Electronic Engineering

INCORPORATING ELECTRONICS, TELEVISION AND SHORT WAVE WORLD

PRINCIPAL CONTENTS

2/- SEPT., 1944

The fact that goods made of raw materials in short supply owing to war conditions are advertised in this magazine should not be taken as an indication that they are necessarily available for export.

WIDE-RANGE TRANSFORMERS

TYPES D-106 & D-139

for Modern Communications Equipment

- **FREQUENCY CHARACTERISTICS**

Practically linear from the lower andio frequencies to over 100 Kc/s. (See representative curves.)

- **IMPEDANCE RATIOS**

Many impedance ratios are available, from 1:1 to 500:1.

- **POWER**

Types D-139 will handle up to one watt A.C. power above 40 c.p.s.

Types D-106 are designed as input and interstage transformers where the power is negligible.

- **SCREENING**

All types double screened against electromagnetic and electrostatic interference.

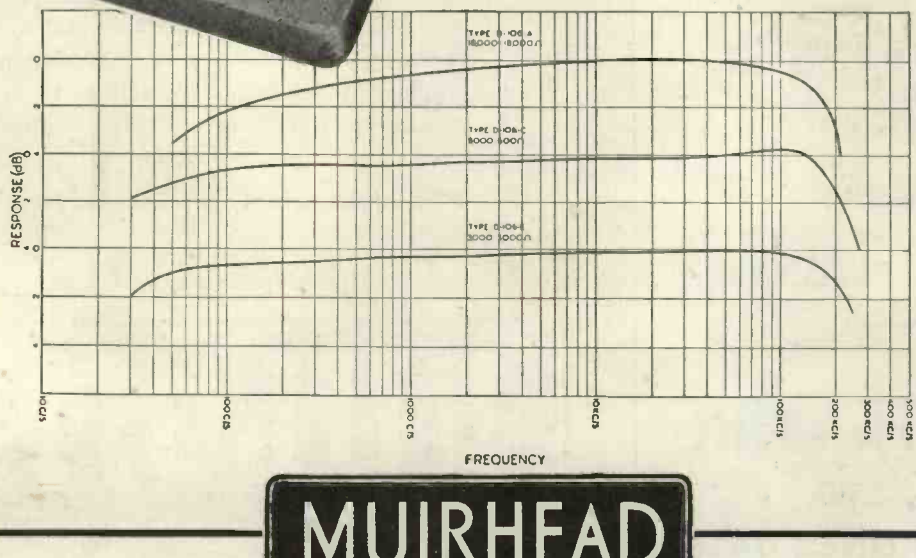
- **DIMENSIONS**

$2\frac{5}{8}$" x $3\frac{1}{2}$" x 3" high overall.

- **WEIGHT**

$2\frac{1}{2}$ lb.

Full information is given in Bulletin B-538-A which will gladly be sent on request.



MUIRHEAD

MUIRHEAD AND COMPANY LIMITED, ELMERS END, BECKENHAM, KENT. BECKENHAM 0041-0042.

FOR OVER 60 YEARS DESIGNERS & MAKERS OF PRECISION INSTRUMENTS

C.R.C 30

A

VACTITE *Wires & Tapes*

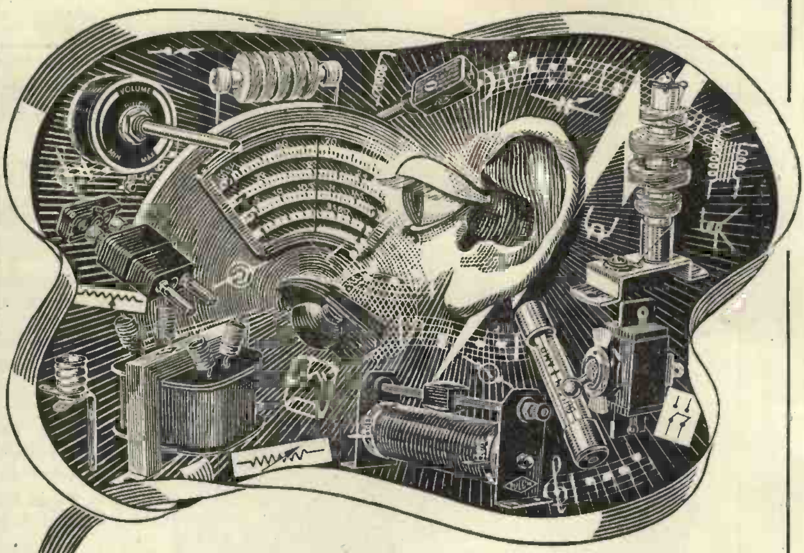
RESISTANCE WIRES TO THE FINEST SIZES

- MOLYBDENUM
- VAC-STEEL
- PLATINUM SHEATHED
- GAS-FREE NICKEL
- WIRES, TAPES, BARS, MESH AND VALVE PARTS

VACTITE WIRE CO. LTD
VACTITE
REGD.
LONDON

VACTITE WIRE
CO., LTD.
19 QUEEN ANNE'S GATE, WESTMINSTER, S.W.I.

Telephone : WHITEHALL 2552,



The Future . . .

ALTHOUGH concealed today in tropical kit or battledress, without its familiar trademark, discerning technicians can easily recognise the well-known brand of **BULGIN RADIO PRODUCTS** in every piece of Service radio apparatus. Today, as in the past, they stand predominant for originality, design and reliability, ready to co-operate in the future, in the shape of 'things to come.'

Please quote priority and Contract Nos.

"The Choice of Critics"

BULGIN

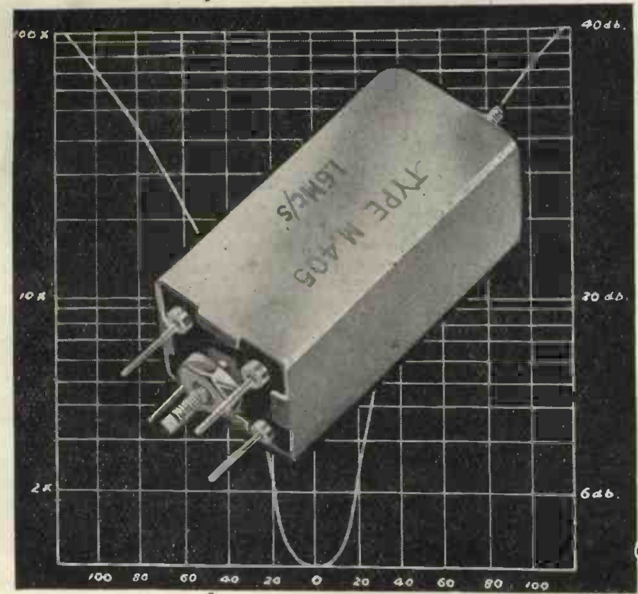
Regd. Trade Mark

A. F. BULGIN & COMPANY LTD.,
Radio and Electrical Component Manufacturers,
BYE PASS RD., BARKING, Essex.

Tel.: RIPPleway 3474 (5 lines)

Miniature I.F. Transformers

DESIGNED FOR MAXIMUM GAIN AND SELECTIVITY IN THE SMALLEST DIMENSIONS



The coils are contained in enclosed pot-type iron dust cores, tuning adjustments being obtained by means of adjustable iron dust centre cores.

Fixed tuning condensers are contained inside the screening can.

Units are made with a number of variations in windings and coupling coefficients for certain circuit conditions, but five Standard types are recommended for general use.

Wartime restrictions prevent our accepting orders other than those covered by priority numbers

The illustration shows the actual size of the Unit which is provided with one hole fixing, the terminal wires being fed through insulated bushings which, in turn, prevent movement of the transformer when mounted in position.

WRIGHT & WEAIRE LTD.

HIGH ROAD, TOTTENHAM, N.17.

Telephone : TOTtenham 3847-8-9.

So much depends on them

Regd. Trade Mark
AVO
Electrical
TESTING INSTRUMENTS

"AVO" Electrical Testing Instruments are actively engaged on the fighting and factory fronts, sharing a great responsibility with a proud sense of duty and high confidence in the future.

It will therefore be appreciated by our numerous trade friends that we can only accept orders which bear a Government Contract Number and Priority Rating.

Sole Proprietors and Mfrs.: **AUTOMATIC COIL WINDER & ELECTRICAL EQUIPMENT CO., LTD., Winder House, Douglas St., London, S.W.1**
'Phone VICtoria 3404-8

Electronic Engineering

SEPTEMBER, 1944

Volume XVII. No. 199.

CONTENTS

PAGE

PROPRIETORS :
HULTON PRESS, LTD.

Electronic Engineering

EDITOR:
G. PARR.

EDITORIAL, ADVERTISING AND PUBLISHING OFFICES, 43-44, SHOE LANE, LONDON, E.C.4

TELEPHONE:
CENTRAL 7400

Monthly (published last day of preceding month) 2/- net. Subscription Rates : Post Paid to any part of the World—3 months, 6/6 ; 6 months, 13/- ; 12 months, 26/-. Registered for Transmission by Canadian Magazine Post.

TELEGRAMS
HULTONPRES, LUD
LONDON.

Colour ?

THE brief report of J. L Baird's further development in colour television, given overleaf, reminds us that since the appointment of a Television Advisory Committee some time ago, very little has been said in this country about plans for the future.

Papers have been read giving suggestions for an improved television service—mainly from the technical point of view—and recommendations have certainly been made to the Committee by outside bodies. but it is doubtful whether the viewing public are aware of the discussions, and certainly so far there has been no attempt to arouse their interest in post-war television.

To those who think that such an attempt would be premature, we can point to the American manufacturers, who are already showing every sign of stimulating public interest in what they will have to offer after the war.

Admittedly, the conditions over there are different from those in this country, and the scope for development is wider, but locally the problems are not so widely diverse. (The recent N.B.C. questionnaire, for example, showed that there were only 5,000 receivers in the New York area). The manufacturers are giving publicity to their schemes for extending the service to cover the maximum number of viewers throughout the country—advertisers are being told how television will help to sell products—television organisations of both broadcasters and producers are being formed, and there is the general preliminary stirring of enthusiasm for the future.

There are several interesting news items about this growth of television interest. One is the formation of the R.K.O. Television Corporation, which has for its object " to make available to the producers of television entertainment a complete programme-building service." This means that expert news-cameramen will be available to film events of outstanding interest for the sole purpose of television broadcasting later. Their service is available to all commercially interested in television, and they have already put out a slogan, "Televise to Advertise." Surely this is the first instance of a commercial firm devoting a special branch of its organisation to television service.

Another matter of interest is the publication of a brochure by the Columbia Broadcasting System " to state and describe the tremendous opportunity which the war has given to television and to state the problems which lie in its path." Naturally the report is coloured (no pun intended) by the outlook of the C.B.S. on the future of colour television, but it is nevertheless a serious attempt to present the fundamental problem of post-war television in all its aspects :—shall we stay where we are for the time being and develop an improved system later, or shall we hold things up until we can have the best ? Which would you do ?

J. L. Baird with his new two-colour Cathode Ray Tube.

Electronic Colour Television

J. L. Baird's New — "Telechrome"

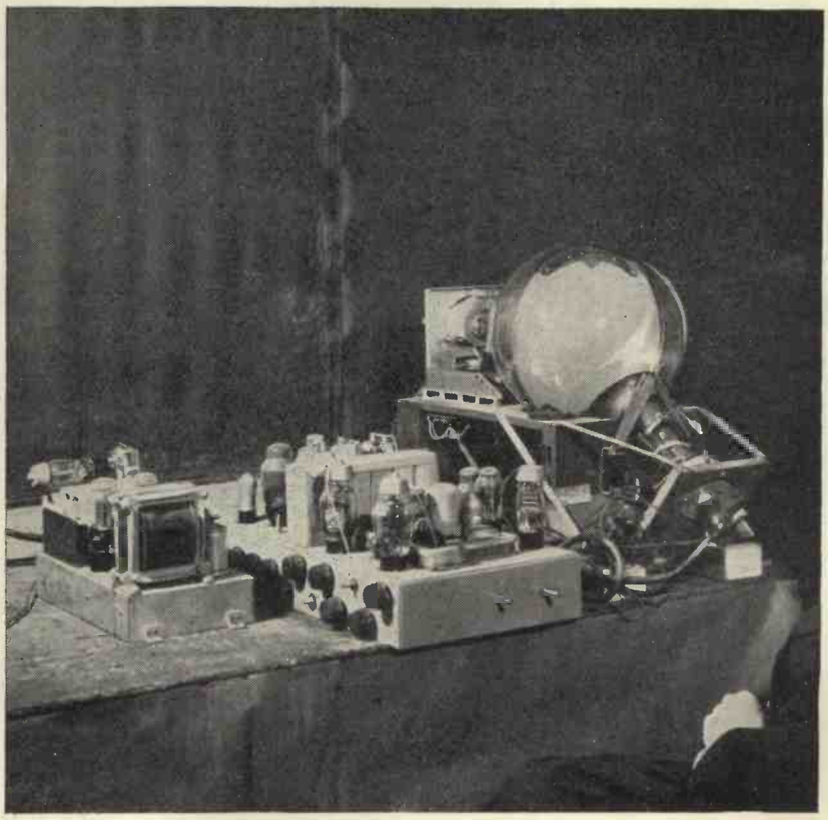
ON Wednesday, August 16, J. L. Baird demonstrated to members of the Press his new system of colour television using a special cathode-ray tube capable of giving direct colour rendering without the aid of intermediate filters.

Hitherto the reproduction of television pictures in colour has necessitated the use of a rotating disk synchronised with the scanning and having colour filters through which the image was seen.

Baird has held the view that the introduction of mechanical moving parts into an otherwise electronic system is a retrograde step which would detract from the merits of a full colour television system.

An earlier experimental method avoided the filter disk by focusing separate pictures on to a screen through stationary lenses and colour filters (see this Journal for January, 1943), but had several disadvantages.

The present method, which is truly electronic, has overcome these disadvantages and is an important step forward in the development of colour and stereoscopic television.



The experimental receiver and Tube assembled.

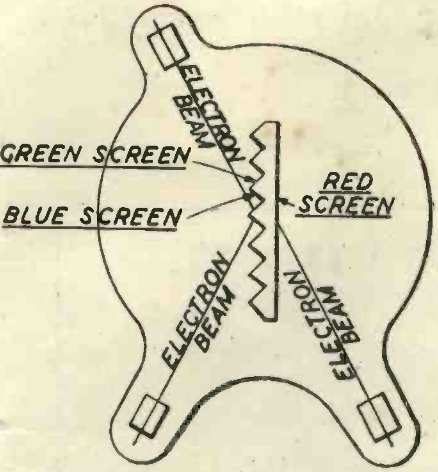


Fig. 2. Diagram of Tube for television reproduction in three colours, the mica screen being stepped on one side as shown.

THE "Telechrome" television system is entirely electronic, the coloured image appearing directly upon the fluorescent screen. Two cathode-ray beams are required for a two-colour system and three for a three-colour system. These cathode-ray beams are modulated by the incoming signals corresponding to the primary colour picture and impinge upon superimposed screens coated with fluorescent powders of the appropriate colours. For example, in a two-colour system the two cathode-ray beams scan the opposite sides of a thin plate of transparent mica one side of which has been coated with orange-red fluorescent powder and the other with blue-green fluorescent powder. Thus the screen has formed upon its front face an image containing the orange-red colour components and on its back face an image containing the blue-green components, these images being superimposed and thus giving a picture in natural colour (Fig. 1).

Where three colours are to be used the back screen is ridged and a third cathode-ray beam added; the front face of the screen then gives the red component, one side of the back ridges gives the green components, and the other side of the ridges the blue component (Fig. 2).

A two-sided tube has been developed to receive a picture from a 600-line triple-interlaced moving spot transmitter using a cathode-ray tube in combination with a revolving disk with orange-red and blue-green filters. The receiving cathode-ray tube is shown in the diagram (Fig. 1) and in the photograph. The screen is a 10 in. diameter disk of thin mica coated on one side with blue-green fluorescent powder and on the other with orange-red fluorescent powder. The colour may alternatively be provided for the back screen by using a white powder and colouring the mica itself.

The tube shown in Fig. 1 may be viewed from both back and front, but if used in this way one set of viewers sees a mirror image. Also, coloured mica must not be used, and a filter has to be inserted between the back viewers and the tube to keep the colour values correct and compensate for the light lost in the mica and fluorescent powder when the direction of viewing is reversed.

The tube shown in the photograph of the apparatus can only be viewed from the front, but having one cathode-ray beam perpendicular to the screen simplifies the set up of the apparatus. The tubes give a very bright picture due to the absence of colour filters and the fact that special powders are used giving only the desired colours, which are seen additively.

The tubes give excellent stereoscopic television images when used with a stereoscopic transmitter, the blue-green and orange-red images forming a stereoscopic pair and being viewed through colour glasses.

New Form of Scanning

In the present form of scanning all the lines in successive frames are of the same colour, the colour changing with each successive frame.

In a new form of scanning now being developed, successive lines are of different colour and the number of lines is made a non-multiple of the number of colours, so that every line of the complete colour picture has successively shown each of the primary colours.

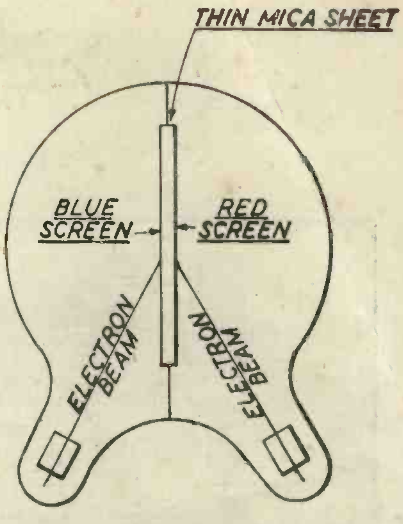


Fig. 1. Diagram of double screen Cathode Ray Tube for viewing television images in two colours.

The object of this is to reduce colour flicker. Where frame-by-frame colour alteration is used flicker becomes prominent in any large area of a single colour, for example, if the picture is showing a large blue area, this blue appears in the blue frame only. While the red and green frames are appearing, it is not shown, so that the frequency of the repetition is reduced and flicker accentuated. With line-by-line colour alteration, each colour appears in every frame.

This form of scanning does not lend itself to the revolving filter disk system.

BIBLIOGRAPHY

Nature, August 18, 1928, pp. 232–4.
Television, Vol. 1, No. 7, pp. 20–21.
Television, August, 1928, pp. 9–10.
Wireless World, August 17, 1939, pp. 145–146.
Electronics & Short Wave World, March, 1938, pp. 541–542.
British Patent No. 473323., 1935.
Electrician, December 27, 1940.
Wireless World, February. 1941.
Electronics & Television & Short Wave World, February, 1941.
Electrician, January 1, 1935.
Wireless World, February, 1943.
Electronic Engineering, January, 1943.
British Patent No. 562168, 1942.
British Patent No. 562334, 1942.
British Patent No. 552582, 1941.
Electrician, December 26, 1941, pp. 359.
Wireless World, February, 1942, pp. 31–32.
Electronic Engineering, February, 1942, p. 620.

Magnetic Materials

I. The Domain Theory of Ferro-magnetism

By F. BRAILSFORD, Wh.Sch., Ph.D., A.M.I.E.E. *

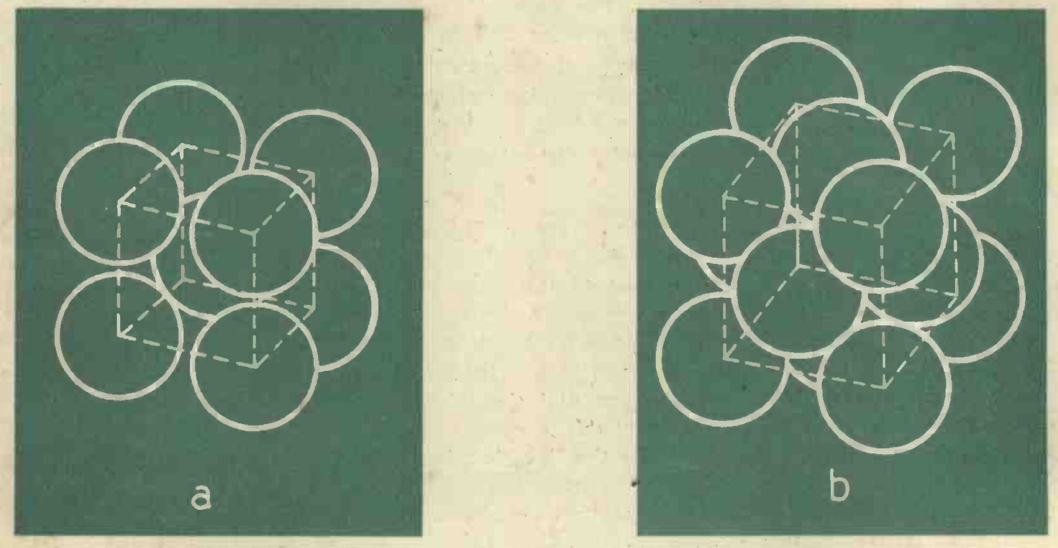


Fig. 1. Illustrating the arrangement of the atoms in a crystal (a) Iron, (b) Nickel.

1.1 Introduction

DURING the past twenty years remarkable progress has been made in the commercial development of high permeability and other special alloys for light current electrical engineering, and in the production of new permanent magnet materials. Developments are also occurring in the sheet steels used for magnetic purposes in heavy electrical plant. In parallel with these achievements, laboratory experiments have led to noteworthy advances in our knowledge of the physical basis underlying ferromagnetic phenomena, and from this has been built up a useful working theory of the subject.

It is proposed in this series of articles to discuss some aspects of the modern theory of ferromagnetism and some relevant laboratory investigations and commercial developments.

1.2 The Nature of Magnetic Materials

The ferromagnetic elements iron, nickel, cobalt, and their alloys, in common with other metals, are crystalline in character. Examination of a sample under the microscope, and even in some cases with the naked eye, shows the metal to consist of a large number of grains with well-defined grain boundaries. Each grain is a single crystal consisting of atoms which are arranged on a regular pattern or lattice. The type of lattice and the spacing of the atoms are known from X-ray examination. In the case of iron the atoms form a regular cubic pattern known as "body-centred," as shown in Fig. 1(a), in which, if we consider an elemental cube of the crystal or unit cell, there will be an atom at each corner of the cube and another at the centre. Nickel also crystallises on a cubic lattice, but in this case the disposition of the atoms is "face-centred" with an atom at each corner of the unit cell and one at the centre of each cube face, as shown in Fig. 1(b). The lattice points, however, determine only the mean positions of the atoms which will, depending on the temperature, be in a state of more or less violent thermal vibration.

In the case of ferromagnetic alloys, atoms of more than one element will be present. In those having high permeability and low hysteresis loss, the "soft" magnetic materials, the metal is always single phase, that is the grains composing it are all of the same composition and type of crystal structure and the atoms of the alloying element substitute themselves for the parent atoms at a number of lattice points. The permanent magnet, or magnetically hard alloys, however, require, by contrast, the largest possible area of hysteresis loop. They may contain five or six constituent elements and are more complex. Their exceptional magnetic properties are the result of their ability to separate out into more than one phase, these phases having differing composition and lattice type or lattice dimensions. In these articles, however, we shall be mainly concerned with the single-phase alloys of cubic crystal structure.

1.3 The Elementary Magnet

Many engineers and physicists still think of magnetic materials in terms of Ewing's theory. Ewing supposed the material to be made up of elementary atomic bar magnets capable of rotation about their centres. These magnets were influenced not only by

*Metropolitan Vickers Electrical Co. Ltd.

the applied field but also by their mutual interaction. Models made up of large arrays of small pivoted permanent magnets exhibited similar forms of magnetisation curve and hysteresis loop to those observed in practice. In spite of this qualitative success, however, the theory fails quantitatively when the appropriate values, not known when the theory was introduced, are inserted for the magnetic moments and spacing of the atomic magnets. Ewing's theory, consequently, is now only of historical interest and has given way to more precise modern ideas.

Now the atom of any element is made up, as is well known, of a central positive nucleus surrounded by a number of electrons which may be thought of as describing orbital motions around the centre in more or less well-defined shells and sub-shells. It is also found necessary to ascribe to the electrons a spin, as though they were minute gyroscopes spinning on their own axes. We should therefore expect to find associated with each electron a magnetic moment both on account of its spin and its orbital motion, just as in the case of a current flowing in a circular path. In some cases, however, the magnetic moments, due to all the electrons in the atom, balance out and the whole atom has no resultant moment, but with other elements this is not the case. The atoms of the latter have a magnetic moment which is due, according to the experimental evidence, to the unbalanced spins of a few of the electrons in the atomic structure. The existence of this magnetic moment may be experimentally demonstrated by deflecting a beam of the atoms by means of a non-uniform magnetic field.

Thus the elementary magnetic particle is the spinning electron which imparts to the atom a magnetic moment.

1.4 Paramagnetism

If now we consider a substance made up of atomic magnets, the application of a steady magnetic field will tend to rotate their magnetic axes into line with the field and thus to magnetise the material. This process will, however, be violently interfered with by thermal agitation. Langevin, neglecting any mutual aligning forces between neighbouring atoms, calculated the relation between the applied field and the resulting intensity of magnetisation, in terms of the atomic magnetic moments and the temperature. The equation of the magnetisation curve, modified more recently by an assumption of quantum theory, may be written as

$$\frac{I}{I_0} = \tanh \frac{\mu H}{kT} \qquad (1)$$

where I is the intensity of magnetisation produced by the field H, I_0 is that for parallel alignment of all the atomic magnetic axes, μ is the magnetic moment of the atom, k is Boltzmann's constant and T the absolute temperature.

From this expression we may determine numerical values for the susceptibility or permeability of a given material, but these are found to be of the right order of magnitude only for those feebly magnetic materials known as paramagnetics, whose permeability is only very slightly greater than unity.

If we substitute in the equation the appropriate values for iron, then remembering that flux density $B = H + 4\pi I$, we obtain for iron at 20° C.

$$B - H = 21{,}900 \tanh \frac{0.51 H}{10^6}$$

where B − H and H are in gauss.

This magnetisation curve is plotted in Fig. 2 at A and it indicates that a

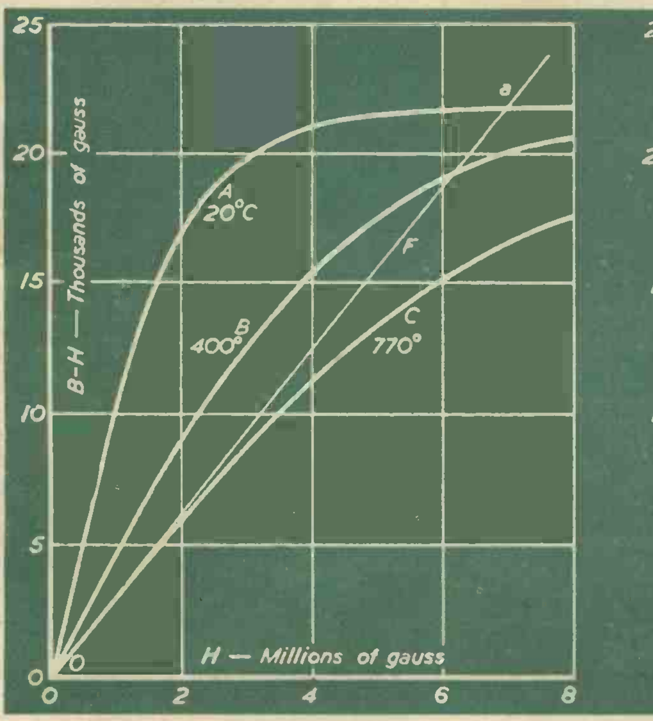


Fig. 2. Calculated Magnetisation curves of Iron according to theory of Paramagnetism.

Fig. 3. Saturation Value of Iron in relation to temperature observed and calculated.

field strength of many millions of gauss would be required to saturate a sample of iron. This is, of course, not in accord with the results of observation since iron, in common with other ferromagnetic materials, may be brought near to saturation by a field strength of only a few hundred gauss.

1.5 The Domain Theory

To overcome this difficulty, Weiss made the hypothesis that in the ferromagnetic materials there was spontaneously produced a "molecular field" acting in the direction of the magnetisation and proportional in magnitude to it. Thus if H was the externally applied field, and I the intensity of magnetisation in the material, the total field acting to align the atomic magnets was $H+NI$ where N was a constant. We may represent this molecular field by the straight line F in Fig. 2 intersecting the magnetisation curve calculated from the paramagnetic theory at (a). A little consideration shows that if such a molecular field exists then, even in the absence of any externally applied field, the material would be unstable in the unmagnetised condition, represented by the point O, and would spontaneously magnetise itself at 20° C. to the intensity corresponding to the point of intersection at (a). In Fig. 2 the straight line F, representing the relation between the molecular field and (B-H), has been drawn at the correct slope as determined by certain considerations mentioned below. We thus see that for iron at room temperature the molecular field acting has a value of about seven million gauss, or about twenty times greater than the highest field strength attained, even momentarily, in the laboratory, and the material is spontaneously magnetised to a saturation value.

Now it is experimentally observed that the saturation value of any ferromagnetic, as determined in the laboratory, falls with rising temperature finally becoming substantially zero at a temperature known as the magnetic change, or Curie point. At higher temperatures than this the material is no longer ferromagnetic. In the case of iron the Curie temperature is 770° C. and the observed relation between saturation value and temperature is shown in Fig. 3. Calculated paramagnetic magnetisation curves for iron are shown in Fig. 2 by A, B and C, drawn by way of example for temperatures of 20, 400 and 770° C. respectively. The theoretical values of saturation magnetisation for these temperatures are given by the intersection of the curves with the molecular field line F, the position of which is fixed by making it tangential to the calculated curve C which corresponds to the Curie temperature. The theoretical relation between saturation value and temperature may also be expressed by the equation

$$\frac{I_T}{I_0} = \tanh \frac{I_T T_C}{I_0 T}$$

where I_T is the saturation value of the intensity of magnetisation at temperature T and T is the Curie temperature in absolute units. This relation is also plotted in Fig. 3, for comparison with the observed curve, and shows the agreement between theory and experiment. Similar curves may be drawn for nickel and cobalt and these give even better agreement.

The Weiss molecular field hypothesis thus leads to the conclusion that, in the ferromagnetics, the material even in the absence of an applied field, is spontaneously magnetised to saturation. Since, however, we know that a piece of soft iron, for example, with no field applied shows no external evidence of being magnetised, Weiss made the further assumption that the material was made up of "domains," or small regions of the material, each of which was saturated but in which the neighbouring magnetisation vectors were randomly directed. With no applied field there was therefore no external magnetic effect.

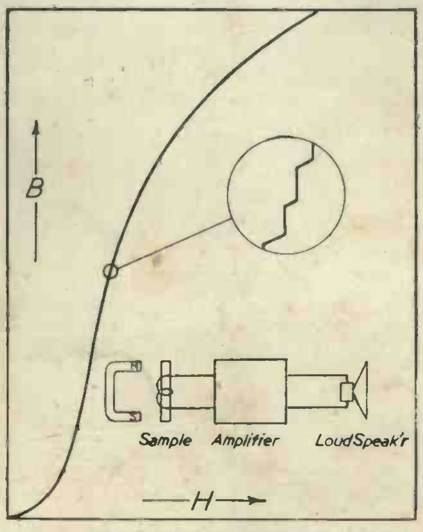


Fig. 4. Illustrating the Barkhausen effect.

The assumption of a molecular field, and the sub-division of a ferromagnetic into spontaneously saturated domains, form the foundation of the modern domain theory of ferromagnetism, a theory now well supported by experimental evidence.

The origin of the Weiss field was at first a mystery since it could not be accounted for in any way known to classical mechanics. However, it now appears from the mathematics of the wave or quantum theory, that if certain dimensional relations connected with the atom and the crystal lattice are fulfilled, powerful mutual forces may exist between the spinning electrons in the atoms, which are the elemental magnetic carriers, making their directions of spin the same and their axes parallel. Those elements which exhibit ferromagnetism conform to the necessary conditions. They will thus be spontaneously saturated by these internal mutual forces of "exchange" between spinning electrons. The source of Weiss's postulated molecular field thus becomes apparent.

1.6 The Barkhausen Effect

On the application of an externally applied field to a piece of iron or other ferromagnetic material, magnetisation occurs by sudden reversals or changes of direction of the magnetisation in whole domains as the field increases. These re-alignments of the magnetisation vectors in the domains can be produced by much lower field strengths than are required to orientate the atomic magnetic axes in a paramagnetic, as will be described in more detail later. The high permeability of the ferromagnetics is thus explained. Moreover, it follows that the magnetisation will increase, in part at least, by a series of discrete jumps. Thus the magnetisation curve, greatly magnified, should show a series of steps as illustrated in Fig. 4. A simple but striking demonstration of the existence of these "Barkhausen jumps" can be given by inserting a small piece of iron, or any other ferromagnetic, into a search coil of a few thousand turns connected to suitable telephones. On magnetising the sample, for example, by approaching it to the poles of a permanent magnet, a rustling noise is heard under quiet conditions in the telephones. By the use of a suitable valve amplifier this noise may be converted into a roar in a loud-speaker. The noise is, of course, due to a rapid succession of minute E.M.F.s induced by the jumps in magnetisation.

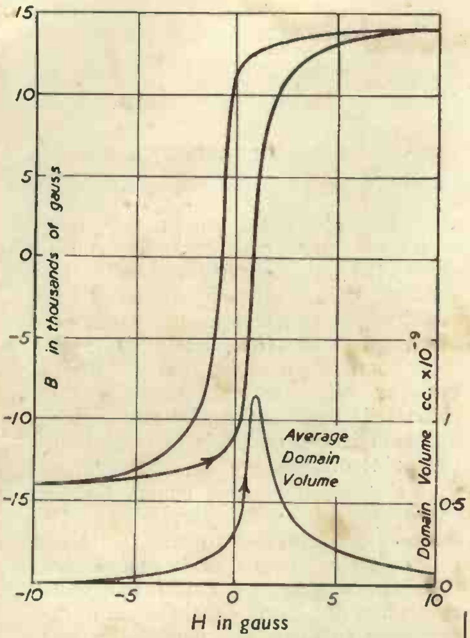


Fig. 5. Hysteresis loop and average volume of Domains for annealed Iron.

Oscillographic records of these discontinuities were obtained by Bozorth and Dillinger, from which the approximate domain sizes were deduced. Fig. 5 shows the average volume of the domains so obtained for one-half of the hysteresis loop of a sample of iron. It will be seen that the largest discontinuities, corresponding to domains with a linear dimension of the order of 0.001 cm. occur near the steepest part of the hysteresis loop.

1.7 Structure of a Ferromagnetic

We have thus seen that a ferromagnetic element or alloy owes its special characteristics to the existence of elemental magnets or spinning electrons which are spontaneously pulled into parallel alignment to form the saturated domains. In general a large number of such domains go to make up each grain in a polycrystalline material. For example, if the latter contained 1,000 grains per cubic mm.^{3}, and the largest domains have a volume of 10^{-9} c.c., there would be at least 1,000 domains in each grain.

The observed magnetic properties of a material are, of course, the resultant of the magnetic processes occurring in all its constituent crystals. It is thus important to understand the process of magnetisation in single crystals. This subject will be considered in the next section.

(*To be continued.*)

Electro-photography

In the July issue of RADIO NEWS magazine, Nicholas Langer describes a new system of producing photographic prints by electronic action instead of by the conventional chemical processes.

The method, which is due to C. F. Carlson of New York,* uses a photosensitive plate which is coated with a uniform layer of "photo-conductive insulating material." This material has a high insulation resistance in the dark but becomes conductive under the action of light, returning instantaneously to its original resistance when the light is removed.

Sulphur or anthracene are quoted as suitable materials, being applied to the metal plate in a layer about .001 in. thick.

The surface of the material is given a uniform charge by rubbing lightly with a dry cloth or brush after loading into the camera in the dark. When the plate is exposed, the parts of the coating illuminated allow the charge to leak away through the photo-conductive layer to the backing plate, and the image is thus stored on the plate as an electric charge pattern—an electrostatic latent image.

Development

The development of the image is carried out by utilising the attraction of the charge for fine particles. These may be in the form of lycopodium powder, powdered ink, resin, or carbon. The photo-conductive powders are near the negative end of the electrostatic series, and for best adhesion it is therefore preferable to use a powder which becomes positively charged on agitation.

Resin powders, which acquire negative charges, will be repelled from the charged areas of the plate instead of attracted, and can thus be used to produce a negative image instead of a positive one.

After dusting the powder over the surface of the plate, the excess is gently blown off, leaving the black portions of the picture with a full coating of powder and the rest in proportion to the tone of the image.

**U.S. Patents*: 2,221,776
2,227,013
2,297,691.

Printing off

The image as viewed on the coated plate will, of course, be a mirror reserve of the original scene. To obtain a final copy it is therefore necessary to roll or press a moist sheet of paper against the coated surface. The damp paper causes the powder to adhere mechanically, removing it from the coated plate. The method of fixing the powder on the paper varies with the type of powder used. If a fusible resin, the paper can be warmed sufficiently to melt the powder on to it. If it is soluble in a solvent such as alcohol, the paper is moistened to carry the dye into the surface. Other powders can be fixed by a thin coating of adhesive. In all cases the result is a positive permanent print. Best results are obtained with powders of .001" grain size.

The size appears to contribute to the ability of the particles to flow or roll readily over the surface of the plate and distribute themselves uniformly in the electostatic field.

The development of the plate by dusting is fairly rapid, requiring only a second or so, as it depends on the mechanical means for applying the powder.

Exposure

The exposure required is longer than that for ordinary plates—30 sec. with a f.4.5 is quoted for an anthracene plate for two photoflood lamps. The maximum response of anthracene is at 5.400 A., and that for sulphur 4,700 A., above which it falls rapidly.

Line Blocks

One suggested application of the process is in the making of line blocks on metal, the coating used being anthracene.

Anthracene has a melting point of 217°C. and a boiling point of 354°C., but in thin layers the transition from melting to vapour takes place almost instantaneously. After exposure, the coating is dusted with asphalt and is then heated slowly to 150—200° C., causing the anthracene to volatilise and allow the asphalt to settle on the metal surface. This forms an acid resist for the conventional etching process. It is stated that the method works equally well for lithographic plates.

REFERENCES
Monkman, *Proc. Roy. Soc.* 46, 143' 1889.
Kurrelmeyer, *Phys. Rev.* (2) 30, 893, 1927.
Pauli, *Ann d. Phys.* 40, 686, 1913.

A Vector Calculating Device

By C. SNOWDON, B.Sc.*

The conversion of vectors of the complex form (a + jb) to the polar form $r|\underline{\theta}$ and vice versa by a graphical method

Introduction

ELECTRONIC engineers and power engineers too are often called upon to use vectors in their calculations. These vector calculations, though usually simple, involve tedious work in the conversion from the complex form $(a+jb)$ to the polar form $r|\underline{\theta}$. Engineers are conversant with the usual method employed, *i.e.*, $r = \sqrt{a^2 + b^2}$ and $\theta = \tan^{-1}\frac{b}{a}$.

It will thus be appreciated that the conversion not only causes delay in calculations, but is also a fruitful source of errors. Special types of slide rule have been designed which enable such conversions to be made with the same ease as ordinary arithmetic calculations, but the number of engineers possessing these instruments is insignificant compared with the number who use vectors.

The purpose of this article is to describe a means of reducing this tedious work to a minimum, consisting essentially of a baseboard chart and a transparent cursor, both of which can easily be constructed.

In order to understand the construction of the chart, a consideration should first be made of the theory of the Argand Diagram (Fig. 1).

OX and OY are rectangular axes, "a" being measured from O along the X axis and "b" measured from O along the Y axis.

The point P has coordinates of $(a.b)$ which produce the vector OP, of length r measured from O and angle θ to the OX axis.

If the radius vector r is kept constant, but the angle θ varied, then the locus of the point P is a circle about centre O. Thus various values of r give rise to a family of concentric circles of appropriate radii.

A calculator embodying these facts suffers from the practical difficulty that all the loci have different curvatures. If then a calculator could be constructed on which all the loci have exactly the same curvature, such a locus could be drawn on a transparent cursor and placed in the required position on the main diagram.

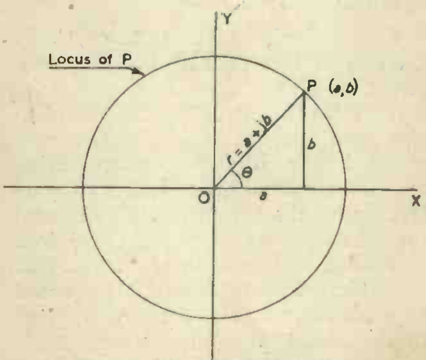


Fig. 1. The Argand Diagram.

Such a result has been obtained by plotting the Argand Diagram on double logarithmic paper.

Construction of Calculator

(i) Baseboard Chart

The chart consists of a sheet of standard double logarithmic graph paper, the 10-inch square type being very suitable, and such paper can readily be constructed using an ordinary 10-inch slide rule. Each scale is marked from 0.1 to 10, values of "a" being plotted along the horizontal axis, and those of "b" plotted along the vertical axis. A diagonal is drawn from the bottom left to the top right corner (Fig. 2).

On this chart is drawn the radius vector r of value 10 units, by plotting "a" = 10 cos θ and "b" = 10 sin θ along the horizontal and vertical axis respectively, values of θ being from 0° to 90°. This curve will be found to be asymptotic to the lines $a=10$ and $b=10$, due to the fact that the origin of both a and b axes is at infinity. Such a curve using this particular size of paper can only be plotted between the angular limits given by:

$$\theta_{min} = \tan^{-1}\frac{0.1}{10} = \tan^{-1}0.01 = .75°$$

and

$$\theta_{max} = \tan^{-1}\frac{10}{0.1} = \tan^{-1}100 = 89.25°$$

but this must not be regarded as a serious drawback since such extreme cases are rarely met with in practice, and in most cases the smaller term would be ignored. If greater accuracy is required, however, a larger sheet of graph paper (*i.e.*, one containing more than two octaves) must be used, but for all practical purposes the chart will be found to be sufficiently accurate if the curve is connected to the point 0.1, 10.

If the angle is kept constant then the locus is a line parallel to the diagonal, again due to the fact that the origin of the paper is at infinity. The curve may be calibrated with respect to these angles, there being no necessity to draw the whole line.

For the proof of these facts reference should be made to the Appendix.

(ii) The Cursor

The curve drawn on the chart for r = 10 units, the diagonal and also the asymptotes should be transferred to a transparent cursor, preferably made of celluloid though tracing cloth could be used.

The cursor should then be calibrated with angles indicated by the expression

$$b/a = \tan\theta$$

suitable values of a and θ being selected and b calculated. A condensed table of such values is given in the Appendix.

Consider the vector $(a + jb)$ in Fig. 2, and hence determine the point P. The cursor is now moved over the chart, with the two diagonals superimposed, until the curve on the cursor passes through the point P. The intersection of the asymptote on either of the axes then giving the value r, the angle of the vector being read off from the scale on the cursor.

Examples in Using the Chart

A few simple examples are now enumerated in order to illustrate the manipulation of the calculator.

1. **To convert the vector (1 + j2) to the form $r|\underline{\theta}$**

Determine the point (1 + j2), moving the cursor along the diagonal until it passes through the point. The asymptotes intersect both horizontal

* Messrs' Reyrolle & Co. Ltd.

The Chart with Cursor Superimposed

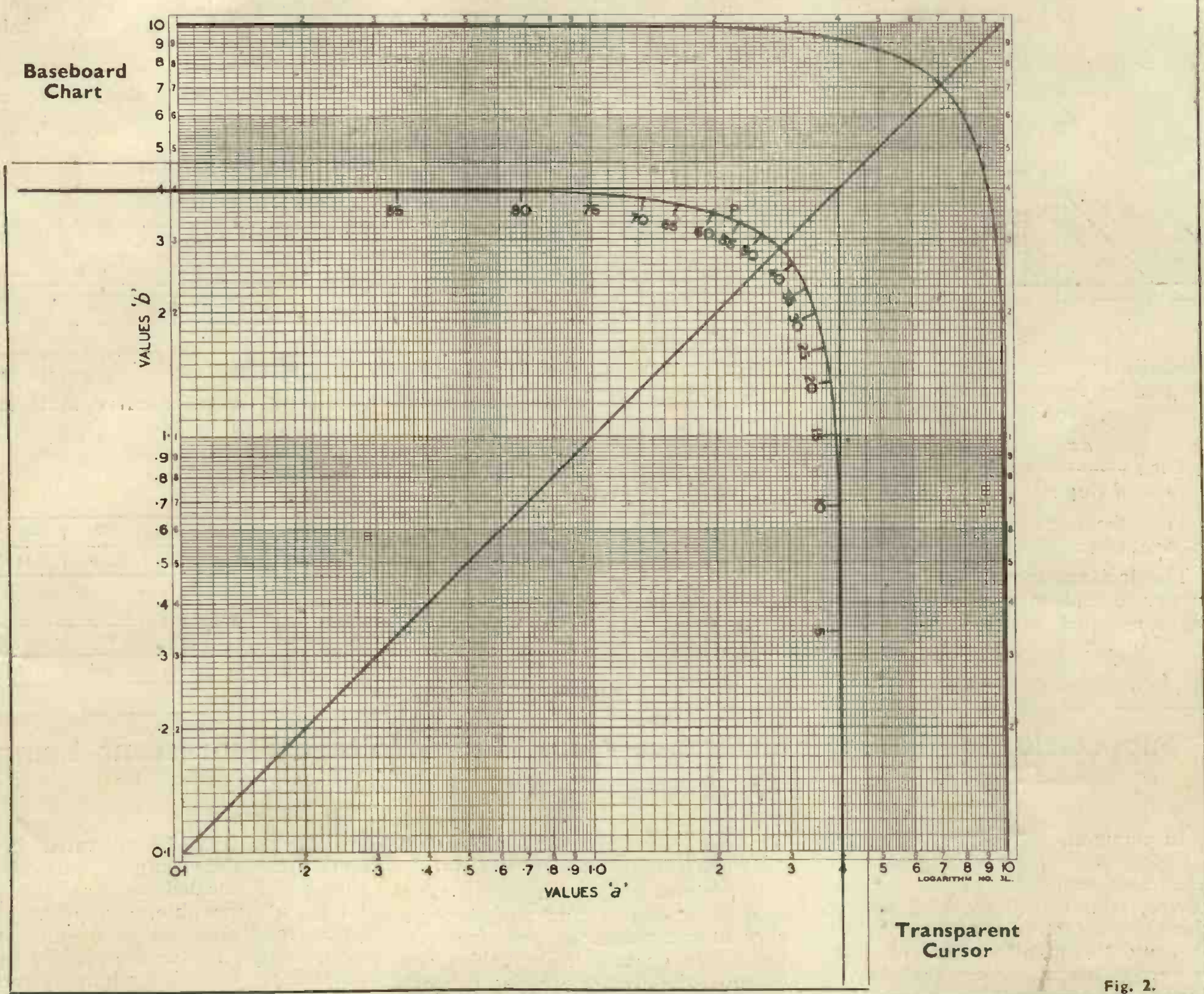


Fig. 2.

and vertical axes at the value of $r = 2.24$, and from the position of the point on the curve $\theta = 62.5^\circ$

(*i.e.*) $(1 + j2) \equiv 2.24\,|\underline{62.5^\circ}$

2. To convert the vector (30 + j75) to the form $r|\underline{\theta}$.

This example is solved by determining r and θ as described in (1) but for $(3 + j\,7.5)$ which will be found to give values of $r = 8.1$ and $\theta = 68^\circ$. However, the decimal point must now be readjusted giving $r = 81$ and $\theta = 68^\circ$.

(*i.e.*) $(30 + j75) \equiv 81\,|\underline{68^\circ}$

3. To convert $3|\underline{22^\circ}$ to the form (a + jb)

Move the cursor along the diagonal until the asymptote intersects both horizontal and vertical axes at 3 units, then tracing along the curve to the angle 22° the values of a and b may be read off $a = 2.8$ $b = 1.1$.

(*i.e.*) $3\,|\underline{22^\circ} \equiv (2.8 + j\,1.1)$

Concluding Notes

The following are a few of the peculiar advantages obtained by the use of double logarithmic graph paper :—

(i) An extremely wide range of values is obtainable.

(ii) The percentage accuracy of reading is (as on a slide rule) consistent, no matter what point is chosen on the scales.

(iii) All loci are of same form and therefore only one such locus is required on the cursor, thus obviating the necessity of the estimation of values by eye between closely drawn loci on the chart.

APPENDIX

Proof of the Cursor construction

Equation to the circular locus described by the point P in Fig. 1 is

$$a^2 + b^2 = r^2$$

Introducing the parameters r and θ

$$a = r \cos\theta \text{ and } b = r \sin\theta$$

Plotting on logarithmic scales, as in Fig. 3.

$$x = m \log a$$

and $y = m \log b$

where m is the scale modulus.

Consider the equation

$$a = r \cos\theta$$

$$\therefore \log a = \log r + \log \cos\theta.$$

Now from above $\log a = \dfrac{x}{m}$

$$\therefore \frac{x}{m} = \log r + \log \cos\theta.$$

$$\therefore x = m \log r + m \log \cos\theta.$$

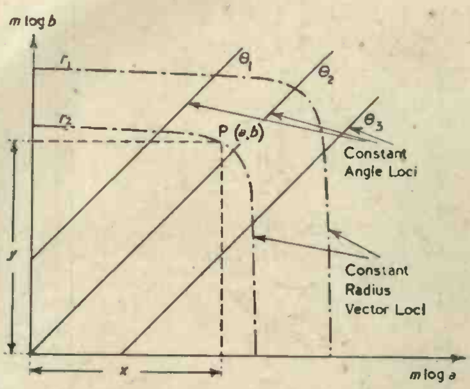


Fig. 3.

Similarly $y=m \log (r+m) \log \sin \theta$. Consider θ as constant and x, y and r variable.

Then $\dfrac{dx}{d(\log r)}=m$ and $\dfrac{dy}{d(\log r)}=m$

Thus the slope of the curve is independent of the value of $\log r$, *i.e.*, of r.

The loci are therefore of the same curvature and same shape and may be represented by one such curve.

$$x=m \log r+m \log \cos \theta$$

$$i.e.,\ m \log r=x-m \log \cos \theta.$$

Also $y=m \log r+m \log \sin \theta$

$$i.e.,\ m \log r=y-m \log \sin \theta$$

$$\therefore x-m \log \cos \theta=y-m \log \sin \theta$$

$$y=x-m (\log \cos \theta-\log \sin \theta)$$

$$=x-m \log \cot \theta.$$

Thus if θ is kept constant the equation is that of a straight line at a slope of 45°, and for various values of θ is a series of parallel straight lines.

This enables the curve to be calibrated for various values of θ.

Table of values for constructing the cursor.

Plot out on to double log paper and trace on to cursor.

a	10	9.9	9.8	9.6	9.4	9.2	9.0	8.50	8.0	7.5	7.0	6.5
jb	0.1	1.39	1.98	2.81	3.4	3.92	4.35	5.27	6.0	6.61	7.14	7.6

a	0.1	1.39	1.98	2.81	3.4	3.92	4.35	5.27	6.0	6.61	7.14
jb	10	9.9	9.8	9.6	9.4	9.2	9.0	8.5	8.0	7.5	7.0

For marking of the angles on the curve, plot the following points and draw a line parallel to the diagonal until it intersects the curve, mark this point with the appropriate angle. $b/a = \tan \theta$

$$i.e.,\ b = a \tan \theta.$$

Plot for $a = 0.10$.

θ	45	50	55	60	65	70	75	80	85
jb	0.10	0.119	0.143	0.173	0.214	0.275	0.373	0.567	1.14

Plot for $jb = 0.10$.

θ	45	40	35	30	25	20	15	10	5
a	0.10	0.119	0.143	0.173	0.214	0.275	0.373	0.567	1.14

Suppression of Radio Interference from Mains Voltage Fluorescent Lamps

By J. N. Aldington, B.Sc., F.Inst.P. *

In common with other cases where interference is caused by electrical apparatus adjacent to a radio receiver, it is considered that each of three main factors may contribute to the audible manifestation of interference currents generated by a fluorescent lamp. These are :—

(1) Direct radiation from the lamp itself with which is closely connected.

(2) Radiation from the wiring connecting the lighting point.

(3) Feed-back into the lighting mains of interference currents, which may therefore, after rectification in the receiver, reach the loud speaker via the power unit.

(1) *Direct Radiation from the Lamp.*

There is small likelihood of direct radiation from a fluorescent lamp producing a disturbing effect from a radio receiver in the same room unless the lamp is mounted very closely to the radio, and even then the normally fitted suppressor condenser is generally found adequate.

(2) *Radiation from the Wiring Connecting the Lighting Point.*

Experiments have shown that the field from the conductors becomes very attenuated a few feet from the lamp. In general if the cables connecting the lamp are in properly earthed and bonded steel tubing or lead-covered cable, and the control gear is mounted in an earthed metal container, it is unlikely that interference due to radiation from the wiring will be encountered.

In order that radiation should be reduced to a minimum, the length of the leads from the lamp to the suppressor condenser should be kept as short as possible, even if this entails mounting the suppressor condenser separately to the choke coil.

(3) *Feed-back into the Supply Mains.*

A simple arrangement of condensers will normally be found effective as a filter. One, of 0.05 mfd., is connected across the lamp, while two others, of the same value, are connected one from each lamp terminal to earth. The three condensers may be mounted in a convenient and ocmpact unit which should be located as near to the lamp as possible, so that besides reducing feed-back into the mains supplying the radio, the length of wiring which might directly radiate is reduced to a minimum.

In conclusion, the magnitude of the interference currents produced by fluorescent lamps is generally of a sufficiently low order to be suppressed adequately by the condenser fitted for this and other purposes. The development of interference from an established installation may denote the necessity for relamping a lighting point. It has been found that the same factors which make this necessary from the point of view of lamp flicker at the end of life may increase the parasitic radiation from the lamp; in which case lamp renewal will effectively restore the original condition of a trouble-free installation.

(Extracted from *Electrical Times*, June 22, 1944.)

* Siemens Electric Lamp and Supplies, Ltd.

Problems in Electronic Organ Design

By S. K. LEWER, B.Sc.

OUT of all the electronic musical instruments which have been devised, the electronic organ has unquestionably the widest appeal. Its production on a commercial basis had been well established in the years immediately preceding the war and there is no doubt that when peace returns its technical development will be resumed.

The fact that electronic organs have been placed on the market is sufficient proof that the technical problems of design and construction can be solved. In commercial instruments, however, it is possible to resort to production methods which are beyond the scope of the private experimenter. Before he can attempt the construction of such an instrument with a reasonable chance of ultimate success he must assure himself that he has reduced the mechanical problems to the most rigorous simplicity. Otherwise, the inescapable complexity of the organ will magnify the task until it assumes prohibitive proportions.

It is not the purpose of this article to discuss the problems of the commercial types of electronic organ. For information on such instruments the reader is referred to a paper by Winch and Midgley[1] and to the relevant patent specifications.[2] The present account is a review of the author's experimental approach to the design of an electronic organ of modest character and of such a nature as to be suitable for private construction.

Fundamental Principles

In the first place, a choice can be made between two alternative principles of tone generation: (1) the direct production of complex, characteristic musical tones for subsequent selection by a keyboard system of control, or (2) the production of pure sine waves and their synthesis into characteristic tones by harmonic addition, followed by a system of keyboard control. Further, there exists a large range of methods by which acoustic tones may be generated in electrical circuits, such as electrostatic or electromagnetic alternators, photoelectric generators, valve reaction and relaxation oscillators. Amongst those methods which rely on electromechanical effects, there is a choice between rotary and vibratory systems.

The earliest experiments carried out by the author utilised the first of the alternative principles mentioned above —the generation of "ready-made" electrical wave-forms corresponding to the desired musical tones—and the electrostatic method of generation was selected as being the most suitable from the standpoint of experimental construction. The chief reasons for preferring the electrostatic method were (a) that it would obviously be easier to cut and shape metal electrodes than to wind large numbers of electromagnets or to set up precision optical systems, and (b) that the desired "attack" or "envelope" of the wave-form could easily be achieved by the use of time-delay resistance-capacity circuits for the control of excitation potentials, or by the mechanical time-variation of capacity. All the investigations which were subsequently carried out have confirmed the belief that the electrostatic method of tone generation is the best on the score of effectiveness, simplicity and flexibility.

Electrostatic Tone-Generator

The basic circuit of the polarised electrostatic tone-generator is shown in Fig. 1. A high resistance R (of several megohms) and a small capacity C (possibly of 1—10 pF) are connected in series to a source of potential difference E. When the capacity of C changes, the charging or discharging current flowing through R gives rise to a voltage e. If the capacity is changing cyclically at an audio frequency, the voltage e will have the same frequency and may be amplified suitably to drive a loudspeaker.

Any number of capacities, each varying at its own specific audio frequency, may be connected in parallel with the condenser C as shown, and the corresponding tones will be heard simultaneously from the loudspeaker. No tone is produced by any of the separate capacities which are allowed to remain fixed in value.

Provided certain conditions are fulfilled, a sinusoidal tone will be generated if the capacity of any of these condensers is caused to vary sinusoidally. The amplitude of the sound is proportional to the value of the excitation potential E. Consequently, tones of different amplitudes can be produced by connecting the capacities separately to points of different potential, as in Fig. 2. If the individual capacities C_1, C_2, C_3, C_4 are varied sinusoidally at frequencies which are harmonics of some fundamental frequency f (*i.e.* f, $2f$, $3f$, $4f$ . . .), the acoustic tone will be a complex one of that frequency and may be characteristic of a flute, clarinet or trumpet according to the number and amplitude of the several harmonic components. This is the well-known principle on which the characteristic tones of an organ can be simulated by harmonic synthesis of a number of sinusoidal component tones.

Alternatively, any individual capacity can be made to vary cyclically in such a form as to give the required tone directly. Such a complex time-variation of capacity can be achieved

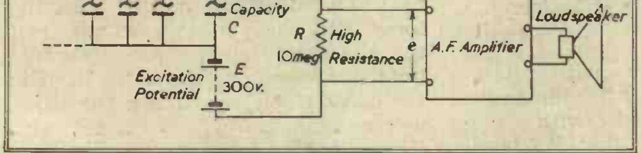


Fig. 1. The basic circuit of the polarised electrostatic tone-generator.

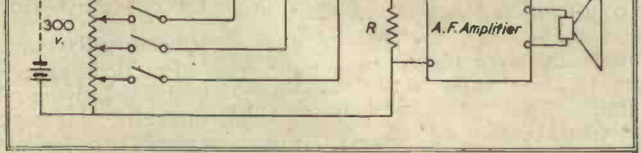


Fig. 2. Harmonic synthesis of complex musical tones by the addition of harmonically-related sine-waves of suitable amplitude

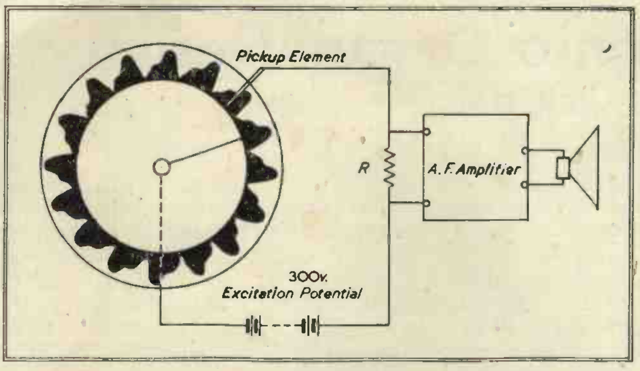


Fig. 3. The author's first experimental tone-generator, using a succession of complex waveforms carried on a rotating disk of insulating material and scanned by a narrow pickup electrode.

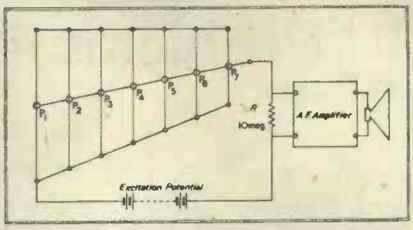


Fig. 4. The basic arrangement of electrostatic pickups in combination with stretched wires tuned to the musical scale. The arrangement exactly as shown is directly applicable with good effect to an ordinary piano.

in several different ways. In the first experimental model made by the author, a rotating insulated disk (actually a 10-inch gramophone record carried on a turntable) was provided with a number of equally spaced waveforms cut from tinfoil and pasted on to the disk A narrow metal strip fixed rigidly at a small distance from the rotating disk constituted the other electrode of the tone-generating condenser, the effective area of whose electrodes varied as the disk rotated. Fig. 3 shows the elements of this arrangement.

The need for a high degree of mechanical precision was immediately apparent, for any deviation from flatness in the disk, or any wobble or rumble in the shaft or its bearings, or any departure from constant speed, became evident as an unwanted modulation or variation of the musical tone. The effect of electrostatic charges on the surface of the insulating disk was also quite pronounced. Tones could still be easily obtained when the tinfoil had been stripped off.

Although the troubles due to surface charges were overcome by resorting to metal disks, the problem of mechanical imperfections remained. The waveforms consisting of cut-out shapes of flat metal sheet, were made stationary and were scanned either by radial arms extending from the periphery of the disk or by radial slits in the disk itself. In this case, as with the disks of insulating material, the generation of the higher harmonics by the use of a complex wave-form did not appear to be possible for ordinary speeds (about 1,200 R.P.M., corresponding approximately to 600 cycles per second) unless the scanning electrodes were made very narrow (less than 1 mm.) and were placed very close to the rotating surfaces (less than 0.5 mm.). This was evidently due to electrostatic edge-effects.

The sensitivity of these systems was reasonably high, and a three-stage amplifier having a gain of about 70 db was adequate for experimental purposes.

Absolute Pitch

In addition to the problem already mentioned, there was the question of the accuracy of frequency, or pitch. Whenever a tone is produced by a rotating system, there must obviously always be an integral number of elements contained within the periphery, and they must all be uniformly spaced. If several different tones are to be generated by elements mounted on a common rotating disk or cylinder, the speed of rotation must be chosen to suit the frequency requirements of the several tones. In practice, one can choose between two methods. The first is to mount all the A elements on one shaft, all the A♯ elements on another shaft, all the B's on a third, and so on. These shafts will then have to run at successively higher speeds, the ratio between the speeds of adjacent shafts being $\sqrt[12]{2}$. The second method is to arrange all the 12 rings of elements contained within one octave, A, A♯, B . . . . . . G♯, on a common shaft running at a suitable speed, and to operate a similar disk (or cylinder) at twice the speed, thereby generating all the tones in the next octave higher, and so on. The problems involved here are mainly arithmetical, but careful consideration must be given to the permissible deviations from the recognised scale of musical frequencies, for such deviations are inevitable where one shaft is used to drive several different tone generators. For further discussion of these matters, the reader is referred to the paper by Winch and Midgley[1].

Vibratory Systems

Practical experience with rotating systems and the numerous mechanical difficulties associated with them seemed to indicate that an easier solution might be found in vibratory systems. Therefore, still using the electrostatic principle, experiments were conducted to examine the possibilities of generating pure and complex tones and of providing satisfactory control with various vibratory elements. The first trials were made with strings, or more accurately, stretched wires. The results were distinctly encouraging and led incidentally to the adaptation of the principle to an ordinary piano. Fig. 4 shows the elements of this arrangement. The electrodes P_1, P_2, P_3, etc. are small metal plates, or studs, placed close to the piano strings at some selected point along the length of each string. The vibrations of the strings produce variations of capacity which are translated into oscillatory voltages across the high-resistance R, exactly as in the system illustrated in Fig. 1. Such electrostatic pianos have been marketed by Everett and by Chappell. The chief feature about their performance is the remarkably fine " body " of the bass tones and, of course, the wide range of acoustic power output[3].

Maintenance of Vibration

For the generation of sustained tones, as in the organ, it was necessary to be able to maintain the wires in steady vibration. It was obviously preferable to keep all the strings vibrating continuously and to excite them electrically when the corresponding tone frequencies were required by applying the necessary excitation potentials, as in the case of the rotary system. The continuous vibration was achieved by feeding some of the output current from the amplifier back into the string itself, a magnetic field being arranged transversely to the string. The alternating current thereby produced an alternating deflecting force, and since in this arrangement the alternating current was generated by the vibration of the string itself in the capacity-pickup circuit, the string was automatically in resonance with the current. Consequently, a state of steady oscillation was readily attained[4].

All the required strings covering the musical frequency range were connected in parallel and fed from the common amplifier which itself was fed from all the corresponding capacity-pickups, similarly connected together. For selecting and converting into musical sound the various tones generated by these strings it was necessary to provide a further set of pickups connected through suitable keying devices to a sound amplifier, separate from the maintaining amplifier. Fig. 5 illustrates the basic features of this arrangement.

It is quite unnecessary, of course, to design the frame which carries the strings on the lines of a piano frame. No acoustic output is required from the strings ; in fact, the quieter they are, the better. Consequently, the strings can be made quite light, of thin wire and of short length, the tension being very much less than that required in any normal stringed instrument. Brass or phosphor-bronze wire is satisfactory. Even copper wire, of gauges between 20 and 36 s.w.g., was frequently used in the early experiments. The magnetic field was produced by two small bar magnets, about 2 inches long, placed on opposite sides of each string.

Good electrostatic screening is essential, as in all of these polarised-capacity systems, to prevent hum pickup.

The keying of the pickups in such a system as this cannot easily be achieved by controlling the excitation potentials of the separate strings because all the strings are connected together for the supply of the maintaining current from the common output transformer. It would be possible to use a separately insulated winding for each individual string, perhaps covering the whole range in a series of eight or ten output transformers with multiple secondaries, but this method must be regarded as too cumbersome to be worthy of serious consideration. Alternatively, the keying can be performed by mechanical displacement of the pickup electrodes or the mechanical adjustment of auxiliary condensers of simple construction connected in the pickup leads.

An examination by means of a cathode-ray oscillograph of the waveform produced by these string generators showed that, provided certain precautions were taken in the choice of the dimensions, the tones could be made reasonably pure. In this connection it is interesting to note that the existence or absence of harmonics in the vibration of the string is very largely determined by the position of the maintaining capacity-electrode and the magnetic field. The best results are obtained when they are placed respectively at the centre and at one third of the length of the string measured from either end. By reason of the feedback principle, there cannot then be a node at either of these points, so that the second and third harmonics are precluded. If required, the system can be elaborated with further pickups and magnets, either to assist or oppose harmonic phases.

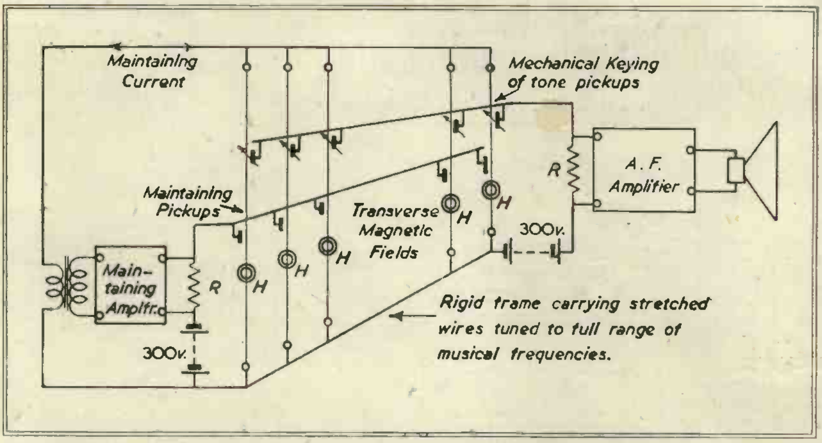


Fig. 5. The basic arrangement of an electronic organ using stretched wires continuously vibrating as tone-generators. One amplifier is used to maintain all the strings in vibration. A second amplifier provides the acoustic output.

The major practical difficulty encountered in all the experimental models based on this principle was the maintenance of absolutely constant amplitude of all the strings. Slight variations in the sensitivity of the pickups or in the gain of the maintaining amplifier, and also certain unintentional feedback effects in the circuit arrangement, gave rise to slow, wandering changes in the amplitude of vibration. Such variations are fatal to the satisfactory synthesis of complex wave-forms, and therefore an improved method of driving the strings was sought.

Air-jet String Resonators

It was discovered that stretched wires could be made to vibrate very easily at their resonant frequencies by means of an air jet (*see* Fig. 6) and that it was possible to produce quite large amplitudes which remained stable over long periods of time without special attention being given to the airflow. This method appeared to be highly satisfactory for all strings vibrating at frequencies lower than about 800 c.p.s. It was extremely difficult, however, to produce vibrations in strings of small diameter or length and where the tension was high (*i.e.* the conditions necessary for the higher frequencies). Although the air-driven string evidently had very promising characteristics for the lower frequencies, and might successfully be combined with some other method better suited to the upper frequencies, no further investigation of its possibilties was made, and the search for a system capable of satisfactory application over the whole audio range was continued.

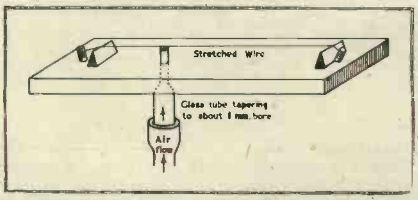


Fig. 6. Air at low pressure emerging from a jet placed close to the stretched wire will maintain it in steady vibration.

Reed Tone-Generators

At this stage, attention was turned towards the vibrating reed as a variable-capacity element. With such elements it is, of course, preferable to use the principle of variable-spacing at constant area (as in the case of strings), rather than that of variable-area at constant spacing (as in the rotary system). Again, therefore, the problem resolved itself into the question of generating pure sine-waves for harmonic synthesis, the production of a range of "ready-made" complex tones by a variable-spacing method being regarded as unattainable.

There seems to be a peculiar prejudice in some quarters against the use of reeds in electronic musical instruments, apparently arising from the belief that the acoustic reed-tone will persist in any electronically-

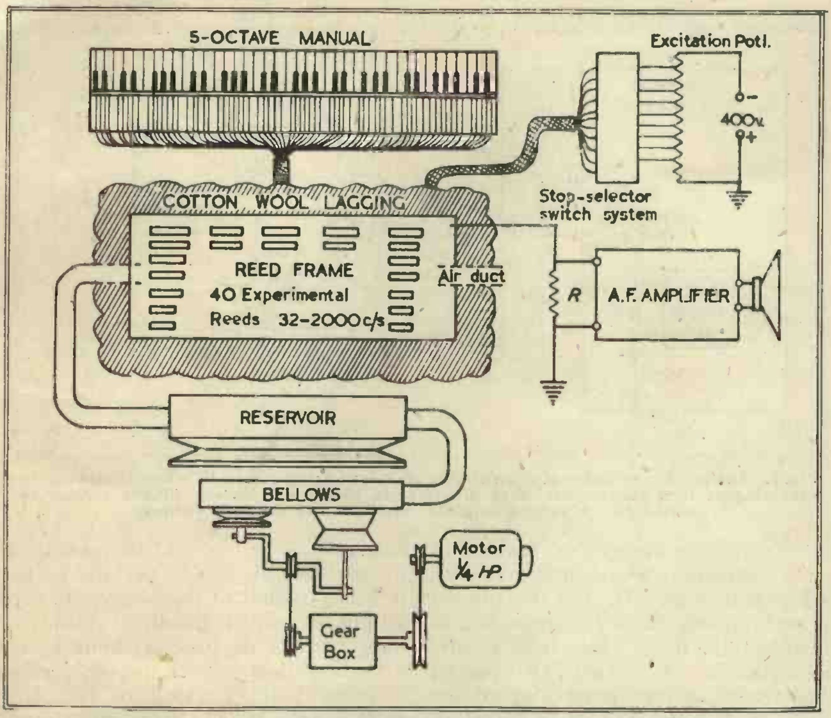


Fig. 7. The general arrangement of the experimental organ using vibrating reed tone-generators with provision for harmonic synthesis of complex tones.

produced tone derived from the reeds. This is entirely without technical foundation. The characteristic tone of a reed is due primarily to the sudden changes in the flow of air through the reed mounting-frame. Thus, air-waves rich in harmonics may be generated even when the reed is swinging sinusoidally, and the electrical output from a capacity pickup in such a case will be unaffected by the existence of the steeply-fronted air-waves (except in a negligible degree by the effects of acoustic reaction on the movement of the reed). The electrical output will be controlled predominantly by the conditions governing the electric field around the pickup ; *e.g.* the shape and position of the electrode in relation to the reed.

Experiments were made first with reeds taken from a harmonica (more commonly known as a mouth-organ). Apart from the difficulty in handling the very small frames when they had been cut out of the instrument, these reeds proved to be quite serviceable. Subsequently, ordinary American organ reeds were used instead, and these, being much larger, facilitated the work of assembly. A model containing 40 such reeds, spread over a range of frequency from 32 to 2,000 c.p.s., was eventually constructed with a 5-octave single manual in order to test the capabilities of the system on a reasonably large scale. A diagram of the general arrangement is given in Fig. 7. The elements of the circuit corresponding to each key on the manual are shown in Fig. 8.

There was considerable difficulty in silencing the direct acoustic output from the reeds, but while it is true that all the reeds are operating all the time —and therefore the sound might be expected to be very much greater than in an ordinary American organ—the reeds themselves were mounted without any resonators or sound-chambers, and it was only the higher-frequency reeds that gave serious trouble. The bass reeds made very little sound. In the experimental model, absorbing screens of cotton-wool were set up round the reeds, but no doubt one of the special sound-absorbing materials would have been more effective.

Key-click filters consisting of a high-resistance and a capacity were placed as close to the pickups as possible to prevent sudden unwanted changes of potential of the pickup electrodes. These filters are shown in Fig. 8. By choosing suitable values, they could conveniently be made to provide the desired degree of " attack."

The experiments were conducted far enough to show that the system of continuously-operated reed generators was capable of reliable performance as an electronic organ, using the method of harmonic synthesis for the production of complex tones. There was however, a rather troublesome fault, which did not appear in the earlier, smaller models but only when the

(*Concluded on p.* 161)

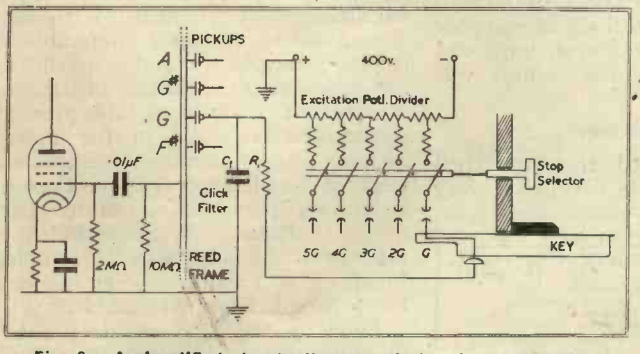


Fig. 8. A simplified circuit diagram of the electronic organ shown in Fig. 7. The depression of the key G causes suitable polarising potentials to be applied to the pickup electrodes corresponding to the G tone-generator and the harmonics 2G, 3G, 5G, etc. Clicks from the switching system are prevented by the filter C_1R_1.

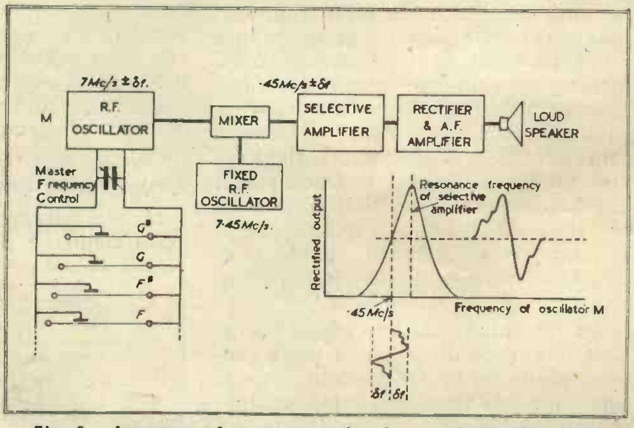


Fig. 9. A system of tone-generation for an electronic organ using the principle of frequency-modulation. The frequency of the acoustic output is determined by the frequency of variation of the tone-capacities and has no relation to the frequencies of the R.F. oscillators.

Cathode-Ray Tube Traces

A Series to Illustrate Cathode-Ray Tube Technique

Part I.—Lissajous Figures (concluded)

By HILARY MOSS, Ph.D., A.M.I.E.E.

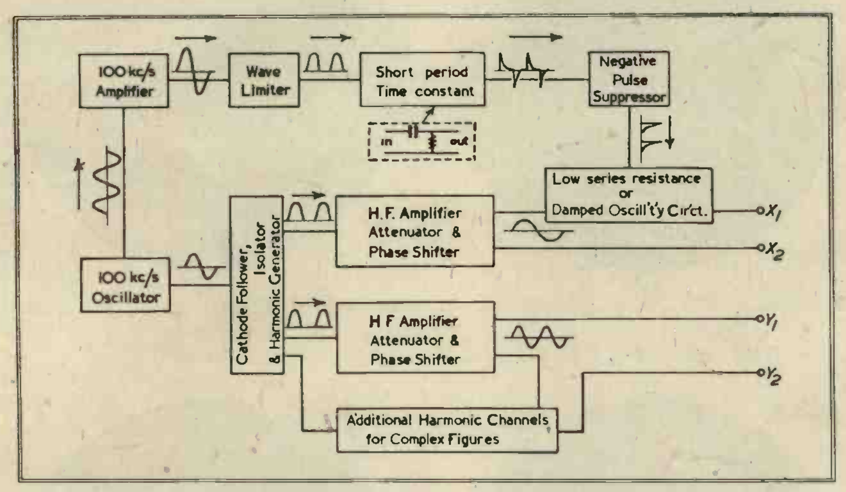


Fig. 6. Circuit Network for pulse injection into Lissajous figures.

8.—Pulse Injection

IT has been shown in the preceding articles that the full interpretation of the Lissajous figure requires that the direction of rotation of the spot round the figure be known. In addition it was shown in the last article that the synthesis of the complex figure from the component oscillations, requires that the common points on these component traces are also defined. These two distinct requirements may be simultaneously met by the injection into the figure of a sharp pulse formed by differentiating a square wave. By suitable choice of the circuit time constants, the relative steepness of the wave front and wave tail can be adjusted so as to form a marking "arrow," with the more gradually sloping wave tail pointing in the direction of rotation.

Fig. 6 shows the fundamental circuit arrangement of Fig. 2 for the generation of the Lissajous figures, but modified to provide for pulse injection. The method is fairly obvious, and is a perfectly standard technique. The 100 kc/s. oscillator frequency is used as the source, since we require only *one* pulse per complete cycle. Derivation of the pulse voltage from one of the higher frequency harmonics would, of course, provide the same number of pulses per cycle as the order of the harmonic. The output voltage is "squared" by the usual saturated valve method relying on grid current. The squaring is assisted by preliminary amplification of the applied voltage so as to produce a sharper cut-off/conduction transition in the squaring valve, which should, of course, have as short a grid base as possible. The approximately square wave output is then differentiated by the short time constant resistance/condenser network, this producing the familiar almost arrow-shaped figures of both negative and positive polarity. By means of a triode valve biased beyond cut-off the negative pulse is suppressed, and the residual positive pulse appearing in its anode circuit is series connected into the output of the 100 K.C. component oscillation. Note that this technique ensures a perfectly synthronised pulse.

Figs. 55, 56 and 57 show some results obtained with this method. Owing to the high frequency of the driving oscillators for the figure, the arrow does not indicate the direction of spot rotation too clearly, since it is difficult to produce a sufficiently sharp wave front. In this connection it should be remembered that the total "X" sweep time is only 5 microseconds, and the wave front of the pulse shown is about 1/5 microsecond. When actually using the apparatus, however, there is no difficulty whatever, since by adjustment of the pulse amplitude control it is very easy to distinguish the wave tail.

In view of this lack of sharpness in the marking arrow, the use of a "ringing" circuit was tried. The pulse was employed to shock excite a damped resonant circuit of suitable natural frequency. Photos 58-66 inclusive show the results obtained, which are perhaps a little clearer, as there is less difficulty in recognising the exponential tail to the oscillation group.

Comparison of photos 58-60 and 61-63 shows the different resultant figure arising from identically-shaped components, due to a reversal in the direction of rotation of the spot around *one* of the component figures. Comparison of photos 61-63 and 64-66 illustrates that a reversal of direction of rotation in *both* components merely reverses the direction of scan in the resultant without alteration of its shape. These questions were discussed fully in the last article.

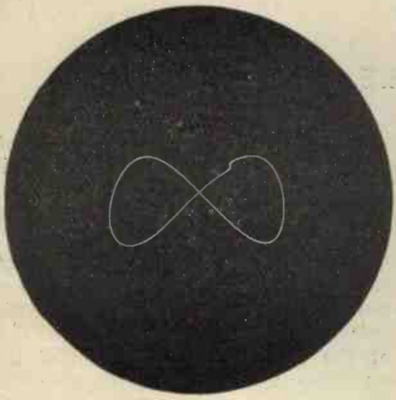
Conversion of Lissajous Figures to Linear Time Base — Ryan's Construction

Where at least one of the component axes of oscillation contains only one harmonic term, Ryan's construction readily permits the wave shape on the other axis to be displayed against the time (or angle θ) instead of against sin θ as in the photos shown.

Fig. 7 illustrates the method which is almost self evident. A circle is drawn, of diameter equal to the total sweep amplitude on the axis of the single harmonic term. This is divided into a convenient number of sectors (say $2.n$) having the same angle at

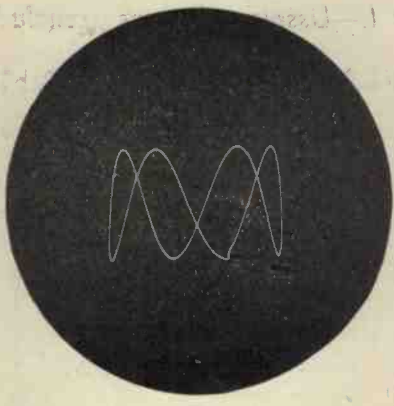
Pulse Injection into Lissajous Figures

$x = A \sin \theta$ $y = B \sin (2\theta + \alpha)$



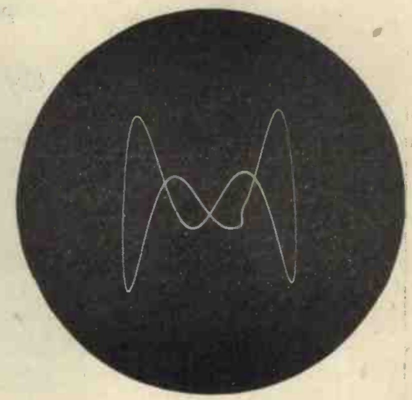
55

$x = A \sin \theta$ $y = B \sin (4\theta + \alpha)$



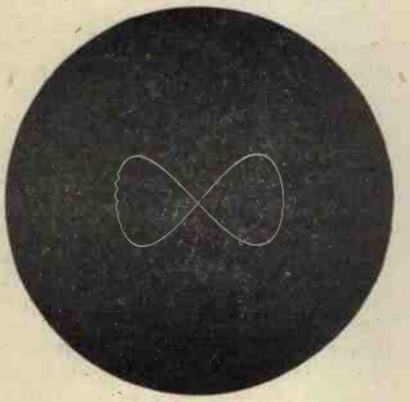
56

Resultant



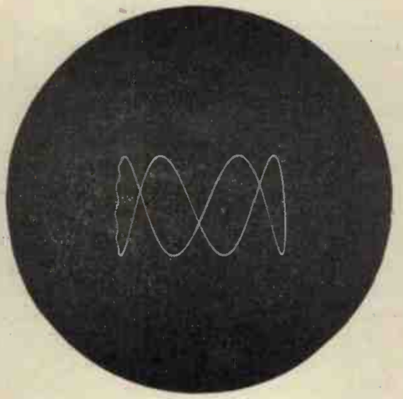
57

$x = A \sin \theta$ $y = B \sin (2\theta + \alpha)$



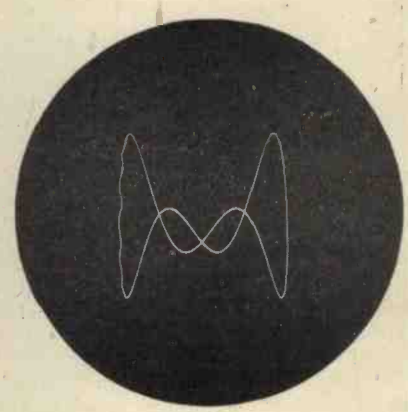
58

$x = A \sin \theta$ $y = B \sin (4\theta + \alpha)$



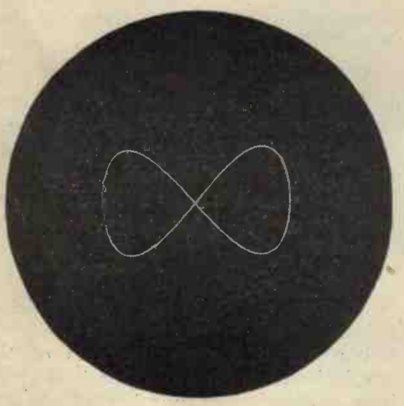
59

Resultant



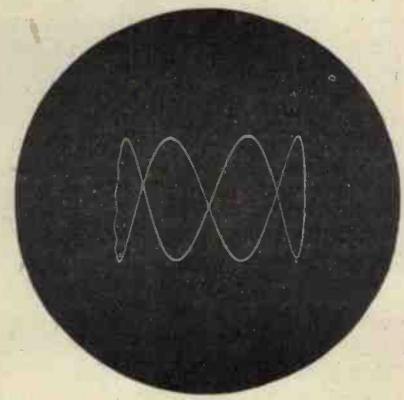
60

$x = A \sin \theta$ $y = B \sin (2\theta + \alpha)$



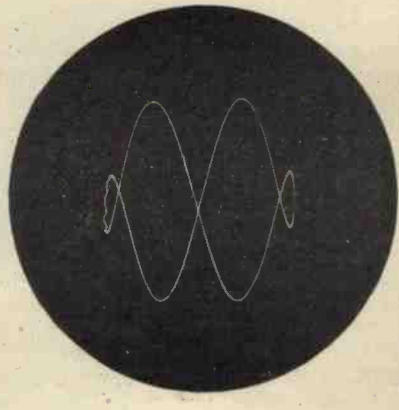
61

$x = A \sin \theta$ $y = B \sin (4\theta + \alpha)$



62

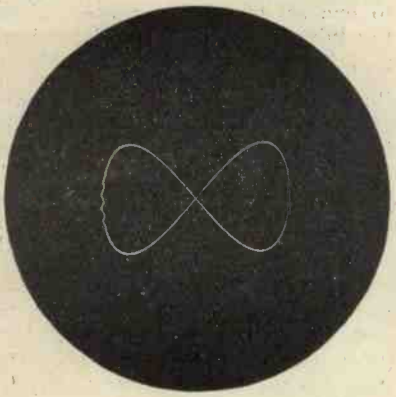
Resultant



63

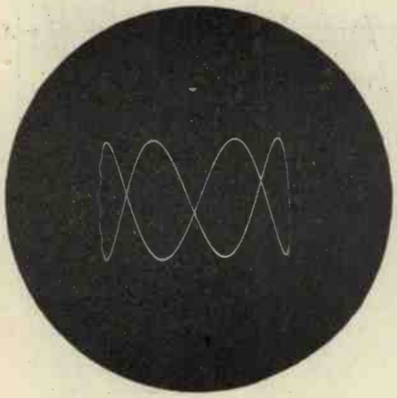
Pulse Injection into Lissajous Figures

$x = A \sin \theta$ $y = B \sin (2\theta + \alpha)$



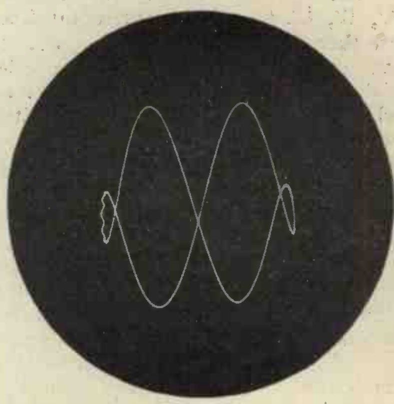
64

$x = A \sin \theta$ $y = B \sin (4\theta + \alpha)$



65

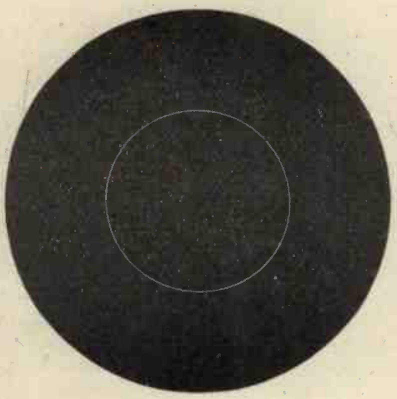
Resultant



66

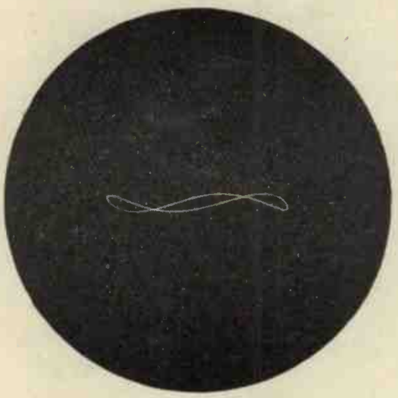
Phase-Splitting with impure waveform

$x = A \sin \theta$ $y = A \sin (\theta - \frac{\pi}{2})$



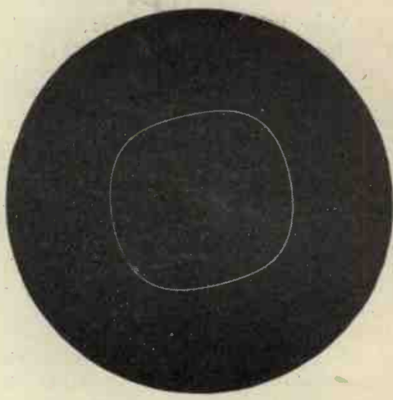
67

$x = A \sin \theta$ $y = B \sin (3\theta + \alpha)$



68

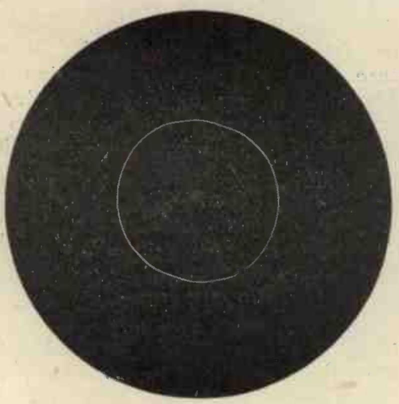
Resultant



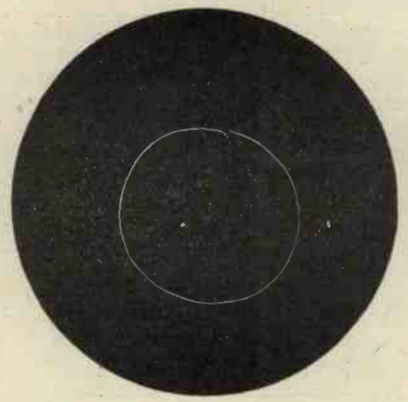
69

Pulse Injection into Low-Frequency Figures

Imperfect circle due to harmonic on 50 c/s mains

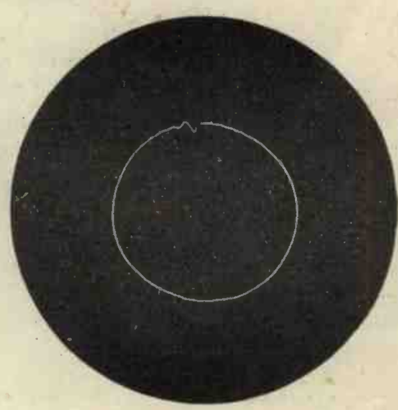


70



71

Rotation anti-clockwise



72

the centre, so that AB=BC, etc. The axis containing the single harmonic term is then divided into n equal parts by vertical lines LM, NP, etc. Verticals are then projected from A. B and C, etc., cutting the curve at A′, B′, C′. . . . Horizontal lines are then drawn from B′, C′ . . . to the appropriate vertical lines LM, NP, . . . cutting them in b, c, . . . which are points on the required converted curve.

Phase Splitting with Impure Wave Form

A form of complex Lissajous figure of some interest in cathode ray tube work is that arising from the phase splitting circuit of Fig. 8. If a pure sinusoidal voltage is maintained between the points A and B of this network, then the voltages across the condenser and resistances are also pure sine waves, but are in phase quadrature, *i.e.*, may be expressed:

$x = A.\sin\theta$ (resistance)

$y = B.\sin(\theta - \pi/2)$ (condenser)

which is merely a special case of (3) and gives rise to the figures of the type shown in traces Nos. 1, 2 and 3 (article 1). Very often, however, it is required to produce such a circular or elliptical trace from an impure source such as the 50 cycle mains. The latter usually contains a pronounced harmonic content, with the third harmonic dominant, and we shall now investigate the effects produced thereby.

Suppose that the equation to the voltage wave applied across AB is

$$e = E_1.\sin\theta + E_n.\sin(n.\theta + \alpha) \quad \ldots \; 20)$$

Since the circuit is linear, the resultant current will be the sum of the currents due to each component of the voltage wave considered separately. Thus

$$i = \frac{E_1.\sin(\theta+\beta)}{\sqrt{\left[R^2 + \dfrac{1}{\omega^2 C^2}\right]}} + \frac{E_n.\sin(n.\theta+\gamma)}{\sqrt{\left[R^2 + \dfrac{1}{n^2\omega^2 C^2}\right]}} \quad (21)$$

where as usual $\theta = \omega.t$, and $\omega = 2.\pi.f$. In practice $E_n \ll E_1$, so that in order to obtain an approximately circular trace, R is adjusted to satisfy the equation

$$R = 1/\omega C \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (22)$$

[deflector plate sensitivities assumed equal.]

Substituting this value of R into (21) gives

$$i = \frac{E_1.\omega C.\sin(\theta+\beta)}{\sqrt{2}} + \frac{E_n.n.\omega C.\sin(n\theta+\gamma)}{\sqrt{(n^2+1)}} \quad \ldots\ldots \; (23)$$

as the resultant current through the network.

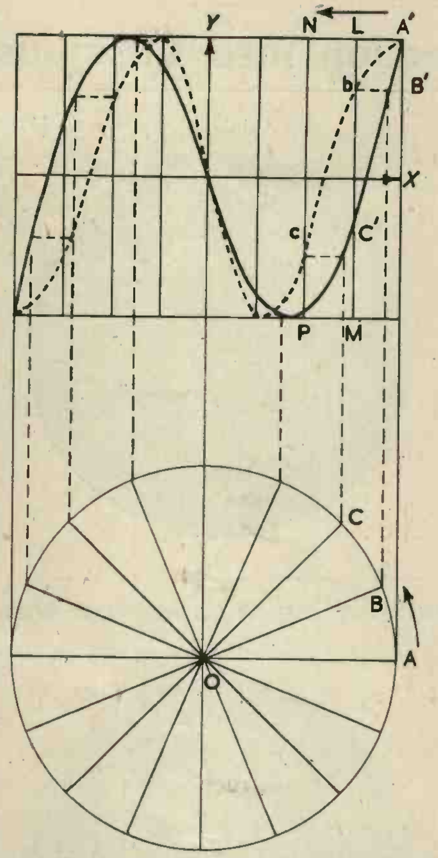


Fig. 7. Ryan's construction for conversion of figure to linear base.

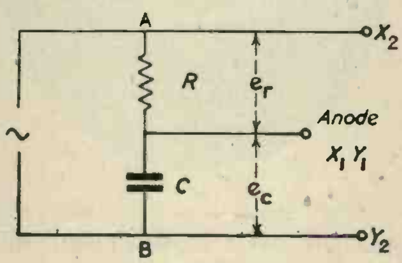


Fig. 8.

Again: $e = i.Z$ .... (24)

where Z is the impedance of the circuit element. Using (22) and (24) in (23) then shows that the voltage across across the condenser, e_c, is given by

$$e_c = \frac{E_1.\sin(\theta+\beta-\pi/2)}{\sqrt{.2}} + \frac{E_n.\sin(n.\theta+\gamma-\pi/2)}{\sqrt{(n^2+1)}} \quad \ldots\ldots\ldots\ldots \; (25)$$

while the voltage across the resistance e_r is

$$e_r = \frac{E_1.\sin(\theta+\beta)}{\sqrt{.2}} + \frac{E_n.n.\sin(n\theta+\gamma)}{\sqrt{(n^2+1)}} \quad \ldots\ldots\ldots\ldots \; (26)$$

Comparison of these last two equations shows that the harmonic component of the voltage across the condenser is only $1/n$ of that across the resistance. To a first approximation, therefore, the voltage applied to one set of plates of the cathode-ray tube can be considered as simple harmonic, since in practice $E_n \ll E_1$. Photos 67-69 illustrate the curve shape synthesis where $n = 3$. Photo 67 shows the perfect circle corresponding to pure harmonic oscillations on both axes in perfect phase quadrature. Photo 68 shows the third harmonic component and 69 the resultant distortion of the circle.

Photo 70 shows the actual circle form obtained from the circuit of Fig. 8 energised from 50 cycle mains. The third harmonic content is smaller than for No. 69 so the circle has less general distortion, but the same effect is clearly visible. The smaller oscillations are presumably due to tooth ripple on the alternators, or perhaps to multi-phase high-power arc rectifiers. The essential point is that to obtain a good circle from the resistance/condenser phase splitting circuit, it is necessary to energise it from a source of low harmonic content, say, less than 2 per cent. total.

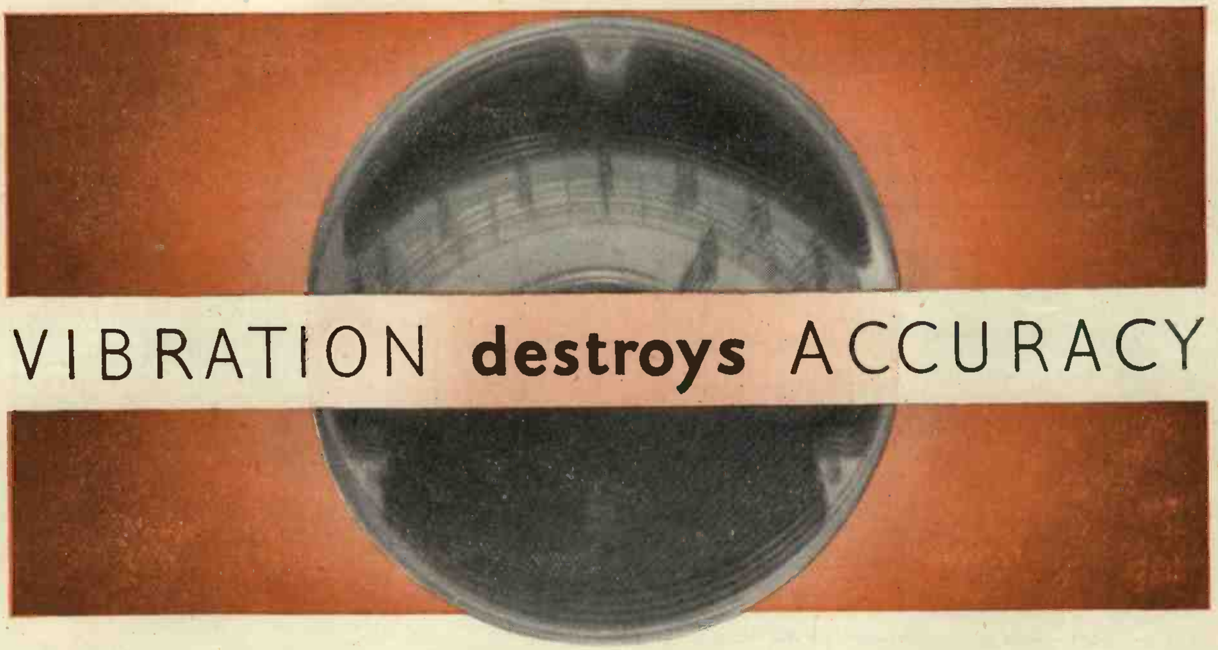
Photos 71 and 72 illustrate pulse injection on to low frequency Lissajous figures. The technique used was identical to that for the high frequency cases treated earlier. The technique is much easier, however, as the pulse writing speed need only be quite low, without detriment to the sharpness of the wave front, and it is now an easy matter to see which way round the spot is moving.

Literature

These four articles are intended as an introduction to the mathematical theory of the Lissajous figure. They do not pretend to be complete in that they do not contain specific reference to circuit investigation. The literature on the specific application of Lissajous figures to special problems is very extensive, but also very accessible. The reader is referred to the standard texts* to which these articles are merely a complement. Once the basic theory is understood, the application is generally fairly obvious.

Part 2 in this series will commence in a few months and will deal with the choice of Time Bases.

* e.g. "*The Cathode Ray Tube and its Applications*" (Chapman & Hall), which contains an extensive bibliography.



VIBRATION **destroys** ACCURACY

Delicate pivots,

fine gearing, tiny links and other details of sensitive instruments are damaged by vibration. Sometimes the damage is not instantly destructive, but is in the form of accelerated wear which sets up extra friction, impairs accuracy, and reduces the value and reliability of the readings obtained.

The importance of providing adequate vibration-absorbing mountings for aircraft instruments is well understood—for these are among the very many thousands for which we design and supply Metalastik mountings.

But in the factory and the power-station, the effects of vibration are not so fully realised, perhaps because they are not so obvious—but serious harm often results.

We in this company maintain a full research staff, with complete equipment, who can analyse vibrations from any source and of any character, and can design mountings to reduce or eliminate their harmful effects.

The small illustrations show three extremely simple Metalastik instrument mountings, the low-frequency type, left, the cross-type, centre, and the stud-type right.

An important development, the Statostable system of mounting, will be shown in a later advertisement.

Metalastik Ltd., Leicester.

METALASTIK

The Mechanism of Leaky Grid Detection—Part II

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

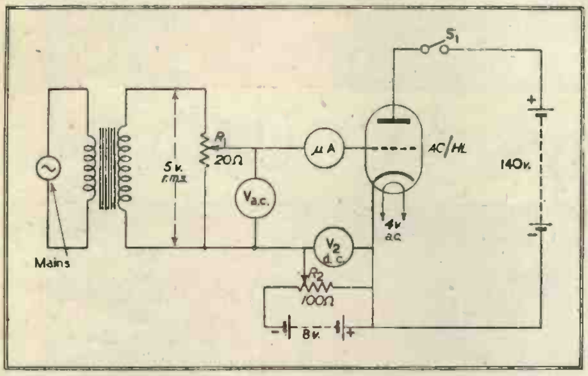


Fig. 1 (above). Apparatus for determining I_g-E_g characteristics.

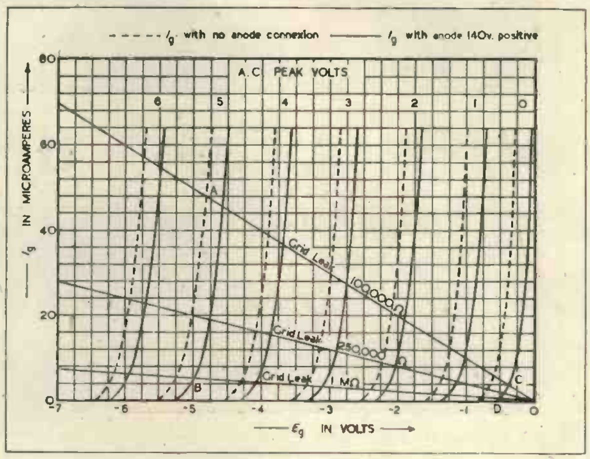


Fig. 2 (right). I_g-E_g characteristics for an AC/HL.

Determination of Ig-Eg Characteristics

THE experimental work undertaken to illustrate this analysis was carried out with a 4-volt indirectly-heated triode, actually an AC/HL. The first step was to determine the I_g-E_g curves and the circuit used for this purpose is represented in Fig. 1. It was made clear in Part I of this analysis that it is possible to construct one I_g-E_g curve for any particular value of A.C. input supplied to the valve. This being so the values of input chosen were zero volts (*i.e.*, no input at all), and 1, 2, 3, 4, 5 and 6 volts peak value (*i.e.*, readings of .71, 1.42, 2.12, 2.83, 3.53 and 4.24 volts R.M.S. as indicated on the moving coil instrument used). For each value of input, two I_g-E_g curves were taken, one with the anode of the valve connected to a source of 140 volts positive, the value of the H.T. supply used throughout the experiments, and the other with the anode disconnected.

The procedure for taking the curves is straightforward enough; the curve for zero volts input is taken with the slider of potentiometer R_1 at the bottom of its travel, by varying potentiometer R_2 in a series of steps and noting at each setting the readings of voltmeter V_2 and microammeter μA. In general we are only concerned with readings of μA of less than 100 μA. The readings of μA and V_2 are repeated with S_1 closed. R_1 is then adjusted so that voltmeter V_1 reads .71 volts R.M.S. (1 volt peak) and the procedure of reading μA and V_2 is repeated as before, with S_1 open and then closed. Readings were thus taken up to 6 volts peak value (4.24 volts r.m.s.). The results for the AC/HL valve are given in Fig. 2, in which load lines for grid leaks of value 100,000, 250,000 and 1,000,000 ohms are also drawn. This diagram is, in reality, a more comprehensive version of Fig. 4 of Part I and from it one can determine the value of E_g' for any given value of A.C. input and grid leak. For example, if the A.C. input is 5 volts and the grid leak is 100,000 ohms (point A in Fig. 2) the peak value of grid current is 46 μA and the peak value of direct potential developed across the grid leak is, from the graph or by calculation, obviously 4.6 volts. By increasing the value of R to 1,000,000 ohms (point B) I_g falls to 5 μA and E_g' increases to 5 volts. In the absence of an input signal the value of I_g is 4 μA with a grid leak of 100,000 ohms (point C), giving a negative bias of .4 volts and .5 μA if R is 1,000,000 ohms, making the bias −.5 volts (point D). The above remarks only apply accurately when the anode is connected to the H.T. supply of 140 volts.

Determination of A.C. and D.C. Characteristics

In order to assess the performance of the valve as a detector it is necessary to determine how the anode current depends on the grid potential both for steady values of grid potential and for A.C. inputs when the bias is obtained automatically from a grid condenser-grid leak combination. The former $I_a - E_g$ curves, usually known as dynamic characteristics, we will call, for want of a better name, the D.C. dynamic characteristics and the latter will be termed the A.C. dynamic characteristics. Using the same valve and H.T. supply the $I_a - E_g$ curves were determined for various values of anode resistance, R. The circuit used is illustrated in Fig. 3 and by noting corresponding readings of V and μA for various values of R_1 the D.C. dynamic characteristics can be determined. They are given in Fig. 4. The circuit drawn in Fig. 5 is the one used for determining the A.C. dynamic characteristics. The alternating input was provided by the alternating current mains and in order that the grid condenser should present the correct value of reactance at this frequency of its value was increased to 2 μF. At 50 c/s. the reactance of a condenser of 2 μF. capacitance is 1,592 ohms, the same value as for a condenser of 100 $\mu\mu$F. capacitance at 1,000 kc/s. The determination is similar to that of D.C. dynamic characteristics the readings of the milliammeter being noted for values of alternating input of 0, 1, 2, 3, 4, 5 and 6 volts peak value. The results are given in Fig. 6 for various values of grid leak. The anode resistance used had a value of 25,000 ohms. The curves are seen to differ considerably from the D.C. dynamic characteristics. To enable a convenient comparison to be made the D.C. dynamic characteristic for R_l = 25,000 ohms is reproduced also in this diagram. The disagreement between A.C. and D.C. curves at low input voltages is due to the presence of the grid leak and grid condenser in the A.C. case, which, as explained earlier, develops a small negative bias even in the absence of an input signal and so reduces the anode current below the D.C. value. The discrepancy for inputs greater than about 2 volts is due to the fact, pointed out in Part I, that no matter how great the value of the alternating potential applied, grid current always flows in order to produce the necessary grid bias, and therefore some anode current is bound to flow on the positive peaks of the A.C. supply. This is obvious from Fig. 8 of Part I.

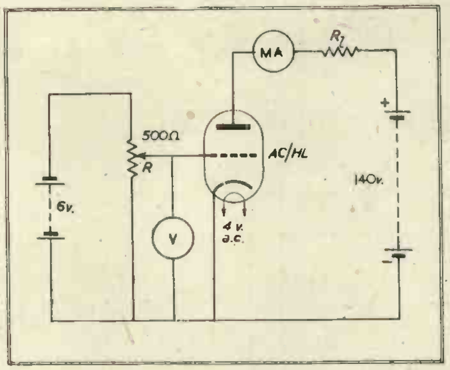


Fig. 3 (above). Determination of D.C. dynamic E_g-I_a curves.

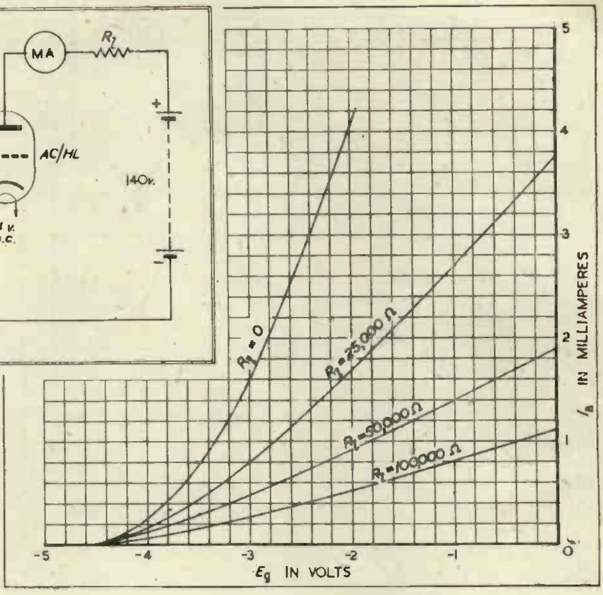


Fig. 4 (right). D.C. dynamic E_g-I_a characteristics for AC/HL.

Distortion Content of Detector Output

It can immediately be seen that the relationship between alternating voltage input and D.C. anode current output is far from linear, and a linear curve is, of course, the ideal requirement. The straightest part of the curve, and this is only approximately linear, occurs for alternating inputs of between zero and 2 volts. This part of the curve is very similar to the D.C. dynamic characteristic of a pentode valve. It shows some cubic curvature and we can therefore deduce that there will be some third harmonic distortion in the detector output. Elsewhere the curve shows mainly quadratic curvature, suggesting the presence of second harmonic distortion. If a carrier of 1 volt amplitude when unmodulated is applied to the valve, when modulation occurs the detector output will contain some third harmonic distortion but small amounts of second harmonic. This will be true for any degree of modulation up to 100 per cent., when the R.F. amplitude is varying from zero to 2 volts. If the carrier amplitude is 3 volts then very severe distortion will result on modulation and the amount produced will depend, from the curve, on the depth of modulation. If a carrier of, say, 6 volts amplitude is applied and if the modulation is so shallow that the bend at 2 volts input is not involved in the detection process, then distortion, mainly second harmonic, will be small as the curve tends to straighten at large input signals. The amplification for these big inputs is very small, however, being measured by the slope of the curve.

The graph of the peak applied alternating potential and the effective grid voltage, E_g'', can be deduced from Figs. 4 and 6. It is given in Fig. 7 and from this we can determine how the amount of distortion introduced by the AC/HL, for a given modulated signal on the grid, depends on the value of the grid leak, the anode load and the depth of modulation. Some numerical examples will make the method of calculation clear.

Numerical Determination of Second Harmonic Distortion

Consider first an R.F. signal of 3

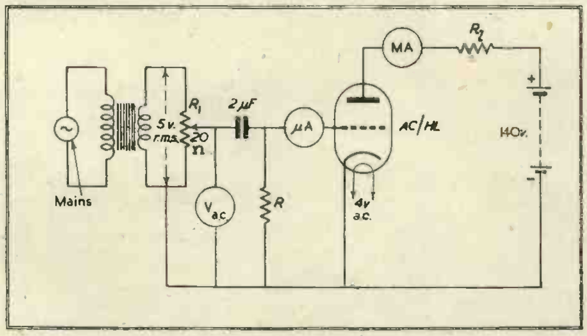


Fig. 5 (above). Determination of A.C. dynamic E_g-I_a characteristics.

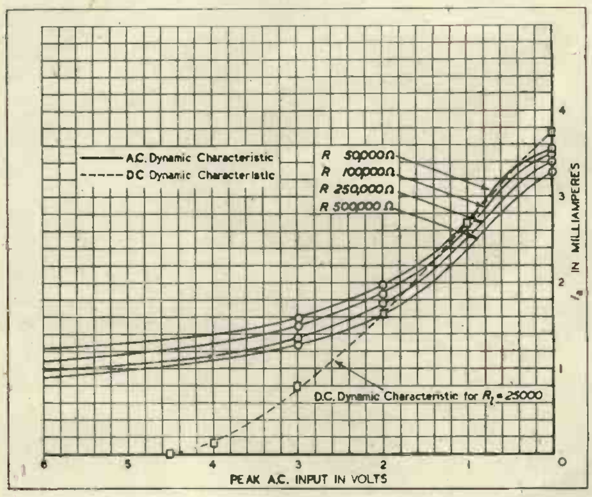


Fig. 6. (right). A.C. dynamic characteristics for R_l 25,000 Ω.

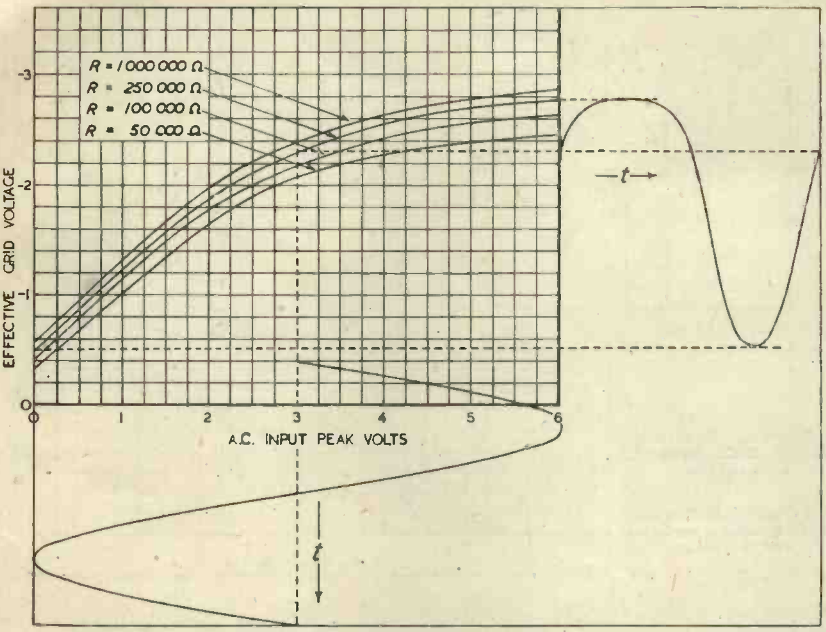


Fig. 7. Relationship between effective grid voltage E_g and A.C. input peak volts fer AC/HL for various values of grid leak.

volts amplitude when unmodulated, and suppose we require to know the percentage of second harmonic distortion introduced by the valve for 100 per cent. modulation. The alternating input clearly varies from zero to 6 volts as shown in Fig. 7 so that the effective grid signal, E_g'' changes from −2.77 volts to −.52 volts, the mean value being −2.32 volts. These figures apply for a grid leak of 250,000 ohms. Reference to Fig. 4 shows that such changes in the value of E_g'' will produce corresponding fluctuations in the value of I_a, which will vary from .97 ma. to 3.2 ma., with a mean value of 1.36 ma. for an anode load of 25,000 ohms. Of course, it is possible to deduce these results directly from Fig. 6, which relates anode current directly to the alternating input for a load resistance of 25,000 ohms, but the advantage of using Figs. 7 and 4 is that this method can be used to give the answers for any value of anode load. Having found that the anode current varies unsymmetrically for this particular value of input we can calculate the amount of second harmonic distortion from the usual expression: percentage of second harmonic distortion,

$$D = 100 \times \frac{\frac{1}{2}(I_{max} + I_{min}) - I_{mean}}{I_{max} - I_{min}}$$

Substituting the values obtained, namely, $I_{max} = 3.2$ ma., $I_{min} = .97$ ma. and $I_{mean} = 1.36$ ma., we have:—

$$D = 100 \times \frac{\frac{1}{2}(3.2 + .97) - 1.36}{3.2 - .97} = 32.5 \text{ per cent.}$$

This calculation has been made for various values of input signal (100 per cent. modulation was assumed throughout) and for various values of anode load and grid leak and the results obtained show that the percentage of harmonic distortion introduced, whether second or third harmonic, is practically independent of the value of the grid leak and anode load resistance, but varies considerably with the amplitude of the input signal. The latter result was anticipated, of course, from the inspection of Fig. 6, but it is interesting to consider the numerical results exhibited in graphical form in Fig. 8. The minimum at 1 volt input is noteworthy.

Voltage Gain of the Detector

From Figs. 4 and 7 it is a comparatively simple matter to evaluate the overall voltage gain of the detector. We will measure the voltage gain by the fraction:—

$$\frac{\text{average peak value of the swing of anode potential (i.e., mean value of both peaks)}}{\text{peak value of R.F. carrier input when unmodulated}}$$

As an example of this calculation we will evaluate the voltage gain for a carrier of 1 volt peak value, a grid leak of 250,000 ohms and an anode resistance of 50,000 ohms. For 100 per cent. modulation the value of the peak alternating potential swings from zero to 2 volts and, from Fig. 7, the effective grid voltage swings from −.53 volts to −1.9 volts. This brings about a change in anode current from 1.63 ma. to .95 ma. for an anode resistance of 50,000 ohms, this being obtained from Fig. 4. The P.D. across the anode load hence swings from $\frac{1.63 \times 50{,}000}{1{,}000} = 81.5$ volts to $\frac{.95 \times 50{,}000}{1{,}000} = 47.5$ volts, so that the average single peak value is $\frac{81.5 - 47.5}{2} = 17$ volts. The voltage gain for these conditions is then clearly $\frac{17}{1}$ or 17 times. This calculation has been repeated for various inputs and the resulting curve is given in Fig. 8. It is interesting to see that minimum distortion and

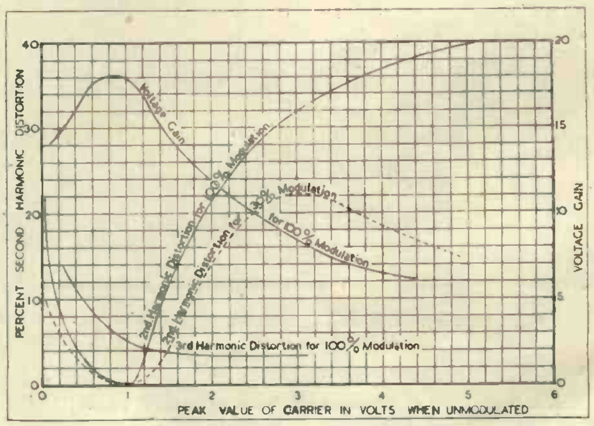


Fig. 8. Distortion of AC/HL for 100 per cent modulation (with 50,000 Ω anode load and 140 volts H.T. supply.

maximum gain occur for the same value of input, namely, 1 volt. An interesting point to notice is that the detector has a certain amount of inherent A.V.C. for inputs greater than 1 volt.

Distortion and voltage gain will be less for modulation depths of less than 100 per cent. To confirm this we could evaluate the voltage gain and distortion for, say, 30 per cent. modulation using Fig. 7. For an R.F. peak of 1 volt peak value the alternating potential will swing from .7 volts to 1.3 volts in value, and using the same technique as above, we could find the corresponding values of E_g'' and then I_a so obtaining the percentage distortion. This calculation has been done and the results are given in Fig. 8. The voltage gain is, as might have been anticipated, about .3 of that for 100 per cent. modulation. This curve is not included in Fig. 8.

Numerical Determination of Percentage of Third Harmonic Distortion

It is frequently stated that the "unpleasantness" of harmonic distortion is dependent on its order, increasing with increase in the order. A particular percentage of third harmonic distortion is thus more unpleasant than the same percentage of second harmonic distortion. This being so, it is necessary to estimate the amount of third harmonic distortion given by the leaky grid detector; the cubic nature of the A.C. dynamic characteristic has already shown the presence of this form. An approximate expression for the percentage of third harmonic distortion, D′, is*:—

$$D' = 100 \times \frac{I_{180} - I_0 - 1.41\,(I_{135} - I_{45})}{(I_{180} - I_0 + 1.41\,I_{135} - I_{45})}$$

in which I_{180} represents I_{max} and I_0, I_{min}, E_{135} and I_{45} are the values of the anode current an eighth of a cycle earlier than I_{max} and later than I_0 respectively.

Consider a carrier 1 volt in amplitude when unmodulated. For a grid leak of 250,000 ohms E_g'' is $-.5$ volts (corresponding to I_{max}) for zero input, and -1.88 volts (corresponding to I_{min}) for 2 volts input, these two cases representing the extreme values for 100 per cent. modulation. I_{135} occurs when the input is .293 volts (*i.e.*, $1-.707$) and E_g'' for this value of I_a is $-.68$ volts. I_{45} occurs when the input is 1.707 volts (*i.e.*, $1+.707$) and E_g'' for this is equal to -1.68 volts. These were obtained from Fig. 7 by interpolation. From Fig. 4 the values of I_{180}, I_{135}, I_{145} and I_0 for $R_l = 50{,}000$ ohms are respectively 1.65 ma., 1.52 ma., 1.07 ma. and .95 ma., giving the third harmonic distortion content as

$$100 \times \frac{1.65 - .95 - 1.41\,(1.52 - 1.07)}{1.65 - .95 + 1.41\,(1.52 - 1.07)}$$

$$= 100 \times \frac{.70 - .63}{.70 + .63}$$

$$= 100 \times \frac{.07}{1.33} = 5 \text{ per cent.}$$

The way in which the percentage of this form of distortion varies with the input is also illustrated in Fig. 8.

Conclusions

Part II of this analysis has shown that the leaky grid detector gives considerable harmonic distortion and that the amount introduced is more or less independent of the values of the grid leak and anode load, being determined chiefly by the value of the input signal. There is one value of input which gives minimum total distortion and this occurs when the peak value of the R.F. signal (when unmodulated) is about one quarter of the value of the grid base (given by the D.C. dynamic characteristic) for the value of H.T. supply used. In practice it is best therefore to adjust the value of the R.F. input so that the mean anode current as indicated by a milliammeter, shows that this condition obtains. This critical value of the anode current can be obtained from the A.C. dynamic characteristic and will depend on the value of the anode load. For the AC/HL, for example, with 140 volts H.T. supply the anode current should be 2.50 ma. for an anode resistance of 25,000 ohms (from Fig. 6 for a grid leak of 250,000 ohms and an A.C. input of 1 volt peak value) and 1.30 ma. for an anode resistance of 50,000 ohms (from Figs. 7 and 4).

The optimum values of the grid condenser and grid leak are best chosen with reference to the conditions given at the end of Part I and the optimum value of R_l is that value which makes the triode most successful as a voltage amplifier (*i.e.*, the value of R_l should be two or three times the R_a of the valve).

* Radio Designers' Handbook, edited by F. L. Smith, p. 284.

Electronic Organ Design—*concluded*

large-scale model was finished. A background of "roar" was detected even when no keys were depressed, and was unmistakably recognised as the composite sound of all the tones in the instrument, each at a very low level. These very weak tones were evidently being generated by the vibrating reeds from the excitation produced by the contact-potential. This is, or has been, a problem in certain other electrostatic organs of the rotary type.

It is regretted that further investigations have had to be suspended owing to the prevailing war conditions, but at least in the interim, the opportunity may be taken to review the successes and the failures of past work and to cast around for new and better methods.

Tone Generation by Frequency-Modulation

In conclusion, brief reference may be made to some preliminary experiments along an alternative line of approach which showed definite promise. Instead of using the undulating capacity to produce a corresponding current in a resistance, it can be made to change the frequency of an oscillator, the resultant modulated frequency being detected in any suitable frequency-modulation receivers A block diagram of the arrangement is shown in Fig. 9, the actual tone generators being represented by strings. Readers will recognise that the greater part of the electrical equipment is, in effect, contained in a conventional superhet receiver. A normal short-wave superhet was, in fact, found to be satisfactory for experimental purposes and served to show that ample output was obtainable from either strings or reeds, especially at low frequencies. It may be remarked that the output from the rectifier will follow the variation of capacity even down to zero frequency—hence the highly satisfactory performance in the bass. Keying must be performed by the control of the capacity in the pickup system.

The outstanding advantages of this method of tone generation over the others which have been described here are the complete absence of mains-hum from stray fields and absolute freedom from the troubles of contact-potential. In the author's opinion, this system merits further careful consideration.

References

1 G. T. Winch and A. M. Midgley, *J.I.E.E.*, Vol. 86, No. 522, June, 1940.
2 British Patent 403444, 433050, 451798, 453846, 454502, 482284 and 499771.
3 F. D. Merrill, *Electronics*, May, 1939, p. 30.
4 British Patent 442379.

A New Electron Beam Switch

A new type of vacuum tube in which a flat radial beam of electrons in a cylindrical structure may be made to rotate about the axis. Features of the tube are its absence of an internal focusing structure and resultant simplicity of design, its small size, its low voltages, and its high beam currents. This description has been taken from the article by A. M. Skellett in the Bell System Technical Journal*, to whom acknowledgment is made.

IT has long been recognised that the substitution of electron beams for mechanical moving parts would offer decided advantages in many applications in the field of communications. The high voltages required for the usual cathode-ray type of tube and the very low currents obtainable therefrom prevent their use in most such proposals; their complicated guns and their large sizes are also undesirable features. The kind of tube described herein has no focusing structure, is small in size, requires only low voltages, utilises the cathode power efficiently, and produces beam currents of the same order of magnitude as the space currents of ordinary vacuum tubes.

Fig. 1 shows the elementary tube structure. It consists, in the simplest case, of a cylindrical cathode of the sort in common use in vacuum tubes, surrounded by a cylindrical anode structure. When this structure is made positive with respect to the cathode and there is no magnetic field in the tube, the electrons flow to the anode structure in all directions around the axis. When a uniform magnetic field is applied with its direction at right angles to the axis, the electrons are focused into two diametrically opposite beams as shown. The beams are parallel to the lines of force of the magnetic field so that if the field is rotated the beams move around with it. Thus the magnetic field serves both to focus the electrons and to direct the resulting beams to different elements of the anode structure.

If ordinary commercial cathodes are used with anode structures an inch or two in diameter, 100 volts or less on the anode will draw the full space current for which the cathode was designed. The application of the magnetic field will then focus from 85 to 90 per cent. of this electron current into the two beams, the remaining 10 or 15 per cent. being lost at the cathode due to an increase in the space charge which the magnetic field produces. Some of the smaller tubes produce beam currents of more than 5 milliamperes with only 50 volts on the anode

* Vol. 23, April 1944, p. 190.

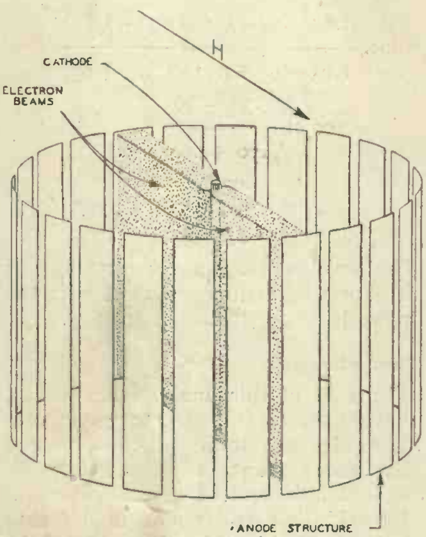


Fig. 1. Elementary tube structure showing focused beams.

structure, and in some of the tubes with larger cathodes beam currents of 50 milliamperes or more are easily obtainable. The magnetic field strengths range from 50 to 300 gauss.

For some applications it is desirable to eliminate one of the two beams and this may be accomplished by substituting a uniform electrical field in the tube for the cylindrical one described above. The uniform field may be obtained by applying to the anode elements a series of potentials that vary according to the sine of the angle taken around the axis. The line joining the maximum potentials (+ and —) is maintained parallel to the magnetic field so that on one side of the cathode the potentials are all negative and the beam on that side is suppressed. The remaining beam will have somewhat less current than the corresponding one in the cylindrical field, but the magnetic field-strength required for focus is reduced.

The photographs of Fig. 2 show the trajectories obtained by introducing argon at a pressure of about a micron into the tube. The electrons are emitted from only two spots of active material located at the opposite ends of a diameter on the cathode sleeve. In Fig. 2a the line joining the spots is lined up with the magnetic field and in 2b this line is at an angle of about 45° with respect to the field. This arrangement does not reproduce exactly the space charge conditions in the tube as actually used, but does serve to give a picture of the electron paths in a qualitative sort of way.

Uniform Electric Field

As mentioned above the uniform field is obtained by imposing potentials around the anode periphery varying as the sine of the angle. The cathode is at a point of zero potential. In this case a real electron optical image of the cathode is obtained.

In applications where the beam is rotated by means of a rotating magnetic field this electrostatic field is made to turn by separating the anode structure into four or six elements (or groups thereof) and applying either two- or three-phase alternating potentials to them.

Magnetic Field Supply

The stator of a two-pole polyphase alternating-current motor furnishes an excellent magnetic field for use with these tubes. The tube is inserted in place of the armature and when the polyphase currents are applied the beams are formed and rotate at the cyclic frequency. For applications where the beams are not rotated continuously, a two-phase stator may be used in which the currents through the two windings are adjusted to be proportional to the sine and cosine of the desired direction angle of the beam. Permanent magnets of the horseshoe design have also been found to be suitable.

Since a polyphase source of power is not always readily available, it is sometimes advantageous to split single-phase power in the stator itself to produce the rotating field. This may be done by inserting a condenser in series with each winding so that the current through one phase winding lags by 45° and that through the other leads by an equal angle. Polyphase potentials for producing a rotating electrostatic field in the tube may then be taken from the windings of the stator if desired.

Tube Design

The particular design of tube depends on its application. The simple design shown in Fig. 1 has been found adequate for some purposes, but more elaborate designs which increase the versatility of the tube are also needed.

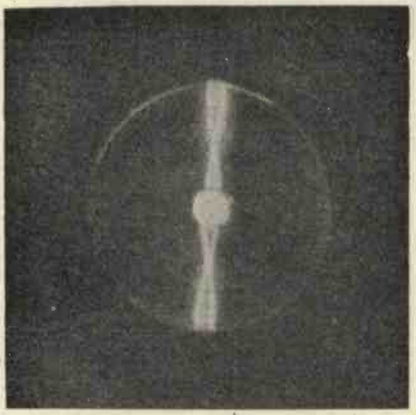
Fig. 3 shows a tube with 30 anodes that incorporates various auxiliary elements. This tube is 2.25 inches in diameter. Closely surrounding the cathode is a control grid that may be used for modulating the current density of the electron beams. Farther out is a cylindrical element with 30 windows that is maintained positive and which by virtue of its similarity in position to the third element of a tetrode is called a screen. Immediately behind each window there is a pair of paraxial wires which because of its similarity in function to the fourth element of a pentode is called a suppressor grid. In back of each suppressor grid there is an anode. In this particular tube there are projections like gear teeth on the back of the screen element to prevent electrons, destined for one anode, from reaching an adjacent one.

The control grid that is close to the cathode is biased negatively and controls the electron current in the same way that it would if the magnetic field were not present. Thus the tube may be used for amplification in the usual way when the electrons are focused. The presence of this grid has no appreciable effect on the focusing of the electrons.

The suppressor grids are generally operated at cathode potential or at a potential that is negative with respect to the cathode. They may be used for three purposes: to suppress secondaries from the anodes, to modulate the beam current to their particular anode, and to suppress one of the two beams. For the first of these functions they are biased at cathode potential. For the second they are biased negatively and have a modulation curve similar to that of the suppressor grid in a pentode.

When one beam is suppressed either by splitting the screen or by grouping the suppressors, the currents to the different anodes are not all exactly the same. For instance, maximum current will be received by an anode back of the centre of one of the screen elements or one of the suppressor groups and a minimum current will be received by an anode back of the junction of two such elements or groups. If two-phase supply is used (4 elements or groups) the ratio of maximum to minimum anode current will be 0.707 and for three-phase supply this ratio will be 0.866. There will be 4 or 6 maxima, respectively, around the tube. This variation may be effectively eliminated by varying the individual anode load impedances or in other ways.

The anode characteristics are similar to those of a pentode if suppressor grids are used and to that of a tetrode if these grids are not used.



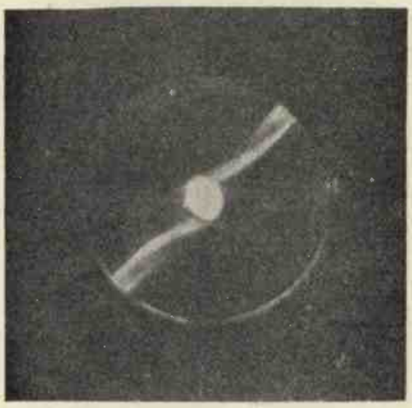


Fig. 2. Electron trajectories made visible with a small amount of gas. (a) Magnetic field lined up with active spots on the cathode. (b) Magnetic field at 45° with respect to the active spots.

Applications

The many possible combinations of the tube elements just described permit a variety of applications. One of the simplest and most obvious is that of an electronic commutator which has the advantages over the corresponding mechanical device of speed and freedom from contact trouble. There is, however, a practical limitation to the speed of this electronic commutator that is set primarily by the alternating-current losses in the stator. This is estimated to be in the neighbourhood of 10,000 c/s. for ordinary stator and tube designs. The highest cyclic speed for a stator that has been used to date was 600 cycles per second which with utilisation of both beams gave an effective cyclic frequency of 1,200 c/s.

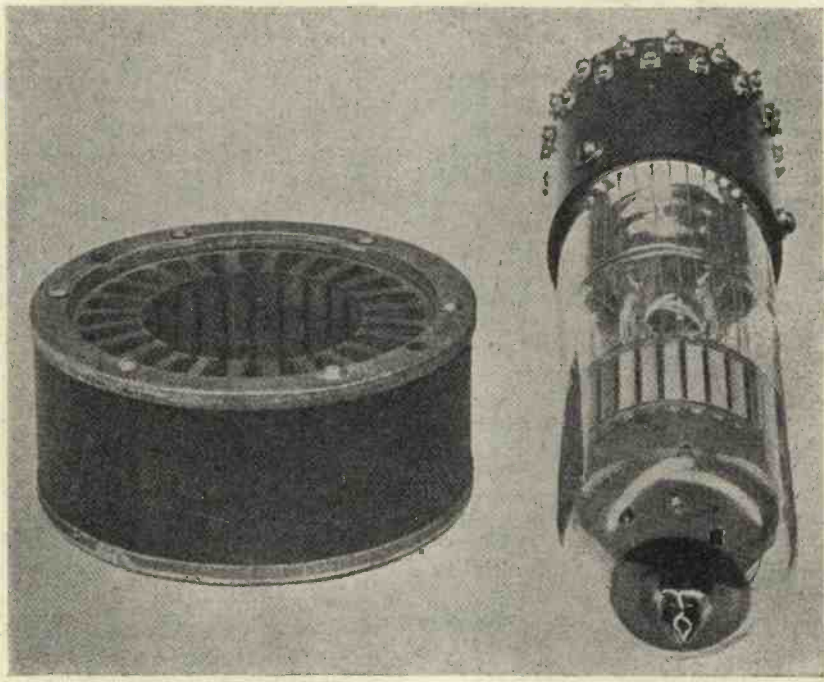


Fig. 3 Radial beam tube with 30 anodes and unwound stator used with it.

The Multiplier Photo-Cell

Its Advantages and Limitations

By A. SOMMER, Dr.Phil.*

AN inherent difficulty in the practical use of photoelectric cells of the emission type is the fact that in most applications the photoelectric current is extremely small, and in many cases photo-currents of less than 10^{-8} amp. have to be dealt with. Therefore, in order to reduce the necessary amount of external amplification a multiplication of the photocurrent within the actual photocell is desirable. This has been achieved by two methods, known as "gas-amplification" and "secondary emission multiplication." In gas-filled cells, which cannot be here considered in greater detail, the fundamental process is as follows: Each primary photo-electron suffers collisions with neutral gas molecules with the result that some of the latter are ionised. In this way additional electrons are produced and by repeating the process of collision and ionisation the primary current can be amplified by a factor of up to twenty times.

Gasfilled cells have found wide application, particularly in sound film projectors, relays, etc. They have, however, two serious limitations: Firstly, in most cases to avoid "flashover" not more than a tenfold amplification is obtainable and, secondly, the frequency response drops rapidly above 5,000 c/s., in contrast to the practically frequency-independent vacuum cells.

With the development of high definition television, photo-cells were required with a frequency response extending into the megacycle range which obviously excluded the use of gasfilled cells. On the other hand, extremely weak signals had to be detected which made an internal amplification of the photocurrent even more imperative than for previously known applications. The demand for high frequency response combined with the highest possible internal amplification encouraged the development of the "Multiplier Photocell."

The principle of this cell is that the electrons released by light from the photosensitive cathode are not collected by the anode as is the case in the ordinary vacuum or gasfilled cell, but are directed towards an electrode which is provided with a surface of high secondary emission factor. Each primary electron impinging on such an electrode (which has, of course, to be maintained at a positive potential with respect to the cathode) will release several secondary electrons which can then be collected by an anode. The great advantage of this process is that it can be repeated many times by adding more electrodes of high secondary emission factor each of which is maintained at a positive potential with respect to its predecessor. In this way any required total factor of multiplication can be obtained, factors of 1,000,000 and over are a practical possibility.

The question may be asked, why with this tremendous superiority in performance the multiplier photocell has not completely replaced the simple vacuum and gasfilled cell. The fact is that, although multiplier cells have now been commercially available in various types for about ten years, they are still used in very small numbers only. As this may be partly due to doubts on the part of the engineer whether the use of a multiplier cell would lead to an improvement in his apparatus it seems worth while to consider in more detail the fundamental facts which determine if for a particular purpose a multiplier photocell is preferable to a simple photocell.

In the following, four main points will be discussed:—

(1) Economic considerations.

(2) Limited output current of multiplier photocell.

(3) Detection of small D.C. signals.

(4) Detection of small A.C. signals.

Economic Considerations

By using a multiplier photocell external valve amplification can be cut down by several valves, which represents a definite saving in outlay and space. Unfortunately, this saving is offset by two additional expenses: The multiplier photocell is more expensive than the simple vacuum- or gasfilled-cell and, furthermore, it requires a high voltage supply (anything between 500 and 1500 volts, according to type and desired factor of multiplication) which in many cases means an additional piece of equipment. From these facts the conclusion can be drawn that economic considerations warrant the use of a multiplier cell only in applications where a high voltage supply is needed for other parts of the apparatus and has not to be specially incorporated for the multiplier cell.

Limited Output Current of Multiplier Cell

Owing to the detrimental effect of heat on the stability of the multiplier the output current in the final electrode of the multiplier cell should not exceed the order of 1 milliampere. Assuming, for the sake of argument, a multiplication factor of 10,000, this means that the primary photocurrent must not exceed 0.1 microamps, or, for an average cathode sensitivity of $20\mu A/L$ (microamperes per lumen) that the illumination must be below 0.005 lumen. This limitation of the output current has two consequences: Firstly, if more than the maximum permissible amount of light is likely to fall on the cathode the multiplier cell can only be used with reduced multiplication factor (this factor can be controlled by the number of stages used and by the potential applied to each stage) the consequence of which is, of course, a correspondingly reduced superiority over the simple cell. Secondly, it can be seen that multiplication factors above 10,000, although practically possible, would be useless for most applications.

A good example is the use of the photocell in sound film reproduction. Here the maximum illumination to be reckoned with is of the order of 0.1 lumen, corresponding to a primary photocurrent of $2\mu A$ (if again a cathode sensitivity of $20\mu A/L$ is assumed). Hence, in order to keep

* Messrs. Cinema Television, Ltd.

Callender

RADIO FREQUENCY CABLES

We are fully engaged on war production and are manufacturing all types of low loss and low capacity cables for use at high frequencies.

We shall be pleased to make available the experience of our extensive research and technical organisations in connection with special cable problems directly related to the war effort.

CALLENDER'S CABLE & CONSTRUCTION CO. LTD. HAMILTON HOUSE, VICTORIA EMBANKMENT, LONDON, E.C.4

All over the World

the output current below 1mA, and multiplication factor of not more than 500 can be safely utilised. When compared with a multiplication of up to 20 in a gasfilled cell this relatively minor additional factor of 25 seems to explain why the multiplier photocell is still not widely used in sound-film reproduction.

It is clear from the above considerations that the useful range of illumination for multiplier photocells is that which corresponds to primary photocurrents of less than 0.1μA and in the two following sections we will be concerned with such small light signals only.

Small D.C. Signals

For the detection of light corresponding to photocurrents of 10^{-6} down to 10^{-9} amp. a simple photocell can be used in connexion with a sensitive galvanometer. The advantage of using a multiplier cell in this range lies in the fact that the galvanometer can be replaced by a less delicate current measuring instrument. If the primary photocurrent is smaller than 10^{-9} amp. the troublesome methods of D.C. amplification have to be applied if only a simple photocell is available. In such a case the use of a multiplier cell obviously represents a great improvement. Examples of applications of this nature are quantitative spectroscopy and photometry.

Small A.C. Signals

In the detection of small A.C. signals, two main points have to be considered when comparing a simple photocell followed by several stages of valve amplification and a multiplier cell: frequency response and signal-to-noise ratio.

(A) *Frequency Response.*

The response of the multiplier photocell is practically as independent of frequency as that of a simple vacuum cell. In other words, very small signals over a wide frequency band are multiplied without distortion with the multiplier photocell, which is a favourable contrast to the difficulties incurred if a simple photocell is used and the same degree of multiplication achieved by valve amplification. Hence, the multiplier photocell is definitely advantageous in connexion with high frequency signals.

(B) *Signal-to-noise Ratio.*

The determination of the signal-to-noise ratio in a particular system consisting of photocell or multiplier photocell and valve amplifier is a complicated problem because there are so many factors which contribute to the noise. The sources of noise can be divided into two main groups, the first group (i) consisting of various types of random electron emission (shot effect) from the photoelectric cathode, while the second group (ii) is connected with components and conditions outside the photocell.

(i) The random emission from the photo cathode can consist of the following three components (for a more detailed explanation see below):—

(a) Fluctuation of photoelectric emission caused by the A.C. signal.
(b) Fluctuation of the photoelectric emission caused by constant (D.C.) background illumination.
(c) Fluctuation of the thermionic emission at room temperature.

(ii) The noise produced outside the cell can be subdivided as follows:—

(a) Thermal agitation in the resistive component of the coupling impedance.
(b) Shot noise in the first amplifying valve.
(c) Various other causes, such as microphonic action, hum pick-up, erratic leakage currents, etc.

The noise produced by the first group cannot be separated from the signal and is obviously multiplied with the signal if a multiplier photocell is used, hence it can be seen at once that the signal-to-noise ratio is not improved by using a multiplier cell if the noise is chiefly due to causes in group (i) above. On the other hand, if the noise is mainly of type (ii) the multiplier increases the signal to such a high level that the signal-to-noise ratio will be greatly improved.

It is outside the scope of this paper to consider how the noise of type (ii) can be reduced. But if in a particular system, owing to preponderance of group (ii) noise, the use of a multiplier photocell is indicated, the improvement will obviously be greater the smaller the group (i) noises can be made. Therefore we have to consider how the most favourable conditions can be obtained with respect to the above named types of random emission.

(i)(a). The fluctuation due to random emission increases relative to the photoelectric emission as the latter decreases and therefore determines the lowest permissible signal for a given minimum signal-to-noise ratio and for a given sensitivity of the photo cathode. This fundamental limitation to the signal is a further reason why in most applications a multiplication factor of more than about 5,000 in the multiplier is of no real advantage.

(i)(b). If part of the photoelectric emission is due to constant (background) illumination obviously the signal-to-noise ratio will be adversely affected because the constant photoelectric emission will not contribute to the signal while the fluctuation by which it is accompanied will contribute to the noise. Hence it can be seen that it is advantageous to work a multiplier cell with a 100 per cent. modulated signal. The lower the degree of modulation the greater the noise relative to the useful signal and consequently the smaller the advantage in using a multiplier cell as compared with a simple photocell.

(i)(c). Even with no light falling on the photo cathode there exists a small constant emission of electrons which is due to thermionic emission at room temperature. The fluctuation of this thermionic emission contributes to the noise, in some cases to quite a large extent. This unwanted effect could in principle be reduced or avoided by cooling the cell, but this is in practice a most inconvenient method. Fortunately, the recently developed Antimony-Caesium photocathode has an extremely low thermionic emission as compared with the more generally used Silver-Oxygen-Caesium cathode and for this reason a multiplier cell with an Antimony-Caesium cathode should be used in all cases in which a required response to infra-red radiation does not make a Silver-Oxygen-Caesium cathode essential.

Conclusion

Summarising all these considerations it can be stated that the use of a multiplier photocell is only indicated if the signal to be detected (D.C. or A.C.) is so small that it corresponds to a primary photocurrent of less than 10^{-7} amp. Furthermore it has been shown that in the case of A.C. signals the superiority of the multiplier cell over the simple photocell (followed by a valve amplifier) is more marked,

(a) With increasing width of the frequency band;
(b) With increasing percentage modulation;
(c) With increasing noise in the system due to causes outside the photocell itself.

Acknowledgment is made to Messrs. Cinema Television, Ltd., for permission to publish the information, and to Mr. T. C. Nuttall of Messrs. Cinema Television, Ltd., for valuable advice.

A Valve Voltmeter for Higher Voltages

UNLIKE the peak voltmeter with diode previously described in these columns[1] the valve voltmeter developed by J. F. Tönnies[2] makes use of a triode and a diode is only used additionally in order to enable the measuring method originally devised for d.c. measurements to be applied to a.c. circuits.

The principle of the method has been known for nearly 30 years, but by certain modifications a valve voltmeter is obtained capable of measuring several hundreds of volts with a high degree of accuracy and the results of the measurements are only slightly influenced by the properties of the valve and by the changes at various points of the characteristic. This is accomplished by avoiding the use of transformers and ensuring a current-free measurement. By applying the reflex principle[3] the upper limit of the d.c. or a.c. voltage to be measured is only determined by the voltage resistivity of the amplifier which for ordinary broadcast receiving valves lies at about 1,000V.

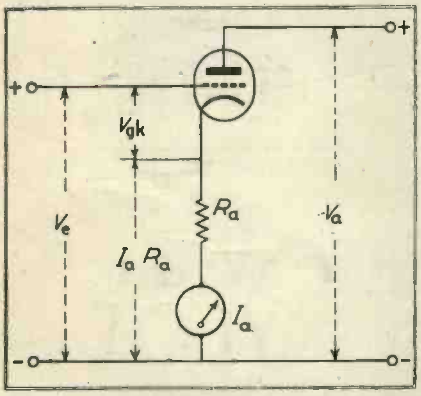


Fig. 1. Fundamental circuit. *Vgk* **voltage between grid and cathode of amplifier.** *Ve* **input voltage to be measured.** *Va* **anode voltage.** *Ia* **anode current.** *Ra* **resistance of the anode circuit.**

The basic circuit diagram is shown in Fig. 1 in which V_{gk} designates the voltage between grid and cathode of the amplifier, V_e is the input voltage to be measured, V_a the anode voltage, I_a the anode current and R_a the resistance of the anode circuit.

The voltage drop I_aR_a counteracts the voltage V_e applied to the grid. it may be as high as 80 per cent of the anode voltage so that with V_a = 700, V_e may be as high as 500V.

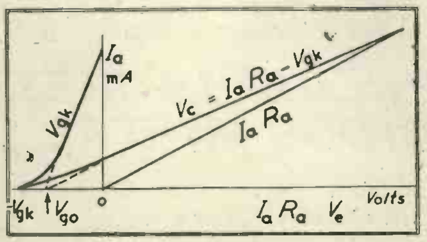


Fig. 2 Relations between *Ia* **and** *Vgk Ve* **and** *IaRa*.

Calling V_{go} that value of the grid voltage which would be obtained at $V_a = 0$ with a straight line characteristic, and v the active amplification factor of the valve the following relations are found:

$$I_aR_a = V_e + V_{gk} \quad \ldots (1)$$

$$V_{gk} = V_{go} - \frac{I_aR_a}{v} \quad \ldots (2)$$

$$V_e + V_{go} = I_aR_a \frac{v+1}{v} \quad \ldots (3)$$

(The minus sign given on the left side of the last equation in the original paper is apparently a mistake).

The value $(v + 1)/v$ which for $v = 20$ is 1.05 characterises the difference between the voltage changes of the grid and cathode. As may be realised the cathode and not the anode is forced to follow any commands given by the grid. The connexion described is similar to that of one of the earliest proposals for a valve voltmeter or ammeter which referred to the accurate measurement of the current changes in a photocell and was the subject of an American patent applied as early as 1914. In this country it is also well known under the name of "cathode follower" and in U.S.A. as "self bias" or "reflex voltmeter."

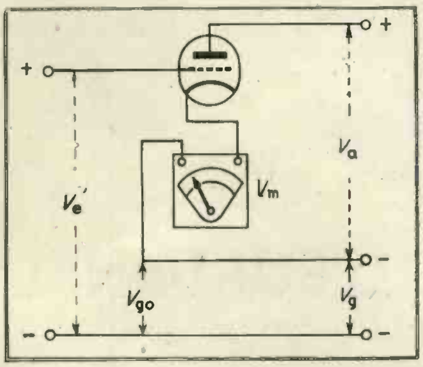


Fig. 3. Use of a boosting voltage (*German Patent 690207*) *Vgo* **grid-cathode voltage for** *Ia* **=0** *Vm* **voltage at an instrument connected as load of the anode circuit.**

The relations between I_a and V_{gk}, V_e and I_aR_a are best understood from the diagram Fig. 2.

The constant value V_{go} of equation (3) is taken account of in Tönnies's improvement of this connexion by inserting a separate boosting voltage into the negative lead for the voltage V_e (Fig. 3) such that

$$V'_e = I_aR_a \frac{v+1}{v}$$

The anode resistance R_a and ammeter may be replaced by an ordinary moving coil voltmeter indicating $V_m = I_aR_a$. This will be proportional to V_e and the factor $(v+1)/v$ may be taken into account either by calculation or by an appropriate reduction of the resistance connected in series to the voltmeter.

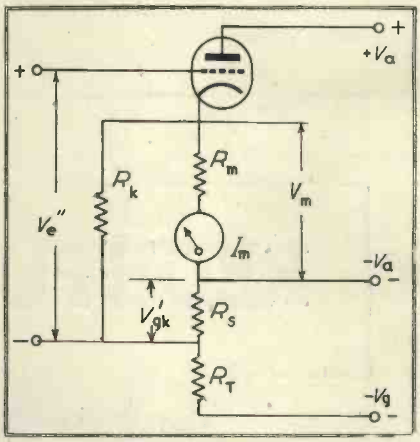


Fig. 4. Counterconnexion of *Vgk*. **By the changes in cathod potential voltage changes at** *Rs* **are caused through** *Rk* **corresponding to** *Vgk*.

Instead of using V_{go} for correcting the measurement a voltage equal to, and varying as, V_{gk} may be generated and used for boosting the input voltage. Such a connexion using a voltage divider is shown in Fig. 4 for which the equation

$$V'''_e = I_mR_m + V_{gk} - V'_{gk} = I_mR_m = V_m$$

is valid. Thus V_m is identical with the input voltage to be measured.

The connexion shown in Fig. 5 may

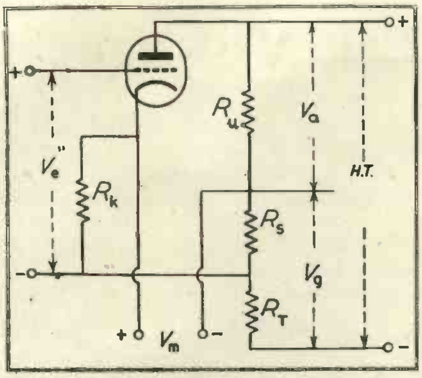


Fig. 5. Connexion of an additional appliance for use with a standard moving coil voltmeter Voltage V_m measured by the latter corresponds to the input voltage V_e

serve as an additional appliance for using any voltmeter as a current-free measuring instrument of high accuracy and which may be used to advantage for connecting an oscillograph.

As may be seen from Fig. 2 the deviations of the V_e curve from a straight line are comparatively small and they are still less if the amplification factor is about 20 (as is customary) instead of 5 which value has been chosen here in order to obtain a clearer diagram. This linear trend of the curve holds also for the values of I_m and I_k and thus also for V'_{gk} corresponding to Figs. 4 and 5. The main cause of errors is therefore the deviation of V_{gk} from a straight line. Changes in the value of v cause only very slight errors as this value enters the equation in the form $(v + 1)/v$. Nor are the errors due to changes in the cathode heating voltage and the anode voltage of great amount. By a proper dimensioning of the resistances R_u, R_s and R_t the influence of changes of V_a may be made to counteract those acting on V_g or V_{gk}, especially if R_a or R_m are large in comparison with the internal resistance of the valve. Taking into account all sources of errors an accuracy of $\pm$ 2 per cent. at the end value of the scale may be obtained which may be considered sufficient for operational measurements in the range of audio frequencies.

Fig. 6 shows a connexion suitable for the measurement of a.c. or d.c. voltages. A diode is inserted between the main valve and the measuring instrument. The resistance R_d connected in series to it and parallel to a conductor connecting one anode plate with the instrument serves for compensating the starting voltage of the cathode of the diode.

By inserting a resistance R_i shunting the instrument the sensibility of the latter is so much reduced that the calibration for d.c. is applicable for a.c. measurements also. C_v and R_v may be connected to the terminals for measuring mixed voltages and for making innocuous the influence of the d.c. potential when measuring the a.c. control at the anode of an amplifier. The earth connexion of point c prevents errors which may be due to the terminal b being capacitively coupled to the mains. The resistance R''_u shunted by the condenser C_k prevents the entrance of destructively large currents into the device during overloads.

A measuring outfit actually built according to the principles described and suitable for mains connexion has a nearly linear scale for eight different ranges of measurement. For inserting these different ranges press buttons are used which are mutually blocked.

R. NEUMANN.

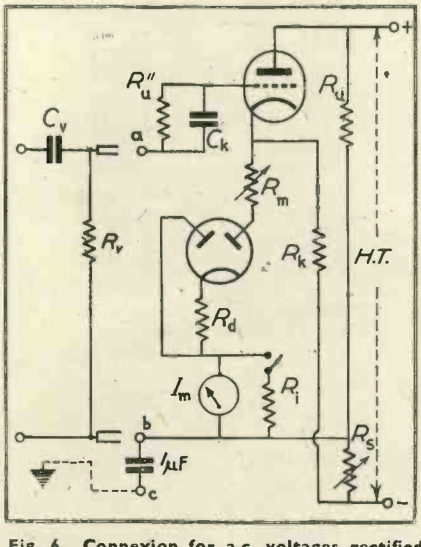


Fig. 6. Connexion for a.c. voltages rectified by a diode (*German Patent* 699719).

References

1 BACON, W., "Peak Voltage Measurements," *Electronics, Television and Shortwave World*, 13, p. 323, 1940.

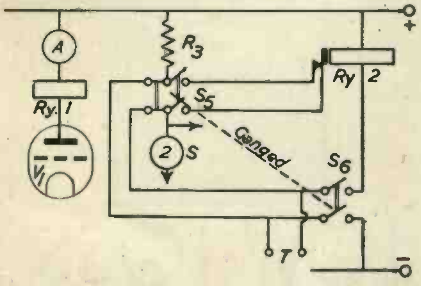
2 TÖNNIES, J. F., "Röhrenvoltmeter für höhere Spannungen," *ETZ* (*Elektrotechn. Z.*) 63, p. 153, April 9, 1942.

3 RIDER, J. F., "Vacuum Tube Voltmeters," New York, 1941.

CORRESPONDENCE

Self-Testing Relays

DEAR SIR,—I read with interest Mr. W. Bacon's article on "Self-Testing Relays" in the June issue of "Electronic Engineering." By the description of the various circuits, it appears that two instruments are re-



quired, one for relays with "make" contacts, and another for "break" contacts. It seemed to me that one universal instrument with a change-over switch incorporated would be more useful. Therefore, I append a modification of Mr. Bacon's circuit which appears as Fig. 4 in his article.

My suggestion is that, instead of the charging circuit including the "break" contacts of a relay under test, it should be connected to the common terminals of a double-pole, double-throw switch. One side of the switch is connected to the contacts of a permanently fitted relay which breaks on operation. The operating coil of this relay is connected across the power supply in series with the contacts of a relay to be tested (if fitted to "make" contacts). The relay contacts are connected to terminals "T." Terminals T are also connected to the remaining terminals on the change-over switch.

When testing "break" contact relays, their contacts are connected to T and the switches arranged as in the diagram. S_6 isolates the test relay from Ry_2. The circuit then acts as in Mr. Bacon's Fig. 4.

With "make" contact relays, S_5 is changed over, switching in the "break" contacts of Ry_2 and S_6 is closed putting the operating coil of Ry_2 in circuit with the "make" contacts of a test relay.

When the "operate" current of the relay is reached, its contacts close, energising Ry_2 which in turn opens its contacts and thus provides the break in the charge circuit. The reverse occurs when ascertaining the "release" current.

Yours faithfully,

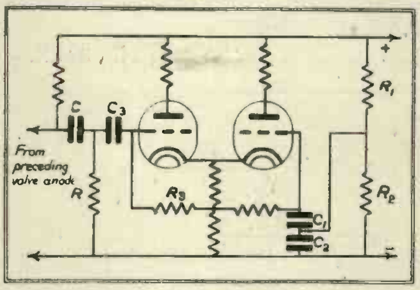
V. N. SPENCER.

Grid Bias Arrangements in Phase-Splitting Amplifiers

SIR,—With reference to the note on the above subject by E.K.M. Bird, published in the August issue of ELECTRONIC ENGINEERING, the danger of over-biasing by the flow of blocking condenser leakage current through the grid leak is a very real one. There is, however, an easy way of avoiding the difficulty by the use of a few additional components. The method is essentially one of balancing the voltage which causes the leakage current. A suitable circuit is given below:—

The resistances R_1 R_2 form a potentiometer across the H.T. supply. The tapping point is arranged to be at the same potential as the junction of bias resistance and cathode load. No leakage then occurs through C_1 and leakage through C_2 is immaterial. The A.C. conditions are unaltered.

At the input side, a well-known arrangement of double coupling condensers and resistance removes the



worst effects of leakage. At D.C. potentials, the resistance of the condenser C is much higher than that of the resistance R, and the P.D. across the latter is so low that objectionable leakage cannot occur through the coupling condenser C_3 and the grid leak R_3.

Yours faithfully,

F. BUTLER.

Identifying Components

SIR,—I am in complete agreement with Mr. Hurran's suggestions for concise reference for circuit components. I have myself for some time adopted a comparable method for convenient reference in varied circuits. My practice has had particular regard to annotations adopted by various draughtsmen and suffers by complication thereby.

In the case of resistors I use "VR" for variables and small letters following "R" to show the function, *i.e.*, R_L = Load R_{SD} = Screen Dropper R_b = bias R_{CL} = Cathode Load and so on; but this could well be obviated by some agreed table, which, however, should not omit wattage. It is a pity that valve bases are so numerous or the number of the pin might have been brought in—as I have done, being mostly limited to 9-pin and Octal bases.

It would, in the least, be helpful if some inconsistencies could be ironed out and uniformity insisted upon. For instance, I have a circuit in front of me which shows a capacity of .0003 μF. and another 1,000 pf. I feel that "μ" has so many uses in theoretical statements that it would be preferable to use small "mf" and small "pf." I notice that ELECTRONIC ENGINEERING still retains "μμ" which, after all, is a rather cumbersome notation. "K" for 1,000 is very well established, but not completely so. (Incidentally, I find that its use in calculation simplifies arithmetic, *e.g.*, a simple parallel path might be 0.5 M and 100K = $500 \cdot 100\ K^2/600K = \frac{500K}{6.0} = 83.3K$, *i.e.*, mental arithmetic throughout).

Yours faithfully,

A. J. PENNELL.

SEPTEMBER MEETINGS

Institute of Physics

The Organising Committee has decided to postpone the Conference on "Instruments for the Automatic Controlling and Recording of Chemical and Other Processes," which was to have been held in London next month.

The date of the postponed conference will be given in due course.

Electronics Group

A meeting of the above Group will be held on September 19, at 5.30 p.m., at The Royal Institution, 21 Albemarle Street, London, W.1 A paper will be read by Dr. A. Sommer of Messrs. Cinema Television, Ltd., on "Principles of Photo-electric Emission and Their Application in Photo-electric Cells."

Institution of Electronics

N.W. Branch

The next meeting of the above will be held on September 22, at 6.30 p.m., at the Reynolds Hall, College of Technology, Manchester. Dr. D. G. Drummond will lecture on "The Electron Microscope."

Tickets may be obtained on application to Mr. L. F. Berry, 14 Heywood Avenue, Austerlands, Oldham, Lancs.

ABSTRACTS OF ELECTRONIC LITERATURE

CIRCUITS

Electrical Hearing Aids
(T. S. Littler)

An account is given of the problems involved in the design of electrical hearing aids and components. Details of a number of circuits, both portable and non-portable, typical of modern practice, are included, and methods of measuring effective amplifications are discussed. Finally, special adaptations, such as tone-control adjustment and automatic gain-control, are considered.

—*Jour. I.E.E.*, Vol. 91, Part III. No. 14, June, 1944, p. 67.

Feed-back Amplifier for C.R. Oscilloscopes
(G. R. Mezger)

Practical application of feed-back for impedance compensation in amplifier design, given wide-band performance with small sacrifice of other characteristics. Both electrostatic and electro-dynamic deflection applications are covered.

—*Electronics*, Vol. 17, No. 4 (1944), p. 126.

Standard Frequency Source
(H. L. Clark and H. Johnson)

The standard frequency source described in this article was developed as a means of generating accurate frequency, primarily for use with stroboscopic methods of measuring small changes of speed. The frequency output is accurate to within 0.02 per cent. The equipment comprises a tuning-fork controlled oscillator, the frequency of which is held constant by the natural frequency of a magnivar tuning fork, an amplifier and a voltage regulator. With an input voltage of 105 to 125 V. at from 50 to 70 cycles, the output up to 25 W. is 115 V. at 60 cycles, with a total harmonic content less than 2 per cent. The operation of the equipment is explained and the tuning fork system described and analysed for free and forced vibrations.

—*G.E. Rev.*, May, 1944, p. 42.*

MEASUREMENT

Photoelectric Torsiograph
(W. Spellmann)

The torsiograph operates on the stroboscope principle, the relative displacement of two flywheels being measured by the amount of light transmitted through suitably spaced slots. For this purpose the two flywheels are in the form of hollow drums, which rotate one inside the other. The drums are closed at one end and their supporting shafts are in line but face in opposite directions. The inner drum is very light and provided with a belt drive to the shaft under investigation, or can be driven directly from the end of this shaft. The second drum is heavy and acts as a reference inertia mass. It is driven from the first drum by means of a radial spring member, the relative motion being limited to $\pm 5°$ by means of a stop. Both drums are fitted with 12 slots inclined at 54° to the axis, the external drum slots being illuminated by a close fitting ring carrying 11 miniature electric light bulbs. The light entering the inner drum is caught by a mirror (paraboloid of revolution) attached to the solid end of the drum and reflected on to a stationary photocell (caesium-gas filled) supported inside the hub of the inertia drum. The time lag of the cell is so short that it can be neglected.

The photoelectric current is observed by means of a cathode ray oscillograph, a polar diagram being preferable on account of the simple relationship between r.p.m. and harmonic order. The basic circle for this diagram is obtained by generating a sine vibration of shaft frequency which is then split up into two components at 90° phase difference and which are passed to the first control grid of a special amplifier and then suitably applied to the two pairs of deflection plates of the oscillograph.

The photocell controls through a second valve grid the anode current in step with the torsional vibrations.

—*Schweizer Archiv*, Vol. 8, No. 8, August, 1942, pp. 252/255).†

Electronic Timer for Microsecond Intervals
(P. B. Weisz)

This article describes an apparatus which, working on the capacitor charging principle, measures small time intervals. The method of operation of the electronic circuit is described, together with problems associated with its design. The mechanical means for overcoming leakage and photoelectric effects in the V.T. voltmeter circuit are shown. Alternative methods of calibration of the instrument are indicated as well as the circuit diagram of the apparatus for generation of a pair of pulses having a given known time spacing.

—*Electronics*, April, 1944, p. 108*

INDUSTRY

An Electronic Indicator for Liquid Separation
(J. W. Broadhurst)

The presence of a non-conducting or conducting liquid in a pipe line is detected electronically by means of an oscillator, which is thrown in and out of oscillation according to the liquid in the line. Passage of a conducting liquid through the oscillator inductance causes an eddy current loss, thus destroying the magnetic feedback.

—*Jour. Sci. Inst.*, June, 1944, p. 108.*

Beryllium Copper in Instrument Design
(L. B. Hunt)

The physical characteristics of beryllium copper are described with particular reference to elastic properties. The usefulness of this alloy for instrument springs and similar parts is shown to be in its combination of high elastic limit with relatively low elastic modulus. The bearing of these and of other properties of beryllium copper upon the problems of arriving at appropriate deflections and working stresses is then discussed for the principal types of springs and pressure responsive elements. Details are given of the technique required for the fabrication and heat treatment of beryllium copper.

—*Jour. Sci. Inst*, Vol. 21, No. 6. June, 1944, p. 97.

A photoelectric Device for Recording Variations in the Concentration of a Coloured Solution
(T. B. Davenport)

An apparatus is described which is capable of indicating by photoelectric means the concentration at any instant of a temperature controlled coloured solution whose concentration is varying with time such that its optical density changes between 3 and 0, the apparatus being calibrated with standard solutions.

—*Jour. Sci. Inst.*, Vol. 21, No. 5 (1944), p. 84.

* Supplied by the courtesy of Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester.

† By courtesy of R.T.P. Section, M.A.P.

BOOK REVIEWS

Practical Electrical Wiring and Contracting

Edited by A. C. Greenwood 384 pp. 400 figs. (Odhams Press 8s. 6d. net).

Although the radio engineer is not often actively concerned with electrical supply matters there must be a number of cases where the local supplier and serviceman is called on to make alterations to supply circuits or install appliances.

This book should not therefore be considered as of interest only to the electrical contractor, and its description of wiring and installation methods is so thorough that there will be no difficulty in making a satisfactory job with its aid.

It is emphasised in the foreword that all the wiring procedure conforms to the latest regulations and standard specifications, and the specifications for lighting installations include the most recent developments in fluorescent lighting fixtures. A chapter also deals with bell circuits, alarms, and electric clocks.

The book concludes with a section on planning and contracting with typical suggested layouts.

Altogether the book is an extraordinarily comprehensive treatise on the subject and is well worth investment, particularly as the price is so moderate.

The Physics of Music

by Alexander Wood. 255pp. 110 figs (Methuen 21s.)

This excellent text by Dr. Wood, the well-known physicist and Faculty Lecturer in Musical Acoustics at Cambridge University, is an attempt to present to those concerned with music the knowledge available to-day of the borderland between physics and music, in which so much new knowledge has been acquired in recent years.

The first five chapters cover the general theory of sound, or, what may be called, classical acoustics, with many historical references, leading up to a chapter on the ear and the mechanism of hearing. The following three chapters survey the production of sound by the vibration of strings, organ pipes, the human voice, and various orchestral instruments, both percussion and wind. The next two chapters deal with dissonance and consonance, and scales and temperament, with the twelfth chapter reviewing briefly the various methods of recording and reproducing sound

Apart from the printer's errors, seemingly inevitable with any first edition these days, serious errors are few, although the passage in the first chapter (p. 20), referring to beats is ambiguous, to say the least.

The publisher's note, inside the paper cover, mentions a mathematical index, but this does not appear in the book itself. The treatment throughout the book is admirably lucid, and although the presentation is designed primarily for those whose chief interest is on the musical side, it is equally informative for those readers concerned with the physical aspects of the subject. D.W.A.

CLASSIFIED ANNOUNCEMENTS.

The charge for miscellaneous advertisements on this page is 12 words or less 4/- and 4d. for every additional word. Box numbers (4 words) plus 1/- extra. 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.

FOR SALE

IN STOCK, Rectifiers, Accumulator Chargers, Rotary Converters, P.A. Amplifiers, Mikes, Mains Transformers, Speakers of most types, Test Meters, etc., Special Transformers quoted for.—University Radio, Ltd., 238, Euston Road, London, N.W.1. Ger. 4447.

RECONDITIONED wirewound potentiometers. 4 watts, 50,000 ohms, 4/- each, C.O.D. only. Hickmott Kendall and Co., Ltd., 23, Carlton House, 11, Regent Street, S.W.1.

LOUDSPEAKERS

LOUDSPEAKERS—We carry on. Sinclair Speakers, 170, Copenhagen Street, N.1.

LOUDSPEAKER repairs, British, American, any make, moderate prices.—Sinclair Speakers, 170, Copenhagen Street, N.1.

MISCELLANEOUS

WE WILL BUY at your price used radios, amplifiers, converters, test meters, motors, pick-ups, speakers, etc., radio and electrical accessories. Write, phone or call, University Radio Ltd., 238, Euston Road, London, N.W.1. Ger. 4447.

WEBB'S Radio Map of the World enables you to locate any station heard. Size 40" by 30" 2 colour heavy Art Paper, 4/6, post 6d. Limited supply on Linen, 10/6, post 6d.—Webb's Radio, 14, Soho Street, London, W.1 'Phone : GERrard 2089.

MORSE Practice Equipment for Class-room or Individual Tuition. Keys, Audio Oscillators for both battery or main operation. Webb's Radio, 14, Soho Street, London, W.1 Phone : GERrard 2089.

ADVERTISERS wish to secure services of small progressive firm desirous to expand business and having facilities for manufacturing radio equipment, and preferably also high-frequency laboratory equipment. The services to consist in the manufacture on a considerable scale, and in the development where necessary of special apparatus in which advertisers are interested. Advertisers desire to acquire financial interest in firm or in special branch of it. Apply Box No. 682, "Electronic Engineering."

BERRY'S (SHORT WAVE), LTD., can offer, in addition to the usual radio accessories, a most comprehensive range of U.H.F. and other precision components, including C.R. tubes; oscilloscopes and test gear; ceramic screw-driver, fixed and variable condensers; high wattage resistances; electronic glassware; polystyrene, &c. If your work is of a priority nature, delivery in nearly all cases by return. Send 1d. stamp for List "E" to BERRY'S (SHORT WAVE), LTD., 25, High Holborn, London, W.C.1. (Tel.: HOLborn 6231).

SITUATION VACANT

DESIGNER of specialised radio and P.A. equipment and electronic devices for Lancashire manufacturers of optical and scientific apparatus. Applicant should outline experience in first place to Box 687, "Electronic Engineering."

SITUATION WANTED

ENGINEER partially engaged on research, would like to represent porcelain or plastics firm, (3 days per week). Travelling not objected to. Very keen post-war applications. Box 689, "Electronic Engineering".

WANTED

WE OFFER cash for good modern Communication and all-wave Receivers.—A.C.S. Radio, 44, Widmore Road, Bromley.

0-50 MICROAMMETER; serviceable or repairable. Price and particulars to: Woodhall, CTC 402, R.A.F., Coldingham, Berwickshire.

ELECTRONIC LABORATORY requires Experienced Scientific Glassblower for Research Work. Write with full particulars to Box No. 688, "Electronic Engineering."


TUCKER EYELETS
AND TAGS
GEO. TUCKER EYELET CO. LTD.
WALSALL ROAD, BIRMINGHAM, 22
Phone: BIRchfields 5024


HIVAC
THE SCIENTIFIC VALVE
BRITISH MADE
Specialists in
MIDGET VALVES
HIVAC LIMITED
Greenhill Crescent,
Harrow on the Hill, Middx.
Telephone: Harrow 0895.


Constant Voltage
TRANSFORMERS
LINE VOLTAGE VARIATIONS OF ± 15 % REDUCED TO ± 1 %
TYPICAL SPECIFICATION
Input Voltage ... ... 190-260 v. 50 c.p.s.
Output Voltage ... ... 230 v. ± 1 %
Max. load ... ... 150 watts.
Input power factor over 90 %
Prices on application. Write for details
ADVANCE COMPONENTS LTD.
BACK RD., SHERNHALL ST., WALTHAMSTOW, E17. PHONE: LARKSWOOD 4366-7

Printed in Great Britain by The Press at Coombelands, Ltd., Addlestone, Surrey, for the Proprietors and Publishers, Hulton Press, Ltd., 43-44, Shoe Lane, London, E.C.4
Sole Agents for Australia and New Zealand: Gordon and Gotch (A/sia), Ltd. South Africa: Central News Agency, Ltd.
Registered for Transmission by Canadian Magazine Post.