condition is fulfilled by making

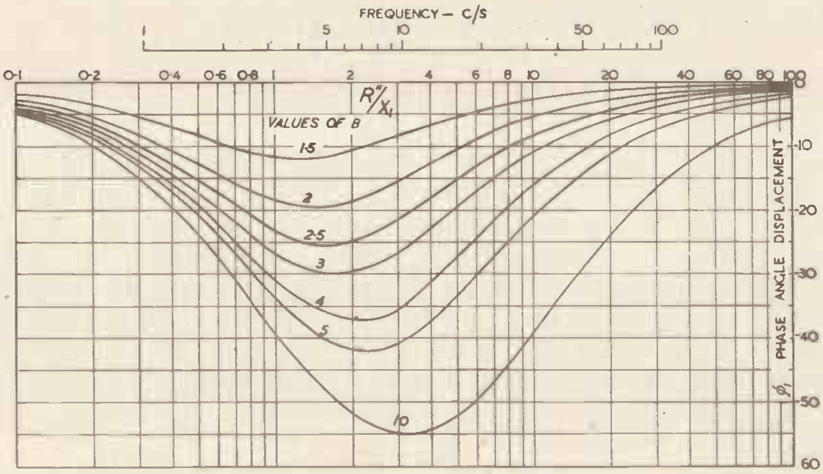


Fig. 36. Phase angle displacement curves for the anode decoupling circuit.

$$C_k R_k = C_1 R'' = \frac{C_1 R_1\left[\dfrac{R_a R_g}{R_a+R_g} + R_o\right]}{\dfrac{R_a R_g}{R_a+R_g} + R_o + R_1} \qquad \text{30a}$$

which fixes the position of the frequency scale.

It is not possible to satisfy Expressions 29a and 30a unless R_o and R_1 are small compared with R_a and R_g. When this is true the two expressions reduce to

$$1 + \frac{\mu R_k}{R_a} = \frac{R_1 + R_o}{R_o}$$

$$\text{or} \quad g_m R_k = \frac{R_1}{R_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{29b}$$

$$\text{and} \quad C_k R_k = C_1 R_1 \quad \ldots\ldots\ldots\ldots \quad \text{30b}$$

As an example of the restricted application of this method of compensating cathode self-bias distortion let us take the valve constants used to illustrate the cathode self-bias circuit, *viz.*, $\mu = 100$, $R_a = 50{,}000\Omega$, $g_m = 2$mA/volt. Selecting $R_o = 5{,}000\Omega$ and $R_k = 1{,}000\Omega$ (it will need to be reduced from $2{,}150\Omega$ because the anode load resistance is greatly reduced and anode current will therefore be increased)

$$g_m R_k = 2, \text{ so that } R_1 = 10{,}000\Omega$$

If $C_k = 25\ \mu F$, $C_k R_k = 25{,}000$, which gives $C_1 = 2.5\ \mu$F. The frequency response and phase angle displacement due to the anode decoupling circuit alone are read from the $B = 3$ curves in Figs. 35 and 36 by locating $f = 3.18$ c/s. against $R''/X_1 = 1$ on the horizontal scale as shown.

It will be noted that $R_1 > R_o$ and this is generally found to be a necessary condition. The low value of R_o makes the method of suitable application only to special types of amplifier as, for example, the vision frequency amplifier of a television receiver. Owing to the extended frequency range (up to 4 Mc/s.) of such a stage the anode load resistance is often as low as $3{,}000\Omega$. Typical valve and circuit constants for a vision frequency amplifier are :—

Tetrode valve, $g_m = 8$mA/volt, $R_a = 1$MΩ, $R_o = 3{,}000\Omega$, $R_k = 150\Omega$, $C_k = 25\ \mu$F. Solving 29b for R_1 we find that $R_1 = 3{,}600\Omega$, while 30b gives $C_1 = 1.042\ \mu$F.

The decoupling circuit has been suggested as a means of A.F. tone control when increased amplification is needed at low frequencies. A serious defect of the method is the low gain at medium frequencies and the reduced value of C_1, which makes decoupling less effective.

A more satisfactory way of cancelling or reducing cathode self-bias distortion is to use push-pull stages with common self-bias.

(To be continued)

Standards for Radio Components

Various specifications in the BS/RC Series for Radio Components prepared by the Inter-Service Components Technical Committee have been issued from time to time by the British Standards Institution, who publish these on behalf of the I.S.C. Tech. C.

For the information of those interested we give below a full list of the specifications in this Series which are now available :—

INDEX.

BS/RC.G/1.	General Guide on Radio Components.
BS/RC.S/1.	General Specification for all Radio Components in the BS/RC. Series.
BS/RC.S/110.	Group Test Specification for Fixed Resistors.
BS/RC.S/110.1.	Test Schedule for Fixed Resistors.
BS/RC.S/120.	Group Test Specification for Variable Resistors.
BS/RC.S/120.1.	Test Schedule for Variable Resistors.
BS/RC.S/130.	Group Test Specification for Fixed Capacitors.
BS/RC.S/130.1.	Test Schedule for Paper-Dielectric Fixed Capacitors.
BS/RC.S/130.6m.	Test Schedule for Miniature Paper-Dielectric. (Metallised Paper Type) Capacitors.
BS/RC.S/130.2.	Test Schedule for Mica Dielectric Fixed Capacitors.
BS/RC.S/130.3.	Test Schedule for Ceramic Dielectric Fixed Capacitors.
BS/RC.S/130.4.	Test Schedule for Electrolytic Capacitors.
BS/RC.S/141.1m.	Test and Performance Specification for Miniature Variable Capacitors (Air-spaced Ganged Type).
BS/RC.S/165m.	Group Test Specification for Miniature Relays.
BS/RC.S/165.1m.	Test Schedule for Miniature Normal Type Relays.
BS/RC.S/165.4m.	Test Schedule for Miniature High-speed Type Relays.
BS/RC.S/130.1m.	Test Schedule for Miniature Paper-Dielectric Fixed Capacitors (excluding Metallised Paper Types).
BS/RC.S/130.2m.	Test Schedule for Miniature Mica-Dielectric Fixed Capacitors.
BS/RC.S/130.7m.	Test Schedule for Miniature (High K) Type Ceramic Dielectric Fixed Capacitors.
BS/RC.G/110.	Guide on Fixed Resistors.

The Index and the first sixteen of the above documents (*i.e.*, up to and including BS/RC.S/165.4m) are published at 6d. each, and the remainder at 3d. each. Orders for the specifications and for the special binders for these (price 4s., or for larger and stronger binders 15s. each) should be sent to the Publications Department of the British Standards Institution, 28 Victoria Street, London, S.W.1.

Corrections

Photographic Materials for the Electron Microscope.

(February issue, p. 365.)

The captions for Figs. 2 and 3 should be interchanged.

Flash-Over at High Voltages.

(November issue, p. 235.)

We regret that the following acknowledgment was omitted from this article:

Abstract supplied by courtesy of R.T.P. Section, M.A.P.

More About "Scale Distortion" and Visual Analogies

By "Cathode Ray"

AS I believe that whatever fame or odium attaching to the origination of the term "scale distortion" belongs to me, I feel I must not let Mr. Patric Stevenson down with regard to his statement that mention of this subject never fails to arouse discussion. His article[1] in the October, 1944, issue is no exception to that statement, as I propose to show.

First, I would like to thank Mr. Stevenson for his thought-provoking contribution to the subject, as a result of which I admit that the term "distortion" in this connexion may mislead. Having admitted that, however, I must point out that his own arguments and data are not altogether free from distortion. He says:—

"Those who argue on these lines" (*i.e.*, my lines, offering photographic reduction as an example of something that doesn't necessarily bring scale distortion, to illustrate how volume control does) "hit on the right analogy for the wrong reasons and so confuse the subject as much as if they had chosen the wrong analogy for the right reasons."

He himself comes into the latter class, in using my analogy for the purpose of introducing perspective effects and orthographical projection and such red herrings, which I ignored because (in keeping with the characteristics of my electronic namesake) my object was to provide a picture that could be seen and understood at a glance. (This was in 1937, remember, when readers had to start from scratch in this subject.) The idea of photographic reduction reducing a man's body 10 times, his head 30 times, and his feet 100 times, is sufficiently far removed from common observation of that process to bring home at once a rough picture of the behaviour of a sound programme when the volume control is turned down. Mr. Stevenson, however, examines this cathode-ray "oscillogram" through his microscope, and, by dint of using focal distances outside the range over which human eyes can be focused, arrives at the conclusion that "photographic reduction cannot be instanced as an intrinsically distortionless process." But who instanced it as *intrinsically* distortionless? I said it did not *necessarily* distort. A little later I will illustrate the truth of this in detail.

In the meantime, it may be noted that Mr. Stevenson takes care to exclude from his argument just those conditions in which scale distortion is most distortion-like, on the ground that "high fidelity then ceases" and it is legitimate to cook the response to get "a less unreal effect." His discrimination must be very subtle to distinguish between an unreal effect and cessation of high fidelity on the one hand and distortion on the other. To me they all seem tarred with the same brush.

His suggested term "orthophonic" is a useful one, so long as it is realised that an *exact* parallel with orthographical projection is impossible in practice except for a programme in which all the component sounds are perfectly constant in frequency and intensity . . . a programme of which one would soon tire! The reason is that the amount of correction required at any frequency depends on the intensity at that frequency (because the equal loudness curves are not evenly spaced) and also on the intensity at all other frequencies (because of the masking effect,[2] which varies with loudness and frequency in an extremely complex manner). I would also like it to be known that any publicity I have given to scale distortion —"aural perspective" if you will— has not been to advocate "bass compensation" or "orthophonic reproduction" as a cure. I entirely agree with Mr. Stevenson that this introduces another form of the very thing it is supposed to abolish. The only cure, in my view, is to listen to the reproduced programme at the same loudness as one would choose to listen to the original . . . and that does *not* necessarily require a loud speaker or pair of headphones that emits the same number of watts of sound as the orchestra itself!

And now to look at the original analogy in detail. Suppose we photograph our much-discussed 6-foot man, and, in order to avoid any uncertainty due to possible distortion introduced by a glass lens, we use a pinhole lens. Then if the film is placed 1 foot behind this lens and the man is standing 36 feet in front of it, his image on the negative and on contact prints made therefrom is 2 inches high. Incidentally, such a negative, having been taken on a flat film, would not differ in perspective from the ideal drawing mentioned by Mr. Stevenson. When a print is held 1 foot in front of the eye, it correctly represents to scale a 6-foot man, in the sense in which I intended that statement to be understood. (If one assumes the use of both eyes, it would be necessary to have twin cameras and a stereoscopic viewer, but we'll leave that out for the sake of simplicity.)

Now make from the negative a 1 : 10 (in diameter) photographic enlargement and hang it on the wall 10 feet away. So far as apparent size and perspective are concerned it should represent the man in exactly the same way as the contact print at 1 foot. The enlarging process (or conversely a reduction from wall portrait to pocket size) does not necessarily introduce distortion, provided that one views the picture so that the image subtends at the eye the same angle as the original. Which is how any sensible person would view it.

Mr. Stevenson chose his example so that in one case the attempt would fail on account of the inability of the human eye to focus satisfactorily at a distance of 4 inches. Having perforce to view the picure so that it subtends a different angle, he thereby introduces the complication of wrong perspective, which has no necessary connexion with photographic enlargement or reduction at all, but can be illustrated by viewing any picture of fixed size at varying distances.

Suppose a would-be portrait photographer takes a picture of his girl friend with an ordinary widish-angle lens sufficiently close up for her head to fill the negative. If then he makes a contact print, she is unlikely to be as pleased with it as he had hoped, for at a reasonable viewing distance the perspective will be quite wrong, as Mr. Stevenson explains. If a

(*Continued in col. i, next page.*)

[1] *Electronic Engineering*, Oct., 1944, p. 207.

[2] Mr. Stevenson's figures derived from the equal loudness curves are invalid, firstly because he has applied them to an example in which sound of more than one frequency is simultaneously present, so that the masking effect comes into play, and secondly, because in lines 3 and 4 he has not taken the same db differences at all frequencies from lines 1 and 2 respectively.

BOOK REVIEW

"Electromagnetics"

By Professor A. O'Rahilly, University College, Cork. (Longman, 42s.)

The author possibly is able to justify an attitude reminiscent of a "bull in a china shop"; perhaps modern physics does need at times an Athanasius contra mundum,, but whether or not Professor O'Rahilly is right in his contentions, this is a book to start you thinking. The electronic engineer will already realise with Schott that "moving electric charges do not behave like the particles of ordinary mechanics; they do not obey the law of action and reaction, their mass varies with their speed, and they generate a magnetic field which reacts on their motion in various ways," and no sensible discussion of their properties can fail to be of some interest.

The author in this book proposes to revert to the tradition of the mathematical electricians of the nineteenth century, that is to "the electron-theories," whereby the phenomena of electricity are to be explained by the mutual forces between charged particles, the forces being dependent on their positions, velocities and accelerations. Weber's appears to be the first of such theories, but it was associated with the assumption that a current flow consists of the motion of positive and negative particles in opposite directions with equal speeds, which is now clearly an untenable theory. However, Bush has shown that using modern values of charges and masses the effect of attributing current flow to electrons only could still be experimentally consistent with Weber's law of force, although there are other objections to this law; Bush was able to account for the apparent variation of ϵ/m with velocity, the effect being due to a variation of force with velocity. O'Rahilly draws particular attention to "the neglected electrodynamic theory of Ritz," in which many of the fatal objections to prior electrodynamic laws are removed. It is now found that the action and reaction between particles are equal and opposite, that the forces depend on their relative velocities, and that again the apparent variation of mass with velocity can be neatly explained as a variation of force with velocity.

Naturally, since the author is opposed to current views, these are assailed with great vigour and the electromagnetic field is apparently left strewn with corpses. One must be grateful that the Maxwellian equations still survive, although the underlying theory is attacked, especially the conception of "displacement current." Although, however, it seems that because convection current alone can give the correct values of retarded vector potentials, therefore "displacement current" is unnecessary, it seems equally plausible to accept displacement current in order to explain why potentials are retarded.

It should be remarked that Lorentz did not always put forward his views with the dogmatism that O'Rahilly ascribes to the exponents of his theory, and that O'Rahilly's criticism of the Lorentzian explanation of the Fitzgerald contraction does not convey to the reader the reasonably expressed views of Lorentz himself.

About a sixth of the book is devoted to a discussion of units and dimensions; it need hardly be said that it is a mighty effort in debunking, yet I like this book for its insistence on exact thinking.

S. R.

---

candid girl, she might call it a distortion.

So, by pursuing the visual analogy along the lines suggested by Mr. Stevenson, we arrive at the same conclusion as for listening, *viz.*, that the size of the portrait (or the output from the loud speaker) may be what we will, within reasonable limits, provided that the distance away is such that the image subtends the same angle at the eye (or the sound is of the same intensity at the ear) as the original. Any other distance results in a more or less out-of-balance effect, which in extreme cases it is no exaggeration to describe as distortion.

MARCH MEETINGS

*NOTE.—In general, visitors are admitted to the meetings of scientific bodies on the invitation of a member, or on application in writing to the Organising Secretary at the address given. In certain cases (marked *) tickets may also be obtained on application to the Editorial offices of this Journal.*

Institution of Electrical Engineers

All meetings of the London Section will be held at The Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2.

Radio Section

Date: March 7. Time: 5.30 p.m.
Lecture:
"Frequency Modulation."
By:
K. R. Sturley, Ph.D., B.Sc.

Date: March 13. Time: 5.30 p.m.
Discussion on:
"Colour Television."
Opened by:
L. C. Jesty, B.Sc.

Date: March 20. Time: 5.30 p.m.
Discussion on:
"Apprenticeship and Trainee Systems in the Radio Industry."
Opened by:
J. Greig, M.Sc., Ph.D.

Measurements Section

Date: March 16. Time: 5.30 p.m.
Lecture:
"The Temperature Compensation of Indicating and Recording Instruments."
By:
G. F. Tagg, B.Sc.(Eng.), Ph.D.
The Secretary:
The Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2.

Cambridge Radio Group

Date: March 13. Time: 6 p.m.
Held at:
Cambridgeshire Technical College.
Lecture:
"Multipath Interference on Television Transmission."
By:
D. I. Lawson, M.Sc., A.Inst.P.

Date: March 27. Time: 7 p.m.
Held at:
University Engineering Department.
Lecture:
"The Design and Manufacture of Radio Valves."
By:
G. Leibmann, Ph.D., F.Inst.P.
Group Secretary:
D. I. Lawson, c/o Pye Ltd., Radio Works, Cambridge.

Institute of Physics

Electronics Group

Date: March 6. Time: 5.30 p.m.
Held at:
The Small Physics Theatre, Imperial College of Science and Technology, Prince Consort Road, London, S.W.7.
Lecture:
"Electron Diffraction."
By:
Professor G. I. Finch, F.R.S.
Group Secretary:
A. J. Maddock, M.Sc., F.Inst.P., Messrs. Standard Telephones and Cables, Ltd., Oakleigh Road, London, N.11.

London and Home Counties Branch

Date: March 21. Time: 2.30 p.m.
Held at:
Lecture Theatre, The Royal Institution, Albemarle Street, W.1.
Lecture:
"Mechanism of Electrode Measurements."
By:
Professor H. T. S. Britton, D.Sc., F.R.I.C. (Washington Singer Laboratory, Exeter).
Group Secretary:
H. Lowery, South-West Essex Technical College, London, E.17.

The Television Society*

Date: March 27. Time: 5.30 p.m.
Annual General Meeting (Members only)—followed by:
Discussion on:
"The Social Aspects of Television."
Opened by:
Capt. C. H. Cazaly, R.E.M.E.
Lecture Secretary:
G. Parr, 43 Shoe Lane, London, E.C.4.
General Secretary:
O. S. Puckle, 8 Mill Ridge, Edgware, Middlesex.

Kingston-upon-Hull Electronic Engineering Society

Date: March 9. Time: 7.30 p.m.
Held at:
Hull Corporation Electricity Showrooms, Ferensway, Hull.
Lecture:
"The Electron Microscope."
By:
G. Parr, A.M.I.E.E.
The Secretary:
H. W. Akester, 720 Anlaby Road, Hull.

The Association for Scientific Photography*

Date: March 24. Time: 2.30 p.m.
Held at:
The Royal Society of Arts, 6 John Adam Street, London, W.C.2.
Lecture:
"An Experimental Approach to Time-Lapse Cinematography."
By:
J. H. Ridley, A.R.P.S.
Followed by:
A general discussion on Scientific Photography.
The Secretary:
Association for Scientific Photography, 34 Twyford Avenue, Fortis Green, London, N.2.

Institution of Electronics

North-West Branch

Date: March 23. Time: 6.30 p.m.
Held at:
The College of Technology, Manchester.
Lecture:
"Pulse Generation."
By:
Dr. F. J. G. van den Bosch.
General Secretary:
L. F. Berry, 14 Heywood Avenue, Austerlands, Oldham.

Brit.I.R.E.

Midlands Section

Date: March 28. Time: 6 p.m.
Held at:
The University of Birmingham (Latin Theatre), Edmund Street, Birmingham.
Lecture:
"Dielectric Heating by the Radio Frequency Method."
By:
L. Grinstead, M.I.E.E., M.Brit.I.R.E.
Section Secretary:
W. W. Smith, 59 Heaton Road, Solihull, Birmingham.

North-Eastern Section

Date: March 14. Time: 6 p.m.
Held at:
The Neville Hall, Newcastle-on-Tyne.
Lecture:
"Proposals for Television and Broadcasting Transmission Systems."
By:
W. A. Beatty, M.Brit.I.R.E.
Section Secretary:
H. Armstrong, 69 Osborne Road, Jesmond, Newcastle-on-Tyne.

ABSTRACTS OF ELECTRONIC LITERATURE

INDUSTRY

The New Microscopes

(*R. E. Seidel and M. E. Winter*)

It is the opinion of several investigators that the generally accepted theories of resolution are seriously in need of revision, and several instruments designed for use in the visible light region of the spectrum and giving a reduction in the theoretical limits of resolution are described. The dark-field microscope, the ultra-violet microscope and the R.C.A. electron microscope are also discussed.

—*J. Franklin Inst.*, Feb., 1944, p. 103.*

Electrostatic Spraying and De-Tearing

(*H. Forsberg*)

The ordinary methods of applying metal finishes by dipping or spraying have the obvious disadvantages of waste, uneven distribution and the necessity of turning the part for the paint to reach all sides. High voltage electrostatic spraying is claimed to overcome these difficulties and to increase the speed of operation. Paint is sprayed into an electrostatic field and acquiring a charge, the paint particles are attracted to the part to be sprayed, which is earthed. By reversal, the method may be used for the "de-tearing" of dipped parts.

—*Iron Age*, 19/10/1944, p. 50.*

Medium Frequency Induction Hardening

(*G. Senlen and H. Voss*)

Surface hardening by the induction method is stated to be finding extensive application in Germany; the present article from *Stahl und Eisen*, December, 1943, deals mainly with the use of medium frequencies of 600-10,000 cycles per second for that purpose. Temperature distribution and depth of hardening are discussed in detail, and the use of high-power inputs is considered.

—*Engr. Digest*, Nov., 1944, p. 323.*

Dielectric Heating

(*L. Hartshorn*)

The mechanism of dielectric heating is not as easily understood by those accustomed to consider currents and voltages only as is induction heating, in which the production of heat by eddy currents is fairly obvious. In this article the author gives a general working idea of the theory of dielectric heating so far as this can be done without entering into mathematical details, and concludes with a brief consideration of frequency and voltage.

—*Wireless World*, Jan., 1945, p. 2.*

MEASUREMENT

Supersonic Measurement of Metal Thickness

(*W. S. Erwin*)

High-frequency sound waves are utilised in the instrument described in this article. Known as the Sonigage, it measures the thickness of metal sections where one of the surfaces is inacessible. It was originally designed for the quick inspection of hollow steel propeller blades and consists of a simple variable-frequency electronic oscillator and a quartz crystal for converting this electrical energy into mechanical vibrations. The quartz crystal is placed in contact with the material being measured and the oscillator tuned to the resonant frequency of the work. An accuracy of 2 per cent. for thickness from 0.02 in. to 0.4 in. is claimed.

—*Iron Age*, 9/11/1944, p. 59.*

Testing Selenium Rectifier Cells

(*W. E. Schwanhausser*)

To obtain uniform quality in the manufacture of selenium rectifier cells, each cell must be tested individually. Since actual operating characteristics are needed, special testing techniques must be used to separate the forward and the reverse measurements. For this purpose various electrical and mechanical methods of separation have been developed, and the methods dealt with are the wattmeter test method, oscilloscope test method, modified semi-automatic tests and life tests.

—*G.E. Rev.*, Nov., 1944, p. 53.*

RESEARCH

Electrons in the Examination of Metals

(*A. G. Quarrell*)

Much progress has been made in the applications of electrons to the examination of metals, and it is the object of this article to trace the development of electron diffraction and the electron microscope and to discuss their potentialities in the metal industries. An electron diffraction camera of a type used extensively is shown diagrammatically and the analysis of electron diffraction patterns is discussed. The high resolution electron microscope manufactured by the R.C.A. is illustrated and its construction described.

—*Sheet Met. Ind.*, Oct., 1944, p. 1,718.*

Electrical Devices in Metallurgical Research

The use of electronic apparatus in metallurgical work is rapidly increasing and there are available numerous appliances to help the metallurgist to measure and control temperature, test products without destroying them and to melt and analyse material. These applications of electrical devices are outlined in this article, which is a summary of a booklet published by the U.S. Department of the Interior, Bureau of Mines.

—*Iron Coal Tr. Rev.*, 10/11/1944, p. 709.*

Bibliography of Relay Literature, 1940-1943

This report was prepared by the relay sub-committee of the A.I.E.E., to cover problems brought about by the war emergency. The articles listed include all those appearing in the *A.I.E.E. Transactions* or *Electrical Engineering*, as well as in most of the chief technical publications of the world, from 1940 to 1943 inclusive, and cover line and apparatus protection, testing and calculations, stability of systems, auxiliary devices, and general and miscellaneous relaying.

—*El. Eng.*, Oct., 1944, p. 705.*

The Development of Polythene as a High-Frequency Dielectric

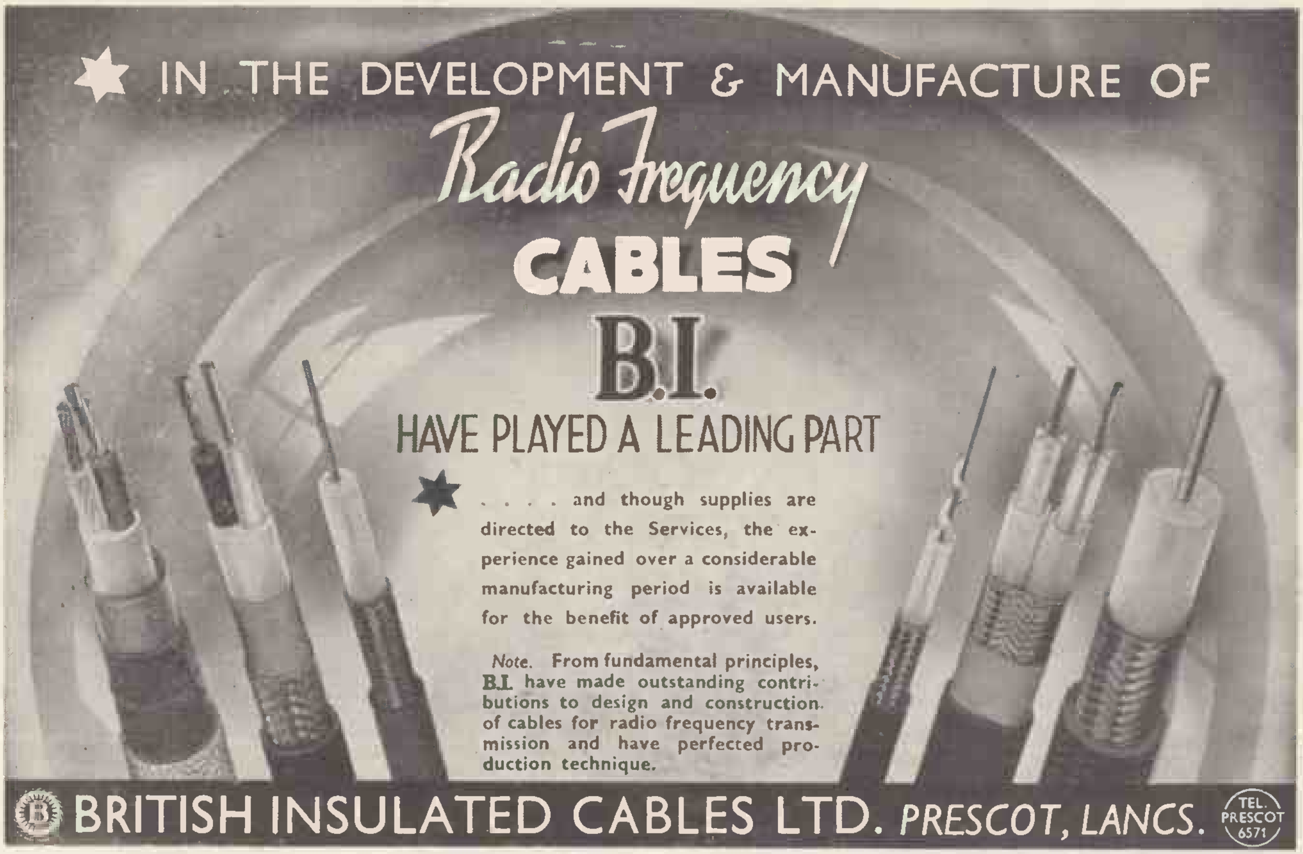
(*Prof. Willis Jackson and J. S. A. Forsyth*)

The paper is mainly concerned with the power factor of polythene (the high polymer of ethylene) which, being normally of the order of 0.00015-0.0003, renders the material highly suitable as a high-frequency dielectric.

A brief account is given of the structure of polythene, and of its main physical and mechanical properties.

—*Jour. I.E.E.* (to be published).

* Abstracts supplied by the courtesy of Metropolitan Vickers Electrical Co. Ltd., Trafford Park, Manchester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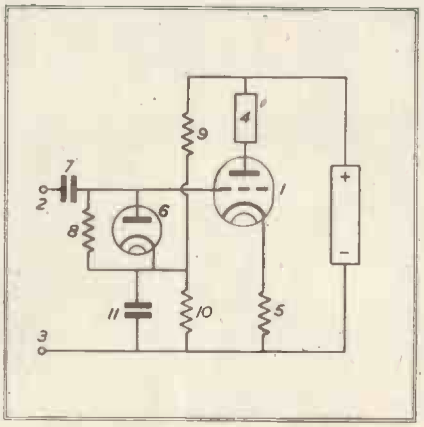
A Stabilised Pulse Generator

A COMMON form of pulse generator is a thermionic valve with a suitable impedance, *e.g.*, a short-circuited delay network in its anode circuit and arranged to be switched on at intervals by pulses applied to the grid circuit of the valve. If normally the valve is biased beyond cut-off, the application of the pulse will cause the valve to conduct and the desired pulse will thereupon be developed across the impedance in the anode circuit.

The amplitude of the pulses developed by an arrangement of this kind is, of course, proportional to the change of anode current, *i.e.*, to the anode current passed by the valve when switched into the conducting state by the applied pulses. This amplitude will therefore be dependent upon the amplitude of the applied pulses and also upon the constants of the valve. If, as is often the case, it is desired that the output pulses shall be of constant amplitude, this may be a serious disadvantage.

These difficulties can, however, be overcome by means of a modified circuit arrangement as shown in the attached figure. Valve 1 is switched on by pulses applied between terminals 2,3 and generates the output pulse across impedance 4 arranged in its anode circuit. The modifications which have been introduced are :—



1. The cathode resistance 5 which introduces negative feedback and stabilises the anode current of valve 1 for a given applied grid voltage, so rendering the amplitude of the output pulses less sensitive to changes of valve or anode voltage. It should be remembered that, due to the negative feedback arising from cathode resistance 5, the amplitude of the applied pulses will in general have to be greater than usual.

2. The diode 6, which acts together with condenser 7 and leak 8 as a peak rectifier and serves to adjust the bias on the grid of valve 1, so that the peaks of the applied pulses always reach the same voltage and cause valve 1 to pass the same anode current. The voltage at which the peaks of the applied pulses are stabilised can be adjusted by choice of the valves of resistances 9 and 10 which determine the bias on the cathode of diode 6. 11 is a by-pass capacity across resistance 10.

If desired, cathode resistance 5 may be replaced by a constant resistance in the form of a delay network terminated with a matched resistance so that further output pulses can be developed from the cathode. If the anode load presents a high impedance, it may be advantageous to use a pentode.

—*Communication from E.M.I. Labs.*

CLASSIFIED ANNOUNCEMENTS.

The charge for miscellaneous advertisements on this page is 12 words or less 4/- and 4d. for every additional word. Box numbers count as four words, plus 1/- extra for replies Remittance should accompany advertisement. Cheques and P.O.'s payable to Hulton Press Ltd., 43 Shoe Lane, E.C.4. Press date—15th month for following issue.

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Classified Announcements (Contd.)

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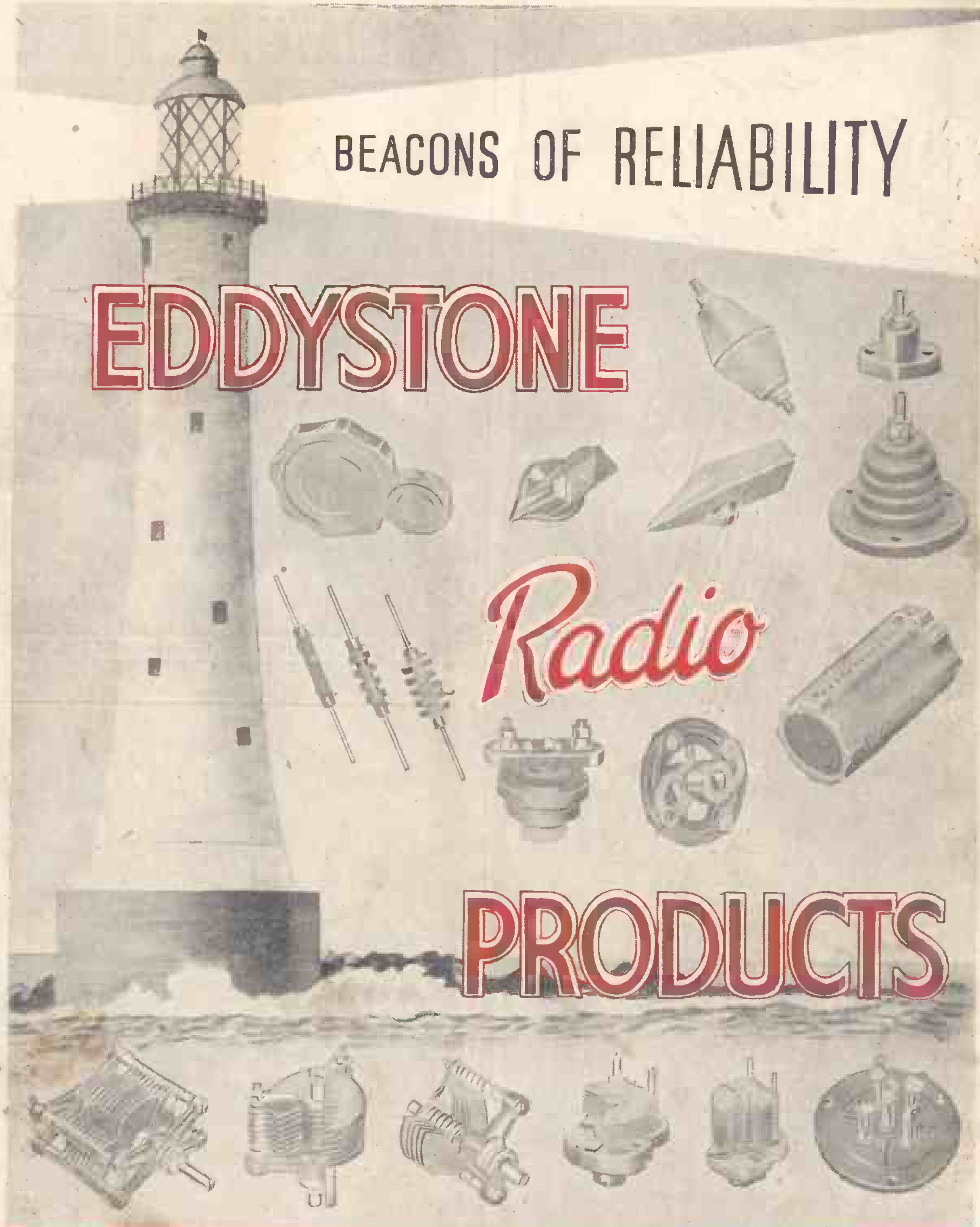

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