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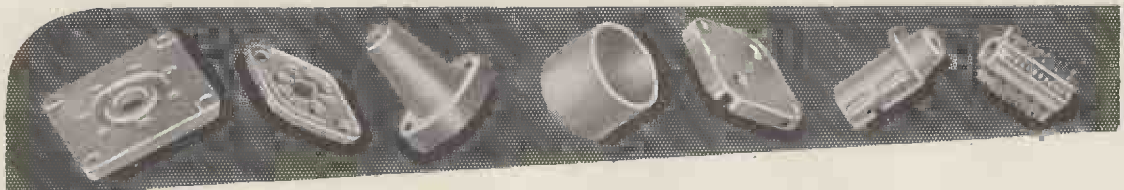
PRINCIPAL CONTENTS

2/- DEC., 1944

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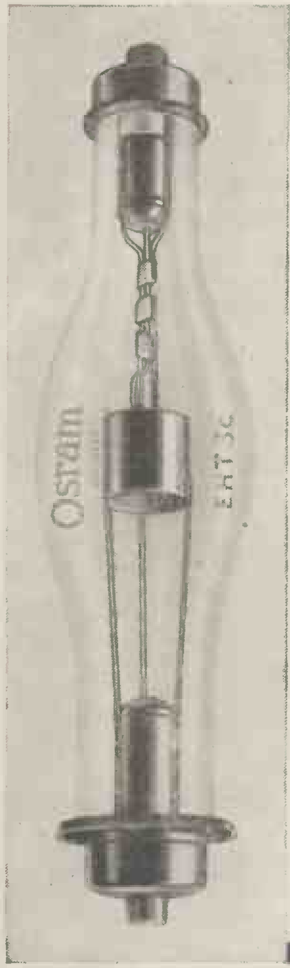

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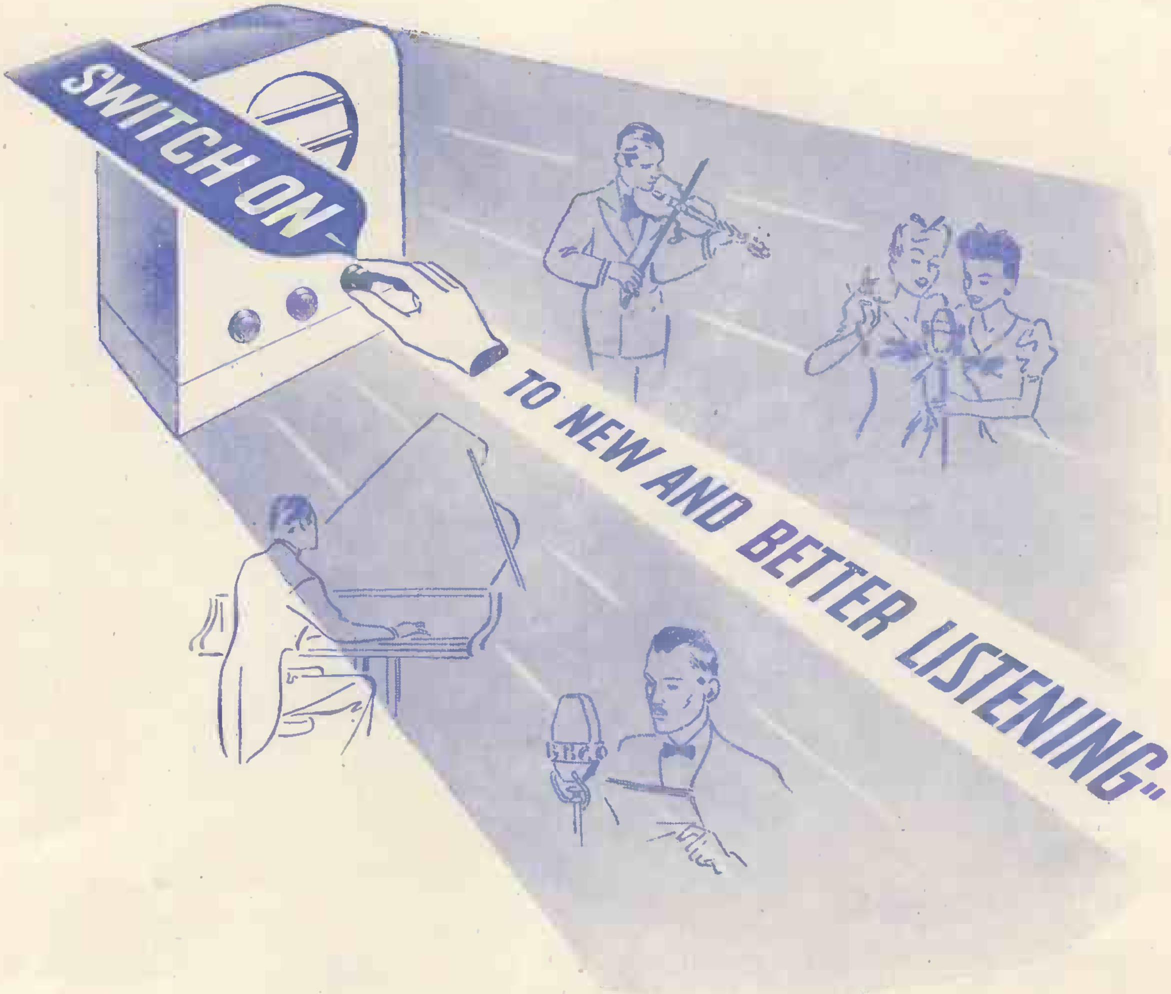
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Post-War Planning

THERE is always something interesting in reading the results of surveys, questionnaires, mass observations, and similar reports which are published from time to time.

It is still arguable whether such surveys really represent the true feelings of the section of the community which they purport to represent, but the reader will nearly always find his own views reflected by some statement quoted somewhere in the report, so they cannot be so far from reality as the cynical suggest.

A recent report of particular interest is one published by Messrs. H. Whitehead* on Post-War Planning and Anglo-American Relations. It presents the results of their research on the opinions of 169 responsible business men in large, medium and small firms.

Summarising their results, half of the firms have got so far with their plans as to have tentative sales budgets for post-war years, but 93 per cent. of them say that they are up against serious hindrances in formulating post-war plans.

The main burden of the complaints is lack of Government guidance as to post-war economic policy. Looking down the pages devoted to detailed replies to questions, the word " Uncertainty " occurs with monotonous regularity, from " uncertainty about everything " to " uncertainty about Germany and Japan as competitors."

In fact the majority of the 169 business men are so uncertain about the future that one is tempted to wonder whether they will remain in business after the war.

The section of the Report dealing with Anglo-American relations is perhaps more important to the radio industry, although it is not mentioned specifically.

Opinions on the desirability of making post-war arrangements with America in export market spheres are evenly divided. The last question : " . . . . What form of co-operation do you think that British Industry should have with American Industry after the war ? " brought a variety of replies, from full co-operation (26 per cent.) to interchange of personnel (10 per cent.), exchange of information (13 per cent.) agreements against competition (5 per cent.).

Two aspects of co-operation which received disappointingly little encouragement were the standardisation of engineering specifications and co-operation in research. The last item, at any rate, seems to be one on which agreement could be reached without upsetting the larger issues of trade policy.

Readers of American technical literature of all kinds are continually finding notes of research which has been done, or is being done, in a similar form in this country and no doubt American workers find the same.

It is not intended to advocate the wholesale pooling of research, with its consequent restrictions, classifications, assignments and whatever might follow in its train, but it is suggested that more intelligent co-operation would save useless repetition and enable the work in certain directions to be carried on faster and farther.

This aspect of post-war co-operation need not wait for Government encouragement or direction. It is merely a continuance of a war-time arrangement in certain quarters which has proved of value. It is likely to prove of more value if both sides agree that contributions to the advancement of science are above trade rivalries in peacetime, and publish their work for the common good.

* " Post-War Planning and Anglo-American Economic Relations," H. Whitehead, Ltd., 31 Palace Street, London, S.W.1. 2s. 6d. net.

A Rotating-Anode

Part I—General and Structural

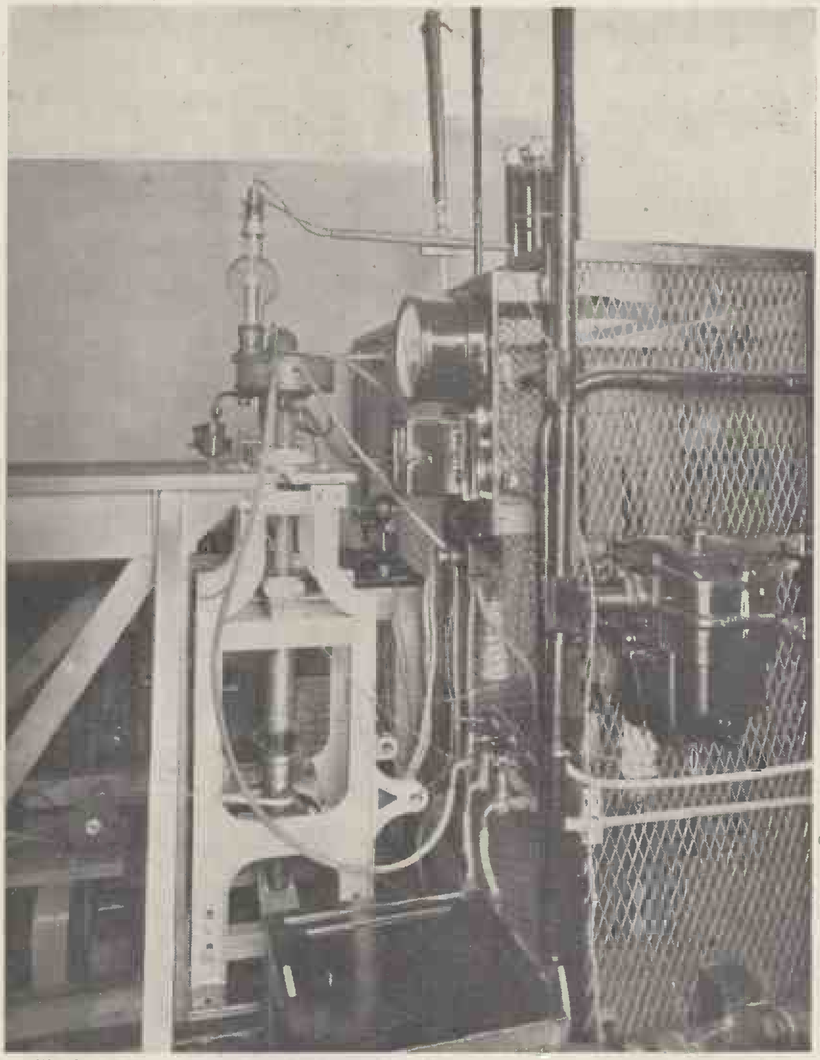


Fig. 1. General view of Rotating-Anode X-Ray Generator and ancillary equipment.

QUICK recording of X-radiograms is becoming of increasing importance. In the modern organic and biological fields, specimens may be minute, polyphase, poorly oriented; really monochromatic radiation may be required. The resolution of macro-cells (*e.g.*, protein) demands fine beams; more information may be obtainable from a comparative study of homologues than from one member, or by examination of fibres, say, under varying conditions of temperature, pressure, humidity, swelling, *p*H, tension, and finely graded chemical treatments. To analyse fairly fleeting physico-chemical changes, or for routine diagnosis in critical large-scale manufacturing processes, speed is essential.

The methods for achieving increased speed are mainly:—

(a) Selection of optimum size, form and disposition of specimen.

(b) X-ray beam concentration, using the appropriate geometric interpretation, *e.g.*

i. Specimen mounted at the focus of a hemispherical cathode, giving line reflexion (Hess[1]).‡

ii. Large specimen, wide-angle beam from small focus (Seemann[2]).

iii. Small specimen, wide-angle beam from large focus (Soller slit[3]).

iv. Primary and secondary foreshortening (line *v.* spot foci, *e.g.*, most commercial hot-cathode tubes; suitably cut crystal reflectors: George,[4] Stephen and Barnes,[5] Brentano,[6] Bernal-Fankuchen[7]).

v. Focusing (including multi-crystal) monochromators (Johann,[8] Cauchois,[9] Johansson,[10] Watson,[11] Guinier,[12] C. S. Smith;[13] DuMond and Kirkpatrick[14]).

vi. Mirror reflexion from smooth surfaces, *e.g.*, Pb-glass capillary slits (Jentzsch and Nähring[15]).

(c). Reduction of loss. Vacuum-, H_2-, or He-filled cameras; beryllium or lithium windows to the tube.

(d). More sensitive recorders. Increased photographic film sensitivity; specialised developing technique; multi-films; intensifying screens; Geiger counters.

(e). Increased X-ray energy at source—the high-power X-ray generator.

* Amplified substance of communication to inaugural meeting of X-Ray Analysis Group of Institute of Physics, Manchester, 16-10-1943.)

† I.W.S. Research Fellow, Department of Textile Physics, University of Leeds.

‡ Figures refer to bibliography given in Part II.

Of all these methods only (e) is applicable to all classes of problem and additive to all the others.

High-Power Generators

The total X-ray intensity is the sum of "characteristic" (monochromatic) and "white" (continuous) radiations, whose intensities (I_k, I_w) for a given target material are functions of tube voltage and current (V, c). In the commoner methods of structure analysis, only I_k is useful, I_w producing spurious reflexions and background fogging. A suitable compromise between beam intensity and clean photographic contrast is obtained at an optimum voltage (approximately 30-40 kV. for Cu), and hence the useful intensity is increased only by increasing c. ($I = (I_k + I_w) \propto c$). As less than 1 per cent. of the electrical energy is converted to X-ray energy, the essential problem in high-power X-ray generators is heat-dissipation to conserve the target. The usual targets having already high melting points, good thermal conductivities, and liquid cooling, this is achieved, without dispersion of the X-ray focal

Fig. 2. General view showing structural detail.

X-Ray Generator*

By IAN MacARTHUR, M.A., B.Sc., Ph.D.†

area, by a suitably oscillating, gyrating, or rotating target. Engineering requisites are liquid- and vacuum-tight seals in moving systems. The former, unnecessary in tubes designed only for instantaneous use (Bouwers[16]), is met by greased packing glands. The latter may be achieved through flexible metal bellows, *e.g.*, of Be-Cu, (gyration: DuMond,[17] oscillation: Hosemann[18]); greased ground joints (low-speed: Fournier-Gondet-Mathieu,[19] high-speed: Stintzing[20]); stuffing-boxes backed by high-speed pumps (Müller-Clay,[21] Beck[22]); target as rotor of molecular pump (Linnitzki-Gorski[23]); or liquid seals (Astbury[24]).

The Astbury X-Ray Generator

This has developed in three stages. The principles were successfully tested in early apparatus; then a working generator was constructed with the material and facilities available; this was a try-out for a finished design (now in the final stages of assembly and test). The test model, however, with its continual improvements, has given such useful experimental and routine service, that it is still in present use in the Textile Physics Research Laboratory, University of Leeds. The wide interest raised by its performance has called for the present account. Designed by Dr. Astbury, and developed chiefly with the assistance of Drs. R. D. Preston, J. A. T. Dawson, E. Green and the writer, its parts, save for the framework, have been constructed by Mr. Robinson and Mr. Moulson with the resources of our own workshop. Of demountable hot-cathode type, and designed for continuous use, its characteristic features include a Torricellian Hg+oil seal for the rotating vacuum joint (thus allowing high rotational speed very free of vibration) and sharp critical focusing (permitting moderate power-input and the use of comparatively cheap electrical equipment without material loss of intensity using pinhole or ribbon slits). In the general description to follow, reference should be made to the appropriate figures, which show essential detail to scale.

Lay Out

Figs. 1, 2 show two views of the general assembly in a basement laboratory. Fig. 3 is a plan of the component lay-out.

The tube is housed vertically in a steel cross-strutted framework (Fig. 1). The lower casing or fixed part is rigidly clamped to cross-bars at two higher levels; bars at two lower levels carry respectively a self-aligning ball-bearing for the target shaft, and a boss carrying a brass water-exit tube.

Target and Shaft

(Figs. 4, 7). The target consists of a hollow copper cylindrical pan, $7\frac{3}{4}$ in. diameter, 1 in. deep, and $\frac{1}{8}$ in. thick. Its upper periphery is bevelled at 6° over an inch-wide path. It screws and is soldered to a backplate carrying a boss which fits the inner race of the upper ball-bearing. Screwed and soldered to the boss is the long stainless steel hollow shaft 1.2 in. outer diameter. This is threaded above its lower bearing (Fig. 6) to carry steel collars with a covering (left-hand threaded) flanged sleeve by which the shaft is pulley-rotated anticlockwise through a reduction gear by means of an $\frac{1}{8}$ H.P. motor (Fig. 3). The normal speed is 620 r.p.m.

Water-Cooling of Target

(Figs. 5, 7). A long stout brass tube, $\frac{3}{8}$ in. diameter bore and $\frac{1}{4}$ in. wall thickness, screws at its lower end into a terminal boss with exit tube. The boss has levelling screws

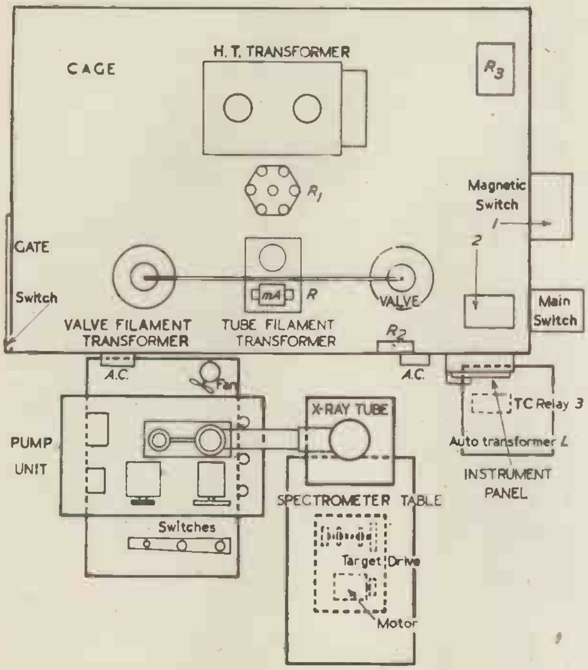


Fig. 3. Plan of lay-out of equipment.

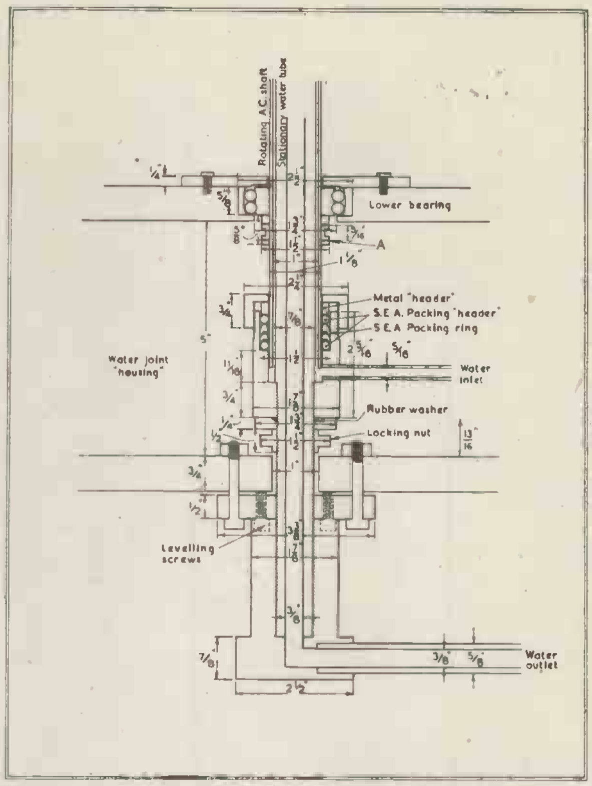
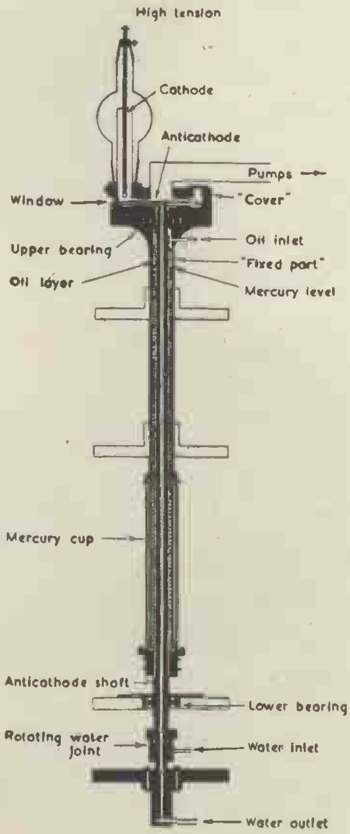


Fig. 5. Rotating water-joint.

Fig. 4 (below). General principles of rotating-anode system — Model 2.



and slight lateral adjustment, so that the tube can be fixed coaxial with the target shaft. The upper end, which reaches to within ⅛ in. of the inner domed top of the target, is kept in position by a circular baffle fixed to the base plate of the target and rotating with it. Water flows in up the annular space 1/16 in. wide between the brass tube and rotating shaft, is deflected to the target periphery by the baffle, and flows to waste down the brass tube. Raising of the target in its seating by the considerable water pressure is prevented by a boss (A) and lock on the shaft, the boss playing on the inner race of the lower ball-bearing. A brass housing for the rotating water-joint screws on to the fixed brass tube just above the lowest fixed bar. Sealed at its lower end by a rubber washer and locking nut, it is recessed to take the water-inlet tube and the lower end of the target shaft. The water-joint is effected by two asbestos-graphite S.E.A. rings with terminal S.E.A. packing "headers," compression being adjusted through a metal header by an upper brass screw-cap. Inaccurate adjustment of this gland, the central water-exit tube, and the face of boss A may cause vibration and undue friction.

Lower Casing

(Figs. 4, 6, 7). This fixed part consists of a 2 in. diameter steel tube 38 in. long, clamped coaxial with the shaft, and screwed and soldered into a massive steel upper plate 9¼ in. in diameter suitably recessed to take the upper ball-bearing. Before assembly, this bearing is oiled with "Apiezon B." A brass disk spacer adjusts the height of the target and, rotating with it, is recessed just to clear the fixed outer race. A smooth-ground peripheral flange on the plate supports the upper casing. An oil layer may be admitted through a soldered brass inlet tube, later sealed by screw-cap and wax. The lower casing terminates ¼ in. from the base of the Hg cup.

Mercury-Oil Seal

(Figs. 4, 6, 7). The upper faces of the two steel collars on the threaded part of the target shaft form the base of the Hg cup; they are held by a boss and lock nut. A cylindrical steel sleeve 16 in. long and 2½ in. inside diameter screws on the left-hand outer thread on the boss to form the outer wall of the cup, which rotates the shaft, its lower end being flanged to take belt drive. Threaded joints are guttapercha-sealed. At

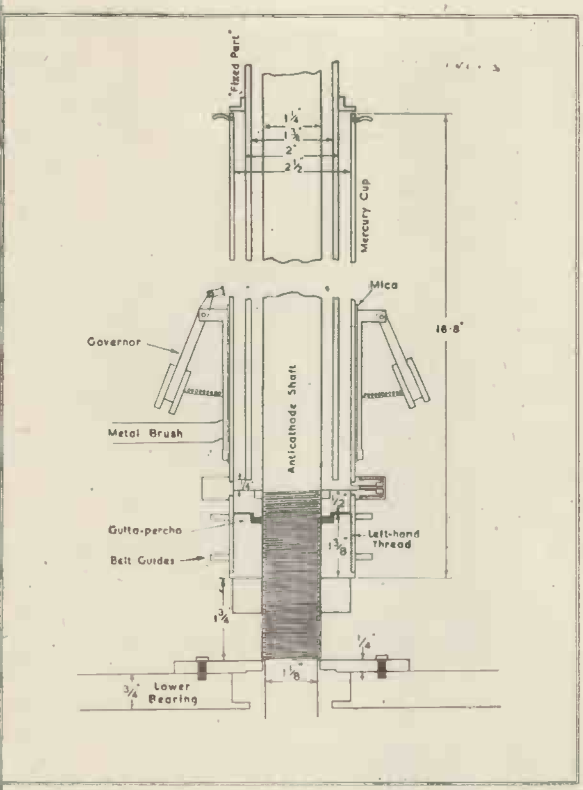


Fig. 6. Mercury cup and governor.

atmospheric pressure, 730ml Hg fill the space between the walls of the lower casing, cup, and shaft, to near the top of the cup. With the tube exhausted and a barometric height of 31 in., this gives a 2 in. depth between cup and casing, and a clearance of 3½ in. between the inner Hg level and that of the oil inlet. There is thus ample room for a 2 in. covering layer of "Apiezon B" oil. An interesting calculation shows that disturbance of the liquid surface levels at 600 r.p.m. is negligible. Normally, the vacuum is held for months; but even after renewing a filament and therefore allowing Hg and oil to fall in the narrower inner annulus, no trouble has been experienced through Hg getting past the oil layer. But walls and liquids must be scrupulously clean. A disk clamped to the lower casing immediately above the cup prevents entry of dust, etc. At the base of the cup, Hg can be drained off through a steel plug, dummy-balanced and normally sealed. The Hg is cooled by the inflow of water to the target.

Upper Casing

(Figs. 1, 2, 4, 7). This cover is essentially a cylindrical phosphor-bronze casting of diameter 9¼ in., height 3 in., wall thickness 11/16 in., with one end face. The open end is smooth-ground to the flange of the lower casing plate; the junction, after sealing with "Apiezon L" grease, is buttressed under vacuum by wax seal or coating of Apiezon "Q" putty and shellac. Three openings in the upper surface carry respectively a 2 in. diameter screwed and soldered vacuum pipe, a plate-glass wax-sealed inspection port for the target surface, and a smooth-ground recessed cylindrical brass plate to carry the seating for the X-ray bulb. A 3/16 in. diameter hole in the cylinder wall to intersect the axes of the shaft and cathode seating at the height of the path of the focal spot on the target bevel, acts as window when sealed with Be sheet or Al foil. Round the window, the wall is recessed to 3/16 in. from the inner surface to admit collimators close to the beam source. Grooves cut (Fig. 7) in the outer casing wall and round the window and cathode seating, closed by soldered brass plate and suitably baffled, permit water cooling. The pressure casting proved rather porous. Cold or hot tinning, electroplating, metal spraying, soldering, and pressure resin adsorption are possible cures. In fact, leaks were sealed by shellacing inside the water channels and outside the upper casing; but this reduces cooling efficiency.

Pump Unit

The standard Metrovac unit (Fig. 1) consists of 02 and 03 condensation pumps in tandem, backed by a rotary oil pump. An Audco tap and P_2O_5 trap are incorporated. The lower vacuum stages are indicated by a glow discharge tube and trembler coil. The line connexion to the upper casing port is by 2 in. diameter steel tube. To avoid transmission of vibration, these are recessed almost to meet and sealed by a 5 in. sleeve of "L"-greased latex cycle tubing. A steel insert above the 03 pump is charged at intervals with solid CO_2 to safeguard efficient condensation of the "Apiezon B" or "Molecular Lubricant C"* employed.

Cathode Assembly

(Figs. 2, 4, 7). As supplied by C. Beaudouin, Paris, this is essentially the same as in the F-G-M[19] tube. Mounted on the upper casing, it consists of (a) conical seating, (b) thick-walled glass X-ray bulb with conical ends smooth-ground to fit (a) and (c), and (c) mounting for cathode proper. The bulb is sealed vertically on its seating with a minimum of "Apiezon L" and buttressed by "Q" compound. It is shielded from electrical stress by a 6 in. brass cylindrical tube screwed into the seating head. A steel cathode tube 15 in. long by ½ in. diameter is carried by a boss screwed internally to a brass mounting joined by flexible metal bellows tubing to a brass cone sealing the upper end of the X-ray bulb. Three screws not only take the stress but also permit alignment of the cathode tube and fine adjustment of the filament-target distance without breaking the vacuum. One filament terminal is fixed to the side of the mounting; the other, sealed above the mounting, is fixed to a long rod concentric with the cathode tube from which it is insulated by mica washers. This functions also as the H.T. terminal of the X-ray tube, the target being earthed. Both rod and cathode tube ends are drawn out into parallel hollow sockets into which the metal pins carrying the filament are clamped.

Filament, Filament Cup and Focus

With sealed-off hot-cathode tubes, and even with the Shearer gas tube at 5 ma and 40 kV, sharp focusing may cause undesirable target wear. In fixed-anode hot-cathode tubes, control of the electron stream, beyond the conventional cup, by externally applied electric or magnetic fields has been largely to obtain a degree of

* Litton Engineering Laboratories, Redwood City, Calif.

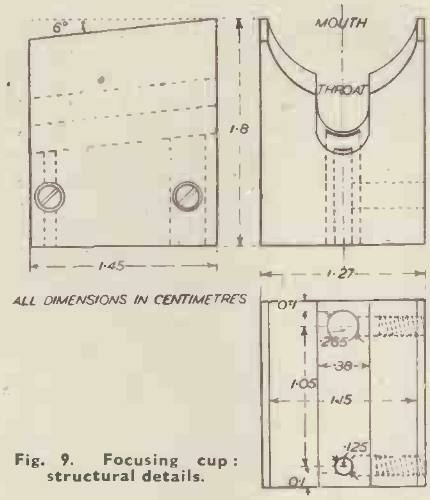


Fig. 9. Focusing cup: structural details.

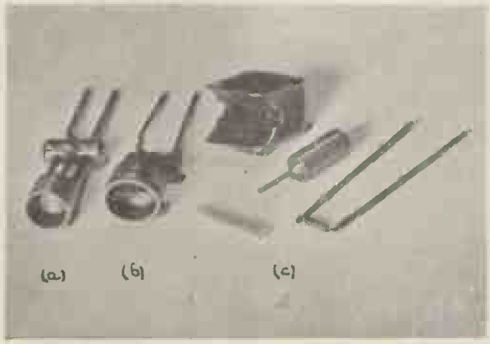


Fig. 8. Filament and cup.
(a) Tungsten filament and cup.
Tantalum helix filament and cup.
(b) Components of line focus system.
Cup, SiO_2, Tubing, Tantalum helix, Former.

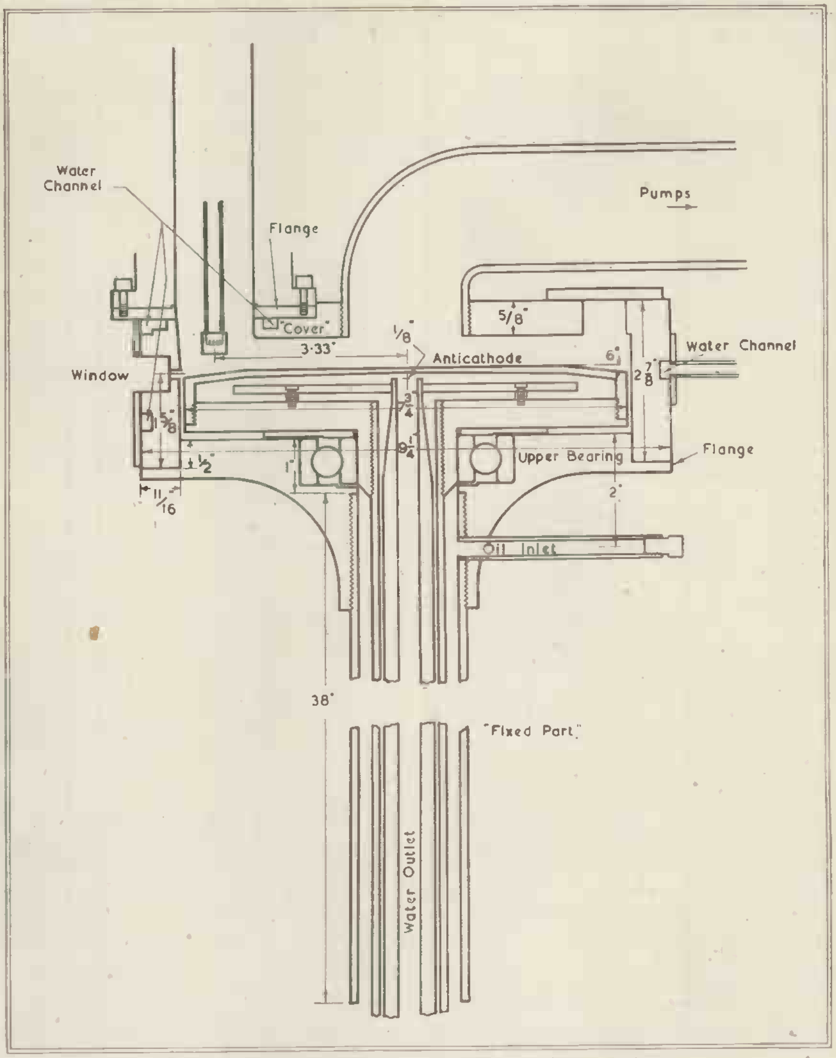


Fig. 7. Target, Cathode seating, upper and lower casings.

internal rectification,[25,26] or to bypass a filament shield inserted to prevent target contamination[27] and/or increase filament life.[28] With the advent of moving targets and increased study of electronics, sharper focusing of electron beams for X-ray production[29–33] is of increasing interest, especially for focal spot control and high specific input. The three systems used here (Fig. 8) employ the electrostatic focusing of cathode form and space charge.

(a). As produced by the Cie Générale de Radiologie. A W-spiral of diameter 4.5 mm. and 6 turns, set 5 mm. deep in a cylindrical focusing cup 9 mm. diameter by 8 mm. deep gives a circular focal spot approximately 0.85 mm. diameter with target-filament distance (s) 1.4 cm.

(b). A tantalum helix 5 mm. long by 0.9 mm. outer diameter, 11 turns, set 4 mm. deep in an oval cylindrical focusing cup 11 × 9 mm. by 8 mm. deep. With s 1.2 cm., a line focus approximately 3.5 × 0.8 mm. is obtained.

(c). Present system. Filament helices of 0.25 or 0.3 mm. diameter Ta wire are wound (14 turns) on a U-screw former of diameter 0.85 mm. and pitch 0.5 mm. The helix is spot-welded to two steel rods. This filament is centred in the throat of a steel focusing cup, one pin being insulated by silica tubing. Adjustment is maintained by flush grub screws. The cup is formed from a rectangular steel block 1.80 × 1.45 × 1.27 cm. with a hemicylindrical hollow and central throat of diameters 1.15, 0.38 cm. respectively, the parallel axes of which are inclined at 6° to the base to give parallel alignment of filament and target bevel. The axis of the throat is 1.5 mm. vertically below the lowest generator of the upper cylinder, the throat mouth being completed by vertical planes tangential at the widest part. Fig. 9 shows structural and dimensional detail. Considerable experiment on the focus obtained shows that it is a function of s, diameter of wire and of helix, and depth (h) of filament axis in throat, corroborating the results of Beese.[34] With s 1.6 cm. and h 0.7 mm., a line focus approximately 7.5 × 0.6 mm. is obtained. All surfaces in the cup and cathode vicinity are smoothed to obtain uniform fields. Although of lower melting point, tantalum is preferred to tungsten because, in addition to being more plastic and with equally good thermionic properties, it deposits little on the target.

(To be continued.)

High Vacuum Gauges

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

" It would perhaps not be too much to say that the physics of the vacuum dominates the modern laboratory."
(Prof. Andrade in Enc. Brit.)

HIGH vacua, that is, pressure reductions to less than 10^{-5} atmospheres, were a laboratory curiosity reserved mainly to the "pure" physicists about 50 years ago. Only a small industry working on a kind of laboratory scale, the carbon filament lamp makers, were "high vacuum conscious" at that time, while the engineers and chemists used to call 1/10 of an atmosphere a high vacuum. The situation underwent a drastic change about 1912 when the electronic valve came into being and when, between 1916 and 1920, the foundations of the modern radio and X-ray technique were laid. It may safely be predicted that ten years hence high vacuum technique will play an important part in the chemical industry by the development of what is called "molecular distillation."[18]

All this progress must not blind us to the fact that the pressure reduction which we call "high vacuum" is not something as outstanding as one should think on the face of it. An easy computation shows that the best vacuum one is able to obtain, *viz*, a pressure of, say, 10^{-7} mm. Hg, leaves still quite a considerable number of molecules within the unit volume: 10^{-7} mm. Hg corresponds to about 10^{-10} atmospheres. At atmospheric pressure the number of gas molecules contained in a cubic centimetre is about 2.7×10^{19} according to Avogadro and Loschmidt, so that at 10^{-10} atmospheres molecules of the order of 10^{9} are still left in the cubic centimetre.

Historical

As is well known, the abortive effort of a seventeenth century craftsman in Florence to draw water with a suction pump from a well about 35 feet deep led to Toricelli's experiments. Otto von Guericke was informed about these experiments by Pater Valerianus Magnus and describes[19] his own "*Experimentum pro demonstrando Vacuo, per Argenti Vivi, e Tubo vitreo superius clauso, descentum*" as follows: "*Quando aer extrahebatur modo dicto idem accidebat, ita ut totum hydrargyrum integri tubi, at dimidiam fere digiti partem contractum fuisse.*"

("Experiment for demonstrating the vacuum by the descent of mercury from a glass tube closed at its top" —"When the air was extracted as described the same occurred such that the total mercury from the whole tube was contracted to about one-half of a digit.")

Similar experiments were carried out by Boyle[20] and, as he pointed out, "repeated a few days afterwards in the presence of those excellent and deservedly famous Mathematic Professors, Dr. Wallis, Dr. Ward and Mr. Wren who were pleased to honour it with their presence; and whom I name, both as justly counting it an honour to be known to them, and as being glad of such judicious and illustrious witnesses of our experiment; and it was by their guess, that the top of the quicksilver in the tube was defined to be brought within an inch of the surface of that in the vessel."

Neither the air pump nor the "diachylon" (a lead paste) used for tightening the joints seem to have been very effective. Boyle also observed that while at the first strokes of the pump the mercury sank about $1\frac{3}{8}$ in. "when the vessel was almost emptied it could scarce at one exsuction be drawn down above the breadth of a barley corn."

For our present-day needs "about one half of a finger's breadth," the "guess of excellent Mathematic Professors" (one of them built St. Paul's) and the "breadth of a barley corn" are not sufficiently exact measures.

There exist quite a number of different units for the measurement of vacua and it is therefore useful to give a comparative table of these units.

This table which is based on the one given by Mönch[10] shows, among other things, that British and American practice differs with regard to the *bar*[14] and that, especially when expressing percentage vacuum, in some cases it is reckoned from atmospheric pressure downwards and in other cases from zero pressure upwards.

Boyle's experiments led to the discovery of what is known as Boyle's law, which states that at constant temperature the product of volume and pressure of a perfect gas remains constant. Boyle himself says the following about this discovery:—

"But before I enter upon this subject I shall readily acknowledge, that I had not reduced the trials I had made about measuring the ex-

PRINCIPAL UNITS USED IN VACUUM TECHNIQUE:

	mm.Hg	Bar	Dyne/cm²	Atm.	at.
1 mm. Hg =	1	1.33×10^{-3}	1.33×10^{3}	1.32×10^{-3}	1.36×10^{-3}
1 Bar =	0.75×10^{3}	1	10^{6}	0.987	1.02
1 Dyne/cm² =	0.75×10^{-3}	10^{-6}	1	0.987×10^{-6}	1.02×10^{-6}
1 Atm. =	760	1.013	1.013×10^{6}	1	1.033
1 at. =	735.5	0.981	0.981×10^{6}	0.968	1

Older nomenclature: 1 Bar = 1 Dyne/cm² (e.g. *Dushman, Newman, Strong*)
" " 1 Megabar = 10^{6} " " " "
New " 1 Microbar = 1 "
= 1 barye (*French writers*)
1 Millibar = 10^{3} Dyne/cm² (*Meteorology*)
1 Atm. is the physical atmosphere = 760 mm. Hg at 0°C.
1 at. " technical " = 1 Kg/cm² = 14.2 lbs./sq. in.
1 per cent. vacuum (starting from zero) = 0.3 ins. Hg.
% vacuum (starting from Atm.) = $\frac{760-x}{760}$ if *x* measured in mms. Hg.
1 in. Hg. = 345 mm. water
1 Tor = 1 mm. Hg
1 micron (μ) = 10^{-3} mm. Hg
1 M = 10^{-6} Atm. (e.g. *J. T. Bottomley*)

* This article is based on a paper read by M. Pirani on June 6th, 1944, before the Electronics Group of the Institute of Physics, London.

pansion of the air to any certain hypothesis, when that ingenious gentleman, Mr. Richard Townsley, was pleased to inform me that having by the perusal of my physico-mechanical experiments been satisfied that the spring of the air was the cause of it, he endeavoured . . . to supply what I had omitted concerning the reducing to a precise estimate how much air dilated of itself loses of its elastic force, according to the measure of its dilation."

This hypothesis of Townsley, based on Boyle's 17th experiment, supposes "the pressures and expansions to be in reciprocal proportion." Hooke expressed the law in the words "the Elater of the Air is reciprocal to its extension, or at least very neer."[21]

Nearly all the gauges used for measuring high vacua are either based directly on Boyle's law (so-called compression gauges), or must be calibrated by means of such a compression gauge. Boyle's law is only valid for ideal gases and the pressure of vapours makes certain precautions or corrections necessary. We shall discuss these later on. In some of the gauges we are going to describe we find metal parts. It seems of interest to look at the order of the vapour pressures of some substances which may be present in a vacuum system. The adjoining graph (Fig. 1) shows the vapour pressure of various substances, mainly of metals, and its dependence on temperature. In this graph the vertical pressure scale is logarithmic while the abscissae are temperatures in Centigrade. This scale (left to right) is irregular as it is based on a regular scale of the inverse of absolute temperature (right to left). The advantage of this kind of representation is the fact that nearly linear curves are obtained. The values are those given by Yarwood[13] without correction.

Some of the gauges to be described presently are based on the fact that certain properties of the gases, *e.g.*, viscosity and heat conductivity, show certain anomalies when the mean free path of the molecules becomes comparable with the dimensions of the apparatus. This mean free path which plays such an important part in Kinetic Gas theory is the average distance a molecule covers before colliding with another molecule. It is usually calculated according to Maxwell's formula, although more recent investigations of Jeans, Chapman and others give somewhat higher values than those obtained by Maxwell. Fig. 2 compares in double logarithmic scale the mean free path for nitrogen in its dependence on pressure according to Maxwell's formula (Strong)[12] with the value as given by Mönch.[10]

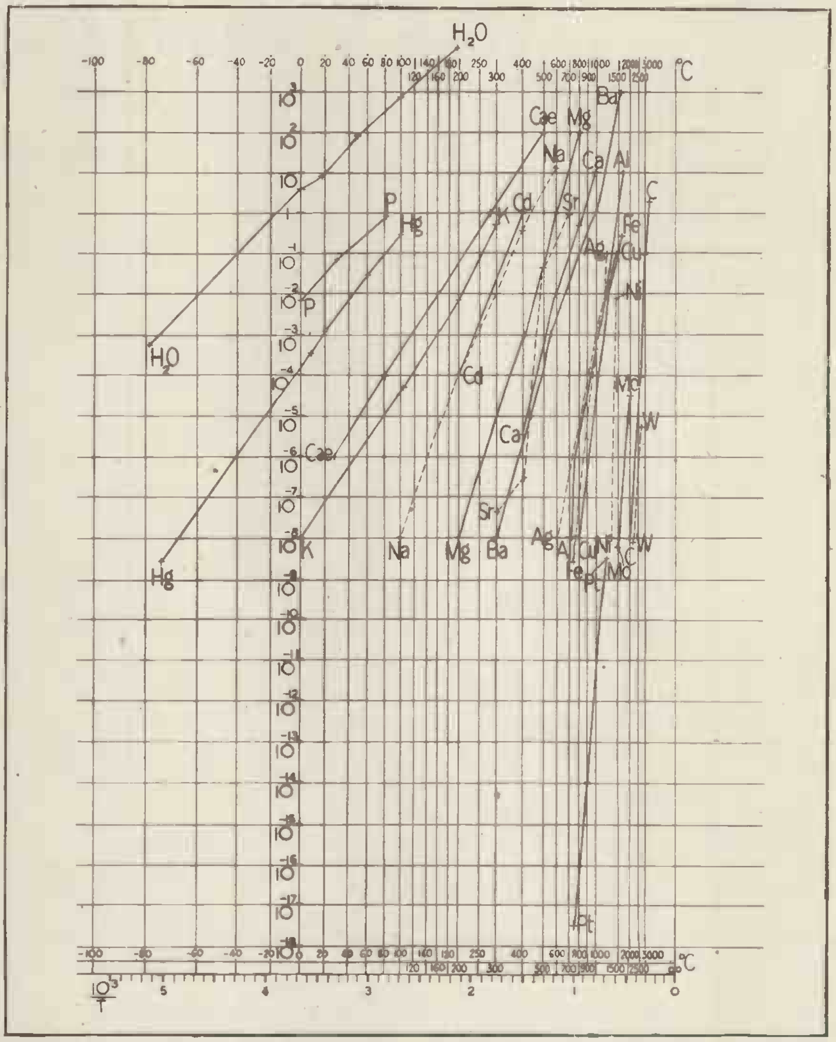


Table 2. Pressures used in various vacuum apparatus.

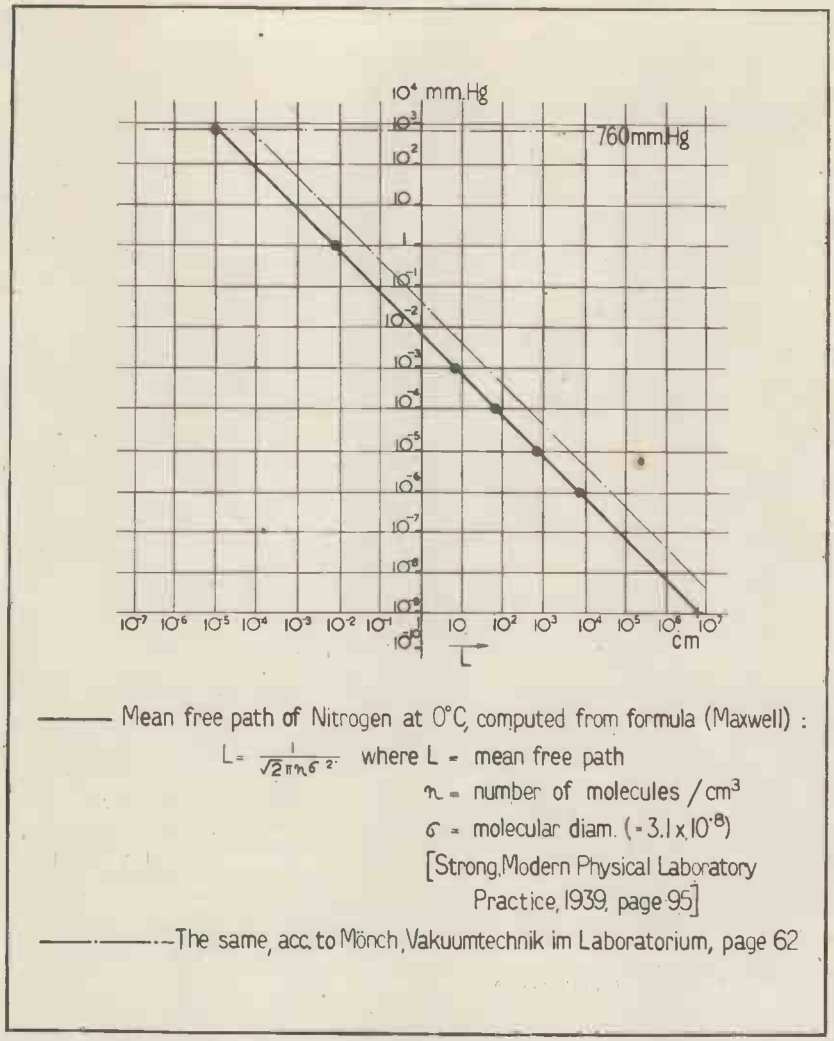
Application	*mm. Hg*
Quartz lamp	100–1000
Gas filled incandescent lamp ...	500
Vacuum Brake (Railways)	230
Condensers in steam plant	25–80
Vacuum drying, impregnating, etc.	10–60
Low voltage hot cathode rectifier	0.5–30
Glow lamp	5–20
Moore light	0.2–2
Gas-filled amplifier	3×10^{-3}–1
Gas-filled photocell	0.5–1
Gas filled X-ray and C.R. Tubes ...	10^{-2}
Content of permanent gases in low pressure mercury vapour lamp and mercury rectifier	0.01–1
Carbon filament lamp	10^{-3}–10^{-2}
Metal filament lamp...	10^{-4}–10^{-3}
Hot cathode oscillograph and rectifier	10^{-4}–10^{-3}
Formation of metallic films on glass by "sputtering"	$<10^{-5}$–10^{-1}
Surface treatment ("blooming") of optical lenses	10^{-5}
Bryan's method of metal vaporisation	$<10^{-5}$
Radio valves	$<10^{-6}$
Hard C.R. tubes	10^{-6}
Photocells	10^{-6}

(See also Yarwood,[13] and Espe-Knoll.[8])

It should be mentioned that the large increase of the mean free path with diminishing pressure must be taken into account when dimensioning the tubing connecting the various parts of a vacuum installation. The larger the mean free path the larger must be the diameter of such tubing if long time-lags in the equalisation of pressure between inlet and outlet of the tube are to be avoided.

As is well known the resistance against flow of gases at low pressures is inversely proportional to the third power of the diameter of the tube.[22]

In Table 2 some examples are



given for average values of pressures used in different applications :—

In the following we shall confine ourselves to dealing only with high vacuum gauges, *i.e.*, with gauges applicable to pressures of, say, 10^{-1} and less. Thus barometers and the ordinary Bourdon or aneroid type of manometer will not be dealt with. We shall further confine ourselves to the most important types of gauges and those which have found a more or less wide practical application.

Principles of Vacuum Measurement

For a rough indication of pressures in many cases a simple discharge tube connected to the vacuum is quite sufficient. Shape and colour of the discharge initiated in the tube by connecting its electrodes to an induction coil are characteristic for different pressure ranges.[23]. Fig. 3 gives an example based on experiments on air made by Stintzing.[24] For different gases or vapours the first cathode layer, the cathode dark space, the negative glow, and the positive column show various colours characteristic for the particular gas, and examples of these were recently described in this journal by J. Yarwood.[25]

In place of the d.c. discharge a high frequency a.c. discharge may be used ("Tesla test") and this may be produced by one of the high frequency devices procurable from medical suppliers. In this case no sealed-in electrodes are necessary as it suffices to touch the glass walls from outside with the bar electrodes of the device, but this method is only applicable for pressures down to 10^{-3} mm. Hg.

On the same principle is based the "Betoray" high frequency spark tester of Baird and Tatlock. (Fig. 4.) It consists of a high-voltage transformer and high-voltage electrode which are contained in a small ebonite handle connected by flexible cable to the mains unit which encloses the primary transformer. It may be connected to an a.c. or d.c. supply. A rough estimate of the degree of vacuum between 10^{-1} and 10^{-4} mm. Hg can be obtained, the colour of the discharge changing from red or violet at 10^{-1} mm. to green at 10^{-3} mm. Green fluorescence of the tube walls remains down to about 10^{-4} mm. Hg.

Fig. 5 gives an idea of a sturdy vacuum test apparatus which can be operated from a.c. mains as designed by Dr. L. Kann in collaboration with the Quadrant Engineering Co. (unpublished private communication). It consists of a quenched spark gap, a capacitor, a glow lamp and a transformer each on the low and the high frequency sides. The electrodes of the spark gap are fitted with large cooling fins. One of the electrodes is carried by a spring blade in such a manner that it moves parallel to itself when adjusted against the fixed electrode by a fine screw with knurled head. The windings of the high-frequency transformer are located inside the handle and specially insulated.

Fig. 2 (left). Mean free path of nitrogen.

Fig. 3 (below). Appearance of discharge at varying presssures.

Quantitative determination of low pressures with discharge tube, air, inductor with variable rheostat for 4-6v, 15mm. spark.

Pressure mm Hg (Order of Magnitude)	Kind of discharge	
	Shape	Colour
10^{1}	Thread	red
	"	"
10^{0}	"	"
	"	"
	Striations	violet-whitish
10^{-1}	"	bluish-whitish
	No striations	same, all edges green
10^{-2}	"	all edges green
	only intermittent	nearly all green and blue-green.
10^{-3}	"	blue-green
	only with current commutation	grayish
10^{-4}	"	"
	No discharge, not even with commutation	

Acc. H. Stintzing, Z. phys. Chem. 108, p. 70, 1924 (Geiger-Scheel II p. 402)

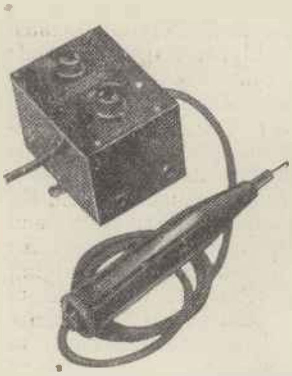


Fig. 4. "Bet-oray" high frequency spark tester. (*Messrs. Baird & Tatlock*).

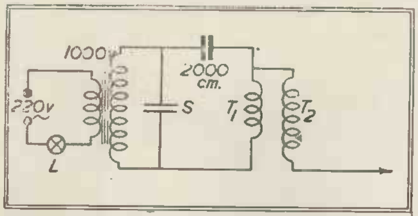


Fig. 5. Kann's spark tester.
S—Tungsten or tungsten carbide plates.
T_1—6 turns.
T_2—300 turns. 3 cm. dia.
L—15 W. lamp.

A discharge tube used by one of the authors as a pressure indicator is shown in Fig. 6. A glass cylinder of about $1\frac{1}{2}$ in. diameter, 6 in. long is fitted with molybdenum wire brush electrodes at each end, consisting of stranded cord (0.05 mm. wires) opened at one end and welded to the sealed-in wire on the other end.

Down to about 10^{-3} mm. Hg the normal discharge phenomena are observed. But at this pressure a strong cathode-ray fluorescence of blue or green colour occurs. The colour depends on the kind of glass used; it will be blue with lead glass and green with lime or soda glass. With improving vacuum fluorescent scintillations are seen on the walls due to sharp cathode-ray pencils impinging on them. The loose tube lying inside the outer tube is necessary because these sharp pencils would pierce the tube walls. At about 10^{-5} mm. Hg the discharge phenomenon is weakened but may be restored by raising the discharge voltage. A spark coil is used giving up to 50 kV, the voltage being measured by a sphere gap connected in parallel with the discharge tube as shown in Fig. 7. The distance of the spheres (maximum about 60 mm.) may be adjusted and is read on a scale.

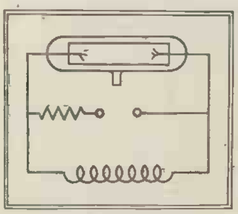
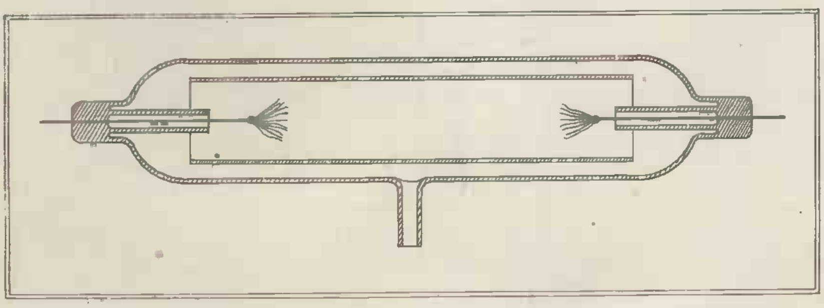


Fig. 7 (left). Connexions of pressure indicator.

Fig. 6 (below). Pirani's pressure indicator.



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(*To be continued*)

Photo-electric Flash Camera

NIGHT-TIME aerial photography has long been an important part of total war. With a magnesium flare supported by a parachute, exposures are made covering large areas to reveal enemy troop movements and much other essential information.

Before the development of the photo-electrically operated camera, photography at night from the air was subject to several limitations. If a slow-burning flare was used, its low intensity light made necessary exposures at large lens apertures with slow shutter speeds, with consequent lack of definition in the result. If an instantaneous flash "bomb" was used, the operator had to be certain to get the camera shutter open just prior to the flash. Any lights on the ground then "burned" paths across the negative.

Produced by Fairchild Camera & Instrument Corp. of New York, the newest type of camera incorporates a photo-electric unit which actuates the camera shutter a few microseconds after the flash bomb has begun to explode, beneath and behind the plane. This provides a high-speed exposure timed to the peak light intensity of the flash bomb.

The entire photoelectric assembly is contained in a cylindrical housing mounted below the camera. Mounted in the lower end, to "view" the flash bomb explosion, is a type 930 phototube, with sensitivity peaks in the ultra-violet at 3,600 Å and in the infra-red at about 8,000 Å. The circuit is arranged to provide a positive pulse to the grid of a 12SJ7 with the receipt of light. This provides a strong negative pulse to the grid of the power amplifier tube, a type 6AG7, in response to the light of the bomb. The beam power pentode has as its plate load a "trip magnet" which holds the camera shutter inoperative while a current of six mA. flows, but allows a spring to trip the shutter with a plate current drop.

To prevent operation of the shutter when the circuits are just energised a "warming up" relay with normally closed contacts shunts the trip magnet coil to ground through a 2,500 ohm. resistor to keep it energised. —G.S.

—*Electronic Industries,* Vol. 3, No. 7, July, 1944, p. 95.

Superheterodyne Whistles

By C. C. McCALLUM*

THE superheterodyne principle in radio receiver design, unlike other distinctive systems, has enjoyed two periods of popularity. The first period occurred in the early days of broadcasting when the quest was mainly sensitivity, and such important features as selectivity and quality of reproduction were of secondary importance. The superheterodyne system of reception undoubtedly offered set designers a most convenient method of achieving high gain far in excess of anything previously achieved, but, as users of those early sets will remember, there were distinct disadvantages. By common consent, the most important disadvantage was the very large number of whistles, self-generated in the receiver, which occurred fairly evenly spaced over the entire medium and long wave bands. So noticeable were these whistles that the superhet. became notorious among early users of radio sets, and they did contribute in a very large measure to its eclipse. Some years after its introduction and abandonment, the superhet. once more appeared, but this time in a very different guise. The whistles which had been such a pronounced feature of the original models had now to a large extent disappeared, and it was a distinct advance on anything so far produced. This position has been maintained right up to the present day, and it is apparent that it will remain the popular type of receiver for mass production for some time to come. The reasons for this great advance were numerous, the most important ones being :—

(*a*) Availability of screen-grid and pentode high-gain valves.

(*b*) Use of extensive screening.

(*c*) Use of higher intermediate frequencies.

(*d*) Provision of pre-selection.

It is the latter point to which we propose devoting our attention.

In general, the early superhet receivers used intermediate frequencies around 50 kc/s, but the new introduction of receivers employed frequencies of 110 kc/s and, in due course, increased further to approximately 456 kc/s. Sets have been manufactured and sold to the public (mainly in America) using even higher frequencies—around 1600 kc/s. This trend towards higher frequencies in the I.F. amplifier is prompted mainly by considerations of freedom from self-generated whistles, and not in any attempt to provide greater selectivity or higher gain. A review of the causes of production of these whistles will obviously be of very great interest to the designer, and may indicate the trend of post-war design.

All self-generated whistles are the result of mixing either the fundamental or harmonics of the local oscillator with the fundamental or harmonics of high power local stations. The possible combinations of such beat notes are, of course, considerable, but since the amplitude of harmonics from either source are practically negligible above the fifth harmonic, the potential whistles are reduced accordingly. The possibilities are set out in detail in the tables overleaf in the column headed "Cause." This table endeavours to show the points on the tuning dial at which interference due to self-generated whistles may be experienced when using an I.F. of 110 kc/s for all parts of the British Isles.

As an example of the use of this table, let us suppose the receiver is situated in the West Regional area. Whistles may then be experienced at 347, 749, 1151 kc/s, etc. Three of the interference frequencies are marked with an asterisk indicating that these points coincide within 9 kc/s of the frequency of another B.B.C. transmitter. The first frequency so marked is 1151 kc/s, which is within 2 kc/s of the London National transmitter frequency, and is caused by the second harmonic of the oscillator in the set beating with a frequency equivalent to the third harmonic of the local station —in this case, West Regional. This latter component may not necessarily be a third harmonic radiated by the B.B.C., but may be artificially produced in the receiver by the frequency changer valve in much the same way as a power output valve generates second and third harmonics of the applied frequency under certain conditions of use. Similarly, the whistle that may be heard at 194 kc/s, or 6 kc/s removed from the long wave Droitwich, is caused by the self-generated third harmonic of the oscillator frequency beating with the fundamental of the West Regional transmitter. An immediate remedy suggests itself in an absorption filter tuned to 804 kc/s and operative on long waves only. The third whistle that may be present on a B.B.C. frequency occurs at 1041 kc/s, or 9 kc/s removed from the Scottish National transmitter frequency. This is caused by the second harmonic of the local oscillator beating with a third harmonic of West Regional transmitter frequency.

These three examples picked out of the table illustrate how the knowledge of the cause of the whistle may in many cases suggest a means of elimination. To have no knowledge of the real cause of the whistle, effectively precludes any intelligent attempt at design. The table may usefully be employed by anyone owning a receiver with an I.F. of 110 kc/s, and checking very carefully at the points indicated for the presence or absence of a whistle. Once the points are identified, reference to the left-hand column gives the cause, and may enable some steps to be taken to remove the more troublesome whistles.

The complete analysis of potential whistle points for all B.B.C. frequencies is interesting in that it shows a total of 112 frequencies spread throughout the medium and long wave band so affected, of which 15 frequencies give direct interference on B.B.C. wavelengths. This picture assumes, of course, that all B.B.C. frequencies are local stations, an assumption that must be made by any designer of a receiver destined to be used nationally.

It was realised that a substantial increase in intermediate frequency would result in an appreciable reduction in the total number of potential whistle points, and a frequency of 456 kc/s was, more or less, standardised both in Great Britain and America. The International Convention for the allocation of frequency channels gave official blessing to this frequency by allowing it to remain a free channel. The reduction in possible whistle points at this I.F. is apparent from a comparison of Tables 1 and 2. For any particular locality or local transmitter frequency, the B.B.C. frequencies

* Radio Division, The Edison Swan Electric Co., Ltd.

TABLE 1. FREQUENCIES AT WHICH INTERFERENCE MAY BE EXPERIENCED INTERMEDIATE FREQUENCY 110KC

Cause	Daventry 200KC	North R. 668KC	Scot. R. 767KC	West R. 804KC	Lon. R. 877KC	North I. 977KC	Mid. R. 1013KC	Scot. N. 1050KC	Lon. N. 1149KC	
o — 2L	—	1336	—	—	—	—	—	—	—	
o — 3L	600	—	—	—	—	—	—	—	—	
o — 4L	800	—	—	—	—	—	—	—	—	
o — 5L	1000*	—	—	—	—	—	—	—	—	
2o — L	—	279	328	347	—	—	—	—	—	
2o — 2L	—	613	712	749	822	922	958	995	1094	
2o — 3L	245	947	1095	1151*	1260	1410	1464	—	—	
2o — 4L	345	1281	1479	—	—	—	—	—	—	
3o — L	—	—	182	194*	219	252	264	276	309	
3o — 2L	—	372	—	—	—	578	602	626	692	
3o — 3L	—	594	693	730	803*	903	939	976*	1075	
4o — L	—	—	—	—	—	162	170	180	205*	
4o — 2L	—	251	301	319	356	—	—	—	—	
L — o	—	—	547	584	657	757	793	830	929	
L — 2o	—	169	218	237	273	323	341	360	—	
L — 3o	—	—	—	—	—	179	191*	203*	236	
2L — o	180	1116	1314	1380	—	—	—	—	—	
2L — 2o	—	—	602	639	712	812*	848	885*	984*	
2L — 3o	—	298	364	—	—	—	—	553	619	
2L — 4o	—	196*	246	264	301	351	369	—	—	
3L — 2o	—	837	985*	1041*	1150*	1300	1354	1410	—	
3L — 3o	—	—	620	657	730	830	866	903	1002	
4L — o	580	—	—	—	—	—	—	—	—	
4L — 2o	235	1171	1369	1443	—	—	—	—	—	
5L — o	780	—	—	—	—	—	—	—	—	
Total Channels										**Total**
Long Waves	4	6	6	5	4	5	5	4	3	42
Med. Waves	5	8	10	9	7	8	8	8	7	70
Total ...	9	14	16	14	11	13	13	12	10	112

Note.—* Interference on B.B.C. frequencies—15. o Oscillator frequency. L Local station frequency.

TABLE 2. FREQUENCIES AT WHICH INTERFERENCE MAY BE EXPERIENCED INTERMEDIATE FREQUENCY 456KC

Cause	Daventry 200KC	North R. 668KC	Scot. R. 767KC	West R. 804KC	Lon. R. 877KC	North I. 977KC	Mid. R. 1013KC	Scot. N. 1050KC	Lon. N. 1149KC	
o — 2L	—	1336	—	—	—	—	—	—	—	
o — 3L	600	—	—	—	—	—	—	—	—	
o — 4L	800	—	—	—	—	—	—	—	—	
o — 5L	1000*	—	—	—	—	—	—	—	—	
2o — L	—	—	155	174	210	260	278	297	346	
2o — 2L	—	—	—	576	649	749	785	822	921	
2o — 3L	—	774*	922	978*	1087	1237	1291	1347	1495	
2o — 4L	172	1108	1306	1380	—	—	—	—	—	
3o — L	—	—	—	—	—	—	—	—	—	
3o — 2L	—	—	207*	232	280	347	371	—	—	
3o — 3L	—	—	—	—	573	672*	709	746	845	
4o — L	—	—	—	—	—	—	—	—	—	
4o — 2L	—	—	—	—	—	—	164	183	232	
5o — L	—	—	—	—	—	—	—	—	—	
L — o	—	—	—	—	—	—	—	—	237	
2L — o	—	—	622	696	842	1042*	1114	1188	1386	
2L — 2o	—	—	—	—	193*	293	329	366	—	
2L — 3o	—	—	—	—	—	—	—	—	158	
2L — 4o	—	—	—	—	—	—	—	—	—	
3L — o	—	1092	1389	1500	—	—	—	—	—	
3L — 2o	—	318	—	—	631	781	835	895	—	
3L — 3o	—	—	162	196*	269	369	—	—	541	
4L — o	—	—	—	—	—	—	—	—	—	
4L — 2o	—	652	850	924	1070	1270	1342	1416	—	
5L — o	—	—	—	—	—	—	—	—	—	
Total Channels										**Total**
Long Waves	1	1	3	3	4	4	4	3	4	27
Med. Waves	3	5	5	6	6	6	6	6	5	48
Total ...	4	6	8	9	10	10	10	9	9	75

Note.—* Interference on B.B.C. frequencies—8. o Oscillator Frequency. L Local station frequency.

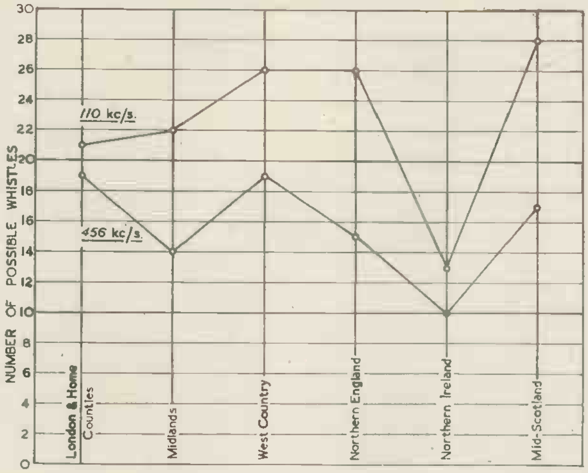


Fig. 3. (Above) Showing the B.B.C. frequencies affected by whistles on the two I.F.s.

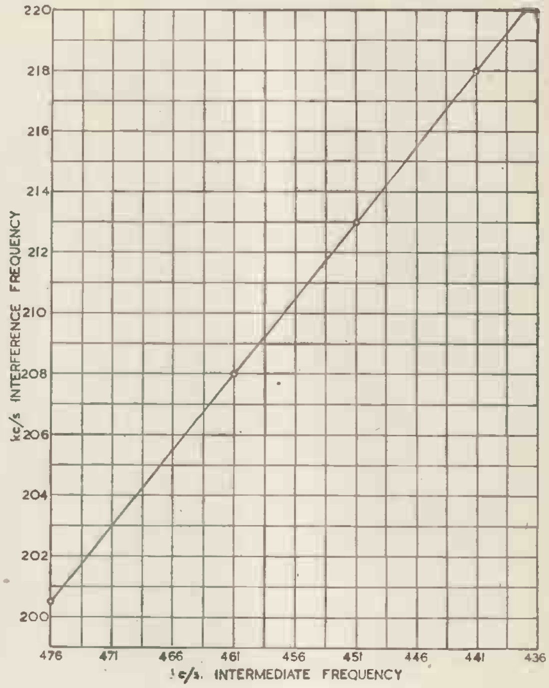


Fig. 5. (Right). Curve giving points at which whistles due to local transmitters are found with various I.F.s.

affected by whistles is also markedly different for the two I.F's.

A comparison of the two appears in Fig. 3 and illustrates a point not generally realised. Whilst the increase in frequency from 110 kc/s to 465 kc/s has resulted in a general reduction in potential whistle points, nevertheless, in particular localities the improvement is very slight. For example, the number of whistles that may be experienced in the London and Home Counties area is only reduced by two. It should be appreciated that the number of whistle points has no real connexion with geographical situation, but since there is a connexion between B.B.C. transmitter frequencies and locality, it is convenient to make the comparison in this manner.

It is even more interesting to consider the possibilities made apparent by Fig. 4, in which three "curves" indicate the potential number of whistles that may be experienced for a local station having a frequency between 150 and 1,500 kc/s, when three different intermediate frequencies are in use. The additional intermediate frequency not previously dealt with in detail is one of 1600 kc/s, which has been used commercially in America, and which may be adopted more widely in the future under certain circumstances.

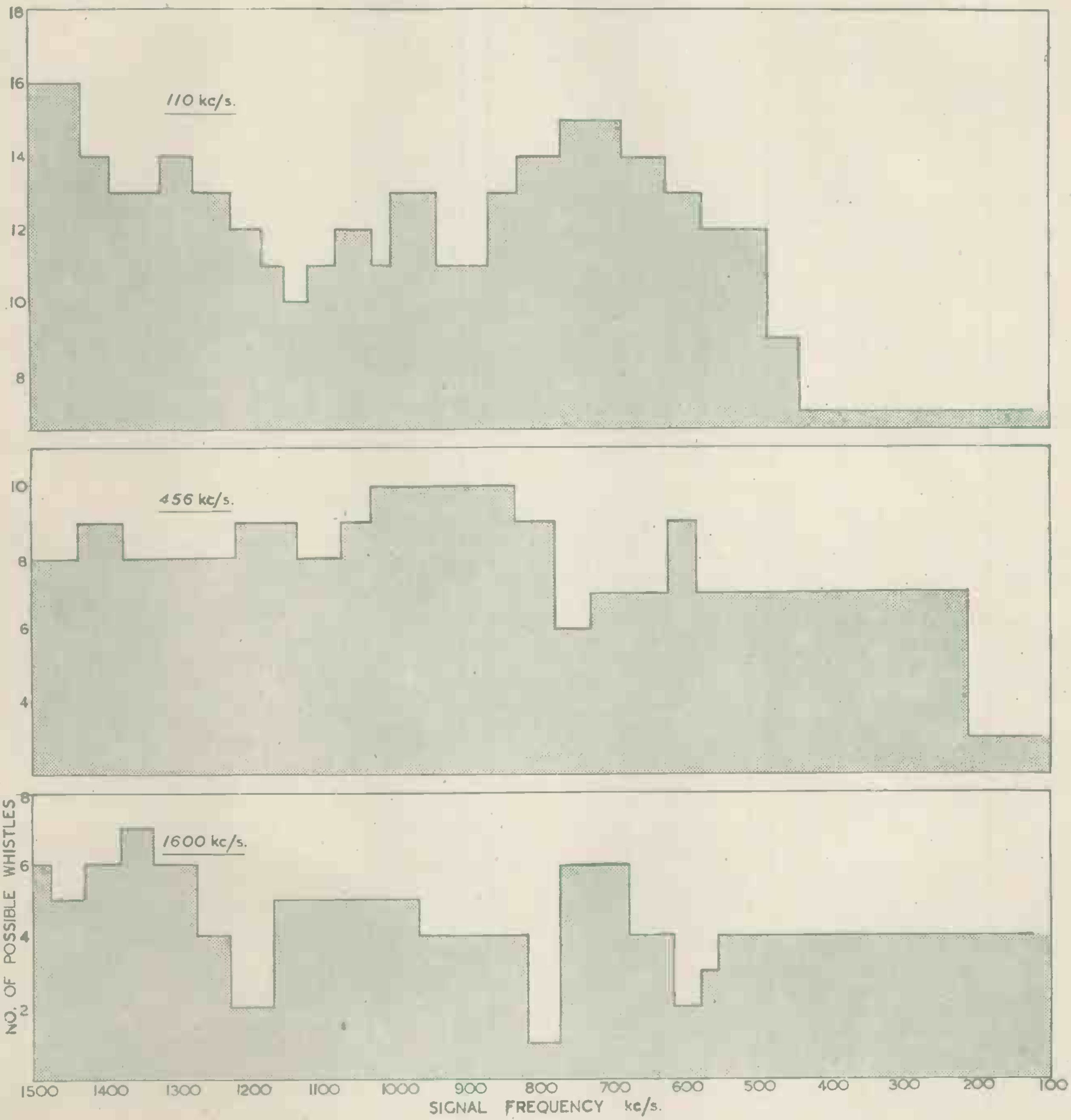
It is evident from the chart that ignoring such factors as selectivity and overall gain, the highest value of I.F. is by far the most satisfactory. Since this particular frequency has not so far been used in this country for domestic receivers, attention will be confined to the 456 kc/s frequency.

From Fig. 4 the number of potential whistles from a local station of 1149 kc/s is seen to be 9, and for a second local station of 877 kc/s the number is 10, making a total of 19 whistle points for that area. Since the two frequencies quoted are London National and London Regional, the figure of 19 possible whistles refers to the London area, a figure confirmed by reference to Fig. 3. Now suppose that the London Regional had been operated on a frequency of approximately 750 kc/s, a total of 6 whistle points may be expected. Also consider the alteration of the London National transmitter to a frequency of, say, 1300 kc/s where the whistle points number 8, making a total of 14 for the London area under the hypothetical revision of frequency allocations. This is a reduction of 5 potential whistles as compared with the existing frequency allocation. In other words, there is such a thing as a "preferred" transmitter frequency for any particular value of intermediate frequency to give maximum freedom from whistle points.

So far, no particular virtue has been attached to these whistles, but for home constructors of superhet receivers, certain whistles have a definite value as frequency markers. The major difficulty experienced by the amateur constructor is the lack of a signal generator to produce the signal of 456 kc/s for aligning the I.F. amplifier. If the I.F. amplifier is lined up on a frequency of, say, 470 kc/s, the receiver will still operate and may even appear to be quite satisfactory in performance. The signal and oscillator frequency circuits will, however, be misaligned and whistles will be experienced which would otherwise be eliminated by the pre-selection of the signal frequency circuits. The tuning range of the receiver will also be materially affected. In the London area a whistle will almost certainly be found at 210 kc/s produced by the second harmonic of the oscillator and the fundamental of the London Regional transmitter if the I.F. is precisely 456 kc/s.

In Fig. 5 is shown the points at which these whistles, due to the local London transmitter, will be found for various intermediate frequencies around 456 kc/s. By identification of the points on the long wave band, the frequency to which the I.F. amplifier is tuned is identified, and an adjustment may then be carried out to obtain the correct I.F. on precisely 456 kc/s.

Possible Whistles at Various I.F.s.



These charts show the potential number of whistles which may be experienced for a local station having a frequency between 150 and 1500 kc/s., when the three values of I.F. shown are used.

Fig. 4.

Cathode-Ray Tube Traces

A Series to Illustrate Cathode-Ray Tube Technique

Part II.—Straight Line Time Bases

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

General — Linearity of C.R. Tube Response

A NORMAL cathode-ray tube displays a trace based on the usual rectangular cartesian co-ordinates. With the axis of the tube horizontal, common convention defines the "X" axis of deflection as also horizontal and the "Y" axis vertical. If we consider deflections in each axis *separately*, it is easy to show that to a first approximation these are proportional to the voltages applied to the corresponding plates. For exact proportionality it is sufficient to assume (a) that the screen is flat; (b) that the deflection voltages are applied symmetrically to the plates; and (c) that the deflecting field is uniform and wholly axial. This third condition (c) cannot be accurately satisfied since it implies an abrupt termination to the electric field. The first condition is generally only an approximation but in practice, owing largely to the small deflecting angles used, it is difficult to detect any non-linearity within the measurement accuracy limited by the finite spot size.

Hence, considering deflections *separately* in each axis we may write

$$x = k_1 . e_x \quad \ldots\ldots (27)$$

$$y = k_2 . e_y \quad \ldots\ldots (28)$$

where e_x and e_y are instantaneous deflector plate voltages the in "X" and "Y" axes respectively.

In applications of a C.R. tube requiring a straight line time base, we seek to divide the screen of the tube into an imaginary series of parallel straight lines, all at right angles to the time base axis of deflection (usually X-axis) such that each is an equi-time line. If this is to be possible then Eqns. (27) and (28) must be satisfied, but it is necessary that they shall be satisfied when deflections are occurring *simultaneously* in *both* axes. In fact we require in addition that

$$x^2 + y^2 = k_1^2 . e_x^2 + k_2^2 . e_y^2 \quad \ldots\ldots (29)$$

Eqns. (27), (28) and (29) are necessary and sufficient for the purpose. They are fundamental equations defining the linearity of response of any C.R. tube. *When satisfied they imply that any voltage/time relationship will be transformed by the cathode-ray tube into an identical displacement/time relationship.* For this reason they will be termed for brevity the "transform" equations.

Photo No. 73 shows a dot mosaic pattern on a typical C.R. tube. The maximum scanning angle is approximately ± 9°. The succession of dots were produced by voltages of equal increments.

It will be seen that the linearity is of a high order, and in all that follows it will therefore be assumed that the transform equations are satisfied.

Types of Straight Line Time Bases

Strictly speaking a time base can be defined as any device for producing a voltage wave which is a definite and repeatable function of the time. Usually, however, the term is reserved for devices producing voltages which are, at least over restricted ranges, closely proportional to time. The discussion is here limited to time bases for electrostatic deflection only.

All time-base waveforms can be divided into two parts. Firstly, there is the forward stroke (generally, although not always, the portion used, and having the lower speed) and the return stroke or "flyback." These two strokes constitute the complete time base cycle, and are present on all types. We then distinguish three derived types of time base:—

(a) Self-running bases where the above cycle is repeated indefinitely without any time gaps between cycles.

(b) Externally triggered bases where the above cycle is repeated at a rate dependent on the external triggering frequency, independent of the period of the cycle itself, and

(c) Single-stroke time bases where the cycle occurs only once or at intervals which are *very* long compared to the period of each cycle.

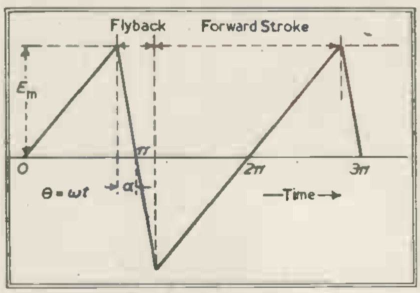


Fig. 1. 'Ideal' time base waveform.

The precise difference between (b) and (c) is rather hard to define. Generally (b) is used when the transient can be initiated by the same pulse which triggers the time base, and (c) when the transient is uncontrollable and is itself used to trigger the time base. Table 1 shows an elementary classification of the commoner straight line time bases for electrostatic deflection. For further information reference should be made to Mr. Puckle's excellent book.[2]

The Ideal Time-Base Waveform

The simplest time base waveform for measurement purposes is one having a linear voltage/time forward stroke. Hence, including the flyback portion of the cycle, the required ideal wave is that shown in Fig. 1. The flyback is shown as straight for reasons of mathematical analysis, but this feature is of no importance. Elementary Fourier analysis of Fig. 1 shows:—

$$e = \frac{2 . E_m}{\alpha(\pi - \alpha)} \sum_{n=1}^{n=\infty} (-1)^{n+1} \frac{\sin n . \alpha}{n^2} . \sin n\omega t \quad \ldots\ldots (30)$$

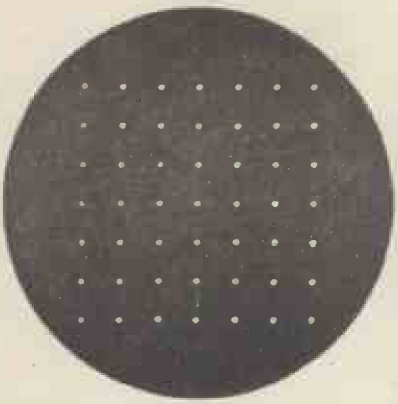
Eqn. 30 shows that the precise reproduction of the waveform of Fig. 1 requires circuits which can pass, without distortion, all frequencies from the fundamental, $\omega/2.\pi$, up to infinity. To obtain a good practical approximation to the desired ideal wave shape, the circuits must be able to transmit frequencies of perhaps 12 times the fundamental. At high repetition rates this may present considerable difficulty, and for this reason simpler types of waveform are often to be preferred. Of these there are two very important types:—

(a) Cut sinusoids, and

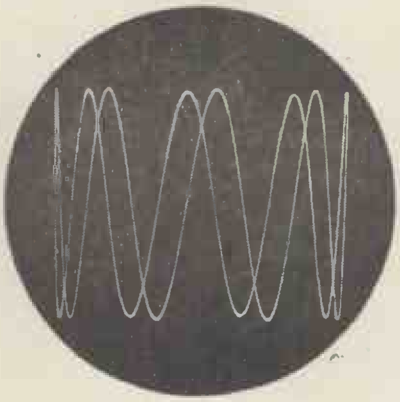
(b) The initial stages of an exponential charging or discharging curve.

These latter have the *additional important advantage over the true*

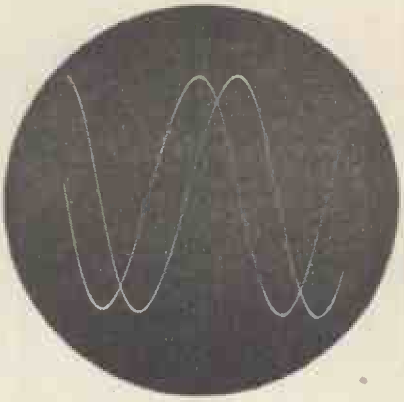
Sinusoidal Time Bases



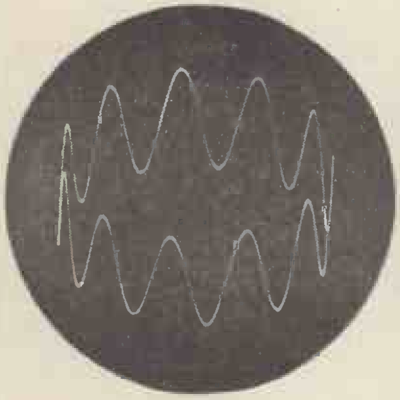
73
Dot mosaic for linearity testing.



74
R.F. wave displayed on sinusoidal base.

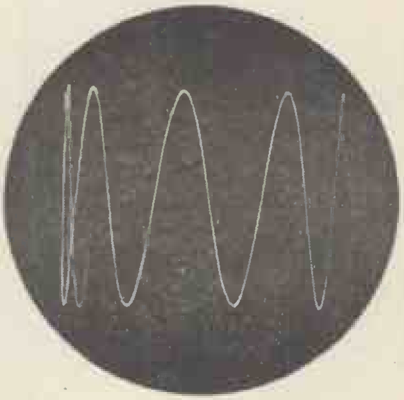


75
As 74, but time base expanded.

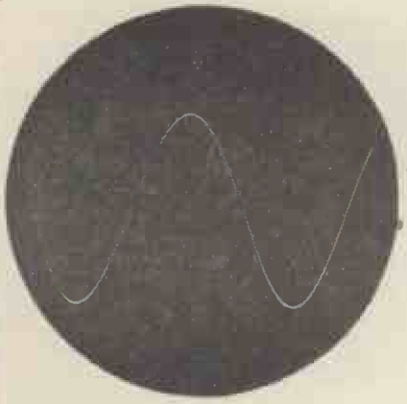


76
Lateral displacement of flyback to avoid confusion.

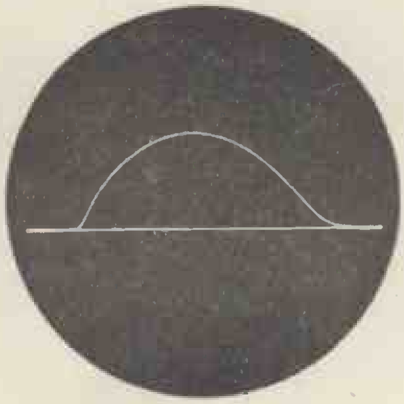
77
As 76, but with expanded time base (66 megacycle wave.)



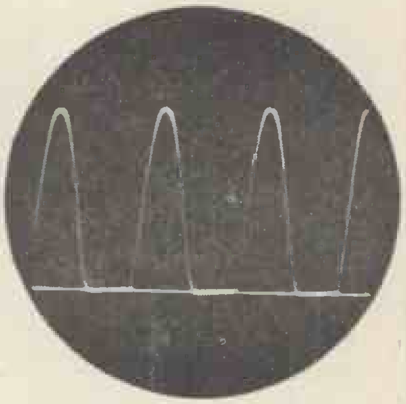
78
As 74, but flyback removed by grid blanking.



79
As 78, but expanded time base.



80
Flyback used to provide base line.



81
As 80, but more complex case (see text.)

To aid in cross-referencing, these photographs are serially numbered from the first article onwards.

STRAIGHT LINE TIME BASES

COMMONER TYPES FOR ELECTROSTATIC TUBES

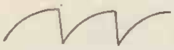
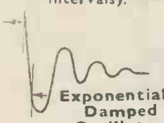
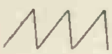
TYPE AND WAVE-FORM	METHOD OF GENERATION			SPECIAL ADVANTAGES	COMMENTS
	Forward Cycle	Flyback Mechanism	Flyback Suppression		
 **Cut Sine Wave** (repetitive)	cut sine wave	cut sine wave	(*a*) Pulse injection into C.R.T. grid. (*b*) Lateral displacement of return trace.	Simple. Can give good linearity but at expense of "occupance." Drive circuit can have very low impedance. Balanced deflection voltages easily obtained from centre tappings on drive transformer. Amplification and attenuation easy as no band width considerations involved. Hence ideal trace expansion. Enormous frequency range, with flyback suppression method (*b*).	If fair linearity is important, suitable only in cases where phenomenon under examination occupies only small fraction of period of one sine wave. *Specially good for examination of harmonic wave derived from sine wave feeding time axis as the synchronising is then perfect.* By means of simple phase shifter between sine wave source and tube, any *part* of wave of period equal to that of sine wave time base can be examined on expanded scale.
 **Cut Sine Wave** (single stroke)	cut sine wave with synchronised correctly phased single grid brightening pulse	—	—	—	Appears to have no application.
 **Exponential** (self running)	Condenser charged through linear resistor	(*a*) Two electrode gas tubes (*b*) Gas filled triode (*c*) Special hard valve circuits (Multivibrators)	(*a*) None. Confusion avoided by difference in writing speeds of forward and return traces (*b*) Pulse injection into C.R.T. grid	Simple mechanism for production of forward sweep in passive network. Suitable for very low sweep rates. Logarithmic time scale of great use in some special applications. With hard valve flyback circuits can go up to about 1 m/c. frequency	Quite good linearity obtainable by using only a small fraction of charging cycle Linearity independent of the occupance. Requires synchronising to period of phenomenon under investigation. A more linear sweep (not simple exponential), can be obtained by use of auxiliary time constant circuit.[1]
 **Exponential** (Single stroke or succession of strokes separated by long intervals).	Condenser charged or discharged through linear resistor	**Special Note** Useful portion generally *discharge* period. Initiation often by spark gap Flyback mechanism is then extinction of spark	Strictly speaking none, but in all single stroke work a brightening pulse is injected during forward used sweep	Simplicity. Very great range of speeds.	Widely used in high speed surge analysis with high voltage pumped oscillographs. Requires a correctly timed grid brightening pulse.
 **Exponentially Damped Oscillatory**	Condenser discharged through linear resistor of low value	As above	As above	Gives very high speeds.	Limiting case of exponential time base—charging resistance so low that residual inductance makes discharge oscillatory. Main difficulty at high speeds connected with proper grid pulsing.
 **Linear** (self running)	(*a*) Condenser charged through constant current device, usually a pentode (*b*) Feedback circuits (c) Combinations of (*a*) with (*b*) or other device for extreme linearity	(*a*) Most usually hard valve trigger circuits such as in Puckle Base (*b*) Gas filled diode (rarely) (*c*) Gas filled triode	As for self running exponential base	Good linearity possible with good occupance. With hard valve flyback circuits can go up to about 1 Mc/s. frequency.	The most common type of time base fitted in self contained commercial oscillographs. Linearity adequate for almost all purposes without any correcting circuits and without use of very high line voltages. As with exponential type becomes complicated when designed to give real freedom of cross coupling between frequency and amplitude controls. Requires synchronising to period of phenomenon under investigation. Any amplifying or attenuating circuits must have adequate band width.
 **Linear** (externally triggered)	As for self running type. Initiation by pulse from some type of multivibrator, etc.	As for self running type	As for self running type	Gives greater trace brilliance than true single stroke working.	Fundamentally a single stroke method but since repetitive the trace brilliance is greater. Used in any transient work where transient can be initiated artificially *in synchronism* with time base.
 **Linear** (single stroke)	Special case of externally triggered type			Timing, but no synchronising required.	For examination of uncontrollable transients. Time base stroke initiated by transient which is itself delayed by suitable network.

TABLE I

*linear wave, that they can be derived from passive networks.**

Sinusoidal Time Bases

This is a most important type of time base which deserves to be more widely used. For certain classes of work it approaches perfection.

Fig. 2 shows the familiar sine curve from which it is apparent that the middle cut from C to D is almost linear. The departure from linearity can be defined as the extreme difference in spot velocity over the used portion of the C.R. tube divided by the maximum velocity. By virtue of the transform equations the spot velocity is everywhere proportional to de/dt where e is the instantaneous voltage between the deflector plates. Here

$$e = E_m . \sin \omega . t$$

so $de/dt = E_m . \omega \cos \omega . t$ .... (31)

whence it is easy to calculate the departure from linearity for any fraction of the total sine wave amplitude employed.[1] This is plotted in curve (A) Fig. 3.

The displacement error arising from non-linearity of the time base can be defined as the maximum difference between the true and observed spot positions divided by the trace length. The true spot position is itself defined as that position which the spot would occupy if the time base were strictly linear and had a velocity equal throughout to the maximum during the trace. This error is plotted in curve (B) Fig. 3. Note that the displacement error is always much less than the linearity error.

Examination of Fig. 2 shows that the spot will be usefully employed only for a fraction $wt/2\pi$ of each cycle, since the flyback is not usable for recording. Hence only this same ratio $wt/2\pi$ of the total beam power will be used, and there is a consequential loss of brilliance. A more serious defect is that any phenomenon of duration comparable to the time base period cannot be examined as a whole. Fortunately, by means of a simple phase shifting network it is usually very easy to change the portion under examination at will. The ratio $wt/2\pi$ will be termed the "occupance."† It is plotted in curve (C) Fig. 3.

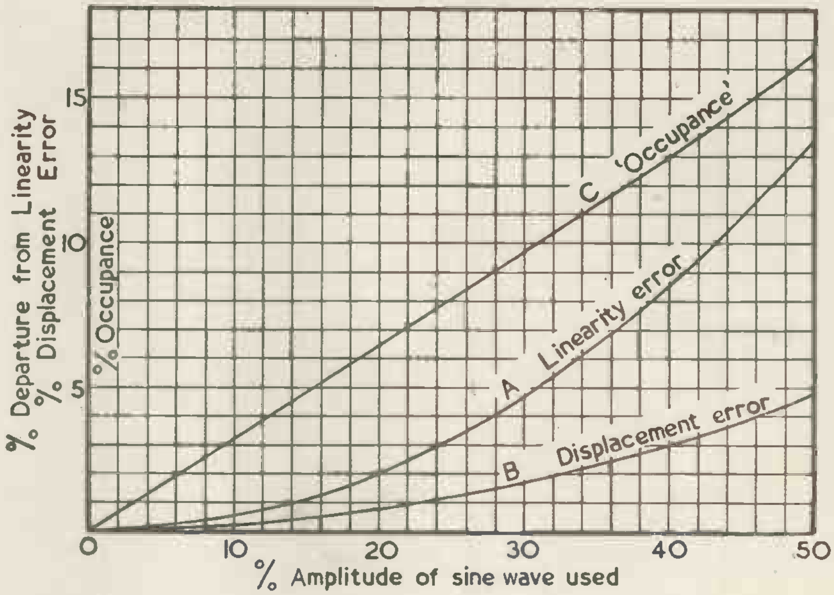


Fig. 3.

Examples of Use of Sinusoidal Time Bases

Photo No. 74 shows the eighth harmonic of a radio frequency wave displayed against the fundamental, the latter being the time base. The result is the familiar Lissajous figure. In order to obtain reasonable linearity, the time base amplitude is expanded, leaving only the centre portion (Photo 75). This process still leaves the return trace which may be confusing with more complicated wave shapes. This may then be displaced laterally to avoid confusion, by introducing a small portion of the time base voltage in series with the wave to be examined. Providing the phasing between the time-base wave and the component on the vertical axis is correct (see Part 1, June issue) they combine to produce an ellipse on which the wave to be examined is superimposed. This is shown in Photo 76. By expansion of the "X"-axis horizontal time base sweep, the linearity is restored, and the return trace does not now interfere with the forward stroke. (Photo 77.)

This technique is most important for the examination of waves of high radio frequencies. The waves on Photo 77 are of 66 Mc/s. frequency.

Alternatively, and preferably at lower frequencies, the return trace may be blacked out by squaring off a portion of the sine wave time-base wave, and applying this to the C.R. tube grid. This is shown in Photo 78, and on expanded scale on Photo 79.

It does not always prove necessary to remove the flyback and in some instances its presence may be an advantage. An instance is shown in Photo 80 which represents the output of a cathode-follower stage fed with a very high sinusoidal input voltage in series with a high steady negative grid bias. The valve was therefore cut off for more than one half cycle, and the return trace serves as a convenient base line for measurement.

Generally, however, the phenomenon under investigation is not zero throughout the flyback period, and confusion results. In such cases, and where a baseline is really essential, it may be worth while to produce a square pulse from the time base wave and use this to suppress the phenomenon under investigation during the flyback. This technique is shown in Photo 81 which is again the output wave of a cathode follower but fed with a high harmonic of the time base sine wave. A square pulse from time base wave was injected into the grid of the cathode follower to suppress its output during the flyback period. This technique is sometimes useful, as an alternative to using the square pulse for grid blocking on the C.R. tube itself.

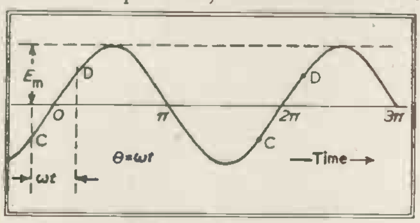


Fig. 2. Sinusoidal time base.

* A sine wave derived from a valve oscillator feeding a coil of low decrement can be regarded as coming from a passive circuit since the valve is purely a maintaining device and does not (or should not) influence the wave shape.

† An expressive term due to L.H. Bedford.

References

1 "Linearity Circuits," Arthur Clarke, *W. Eng.*, June, 1944.
2 "Time Bases," (*Book*), O. S. Puckle, Chapman and Hall.

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GA

Low Frequency Amplification—*Part II*

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

APART from the D.C. amplifier, which can amplify down to zero frequency without attenuation or phase distortion, the best type of amplifier for extended low frequency response is that employing resistance-capacitance coupling. Inductance-capacitance coupling is generally unsatisfactory because it is impossible to obtain a large enough inductance to have, at the lowest frequency, a reactance much greater than the valve internal or slope resistance—this is the condition for negligible attenuation and phase distortion. A further disadvantage of this coupling is that it forms with the stray capacitance a lightly damped parallel tuned circuit resonating at some comparatively high frequency, and transient distortion is likely to be experienced with steep-sided pulse input voltages. A combination of resistance-inductance-capacitance coupling is used in television amplifiers in order to achieve extended high frequency response by neutralising stray capacitance, but the parallel tuned circuit so formed is heavily damped and transient distortion is generally negligible. Since low frequency response is the main interest, we shall examine in detail the case of the resistance-capacitance coupled amplifier only, but before doing so let us consider the relative merits of the triode and tetrode valve as an amplifying agent.

A Comparison between the Triode and Tetrode Valve in a Low Frequency Amplifying Stage.

The chief advantages of the triode valve are its low slope resistance and its capability of delivering a large output voltage with lower distortion than the tetrode. A low slope resistance means that frequency response is less dependent on the characteristics of the anode load impedance. A much larger input signal voltage is normally required to give maximum output from the triode than from the tetrode valve. The important features of the tetrode are higher amplification (it is generally about twice that of the triode for the same mutual conductance) and very much reduced feed-back through the anode-grid capacitance. The latter has an important bearing on high frequency response, because it increases the grid input capacitance by an amount equal to the grid-anode capacitance multiplied by $(1+A)$, where A is the amplification from grid-to-anode of the valve. For example, average values of C_{ga} and A for a triode valve are 3$\mu\mu$F and 50 respectively, giving a grid input capacitance additional to the "cold" input capacitance of $3.\times 51 = 153$ $\mu\mu$F; average values for a tetrode are 0.01 $\mu\mu$F and 100 respectively, giving an additional input capacitance of 0.01 × (101 = 1.01 $\mu\mu$F. Hence the use of a tetrode valve (by reason of reduced grid input capacitance) contributes to an improved high frequency response from the stage preceding it. The chief disadvantages of a tetrode are the greater circuit complication (a screen resistance and by-pass capacitance are required) and, as far as audio-frequency amplification is concerned, the more objectionable type of distortion, consisting of the higher harmonics and intermodulation products.

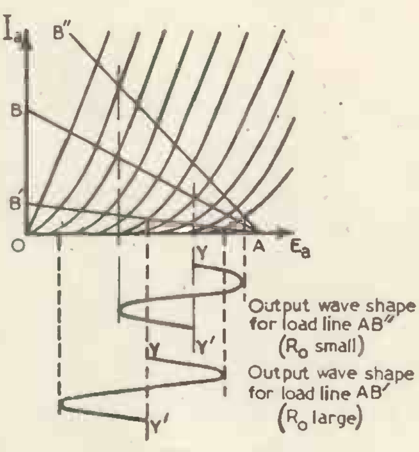


Fig. 13. Effect of varying R_o on the harmonic distortion from a triode valve.

The reason for the smaller amplitude distortion of lower order harmonics produced by the triode valve can be seen by referring to the I_aE_a characteristic curves in Fig. 13. The anode load resistance R_o is represented by the straight line AB starting from an anode voltage equal to the total H.T. voltage to the stage (if there is no decoupling resistance). The angle of AB to the E_a axis is determined by the value of R_o, a large value giving a line of lower slope such as AB′. The inverse slope of AB, *i.e.*, $\frac{OA}{OB}$, equals the resistance R_o. Maximum harmonic distortion for a fixed large input voltage is obtained when R_o is small (line AB″); the output voltage wave shape, which is distorted as shown below the E_a axis, is symmetrical about a horizontal line through maximum or minimum amplitude, but asymmetrical about its vertical centre line YY′, and so contains mainly even harmonic distortion (mostly 2nd) as shown by Fig. 6a of the previous article. As R_o is increased, the top end of AB leaves the region where the I_aE_a characteristics have opened out, and enters the lower current more cramped region, where the intercepts it makes with the grid voltage lines are smaller but more equal. Hence distortion progressively falls as R_o is increased and at the same time output voltage tends to increase. The maximum value of R_o is fixed by the maximum permissible value of the grid leak resistance for the succeeding valve, and also by high frequency considerations, because the larger R_o is made the greater is attenuation and phase distortion due to stray capacitance. The rate of increase in amplification falls as R_o is increased above the slope resistance R_a of the valve, and there is practically no advantage to be gained by making the ratio of R_o/R_a greater than 3 to 4.

The effect on harmonic distortion of varying R_o is different in the case of a tetrode valve. Referring to the tetrode I_aE_a characteristics of Fig. 14, we see that a low load resistance (line AB″) produces an output voltage wave shape which is peaked at low E_a and flat at high E_a in a manner similar to that for low R_o with a triode. Hence distortion consists mainly of even harmonics. As R_o is increased the high E_a end of the curve tends to become less flat and the low E_a end less peaked until, for the line AB, the output is symmetrically distorted and, as shown by Fig. 6b of the previous article, distortion consists chiefly of the odd higher harmonics (including intermodulation products if more than one frequency is present in the input). A further increase in R_o flattens the low E_a part of the output wave and opens out the opposite end. This results in the reappearance of even harmonics, odd harmonics are also increased. Reduced harmonic distortion and increased amplification is realised for high values of R_o by increasing the bias on the valve from point K′ to H to bring the lower part of the output voltage away from the knee of the I_aE_a characteristic. Thus we see that, unlike the triode the tetrode has for maximum amplification, an optimum bias which increases with increase of R_o. Total R.M.S. harmonic distortion is a minimum at a given value of R_o (corresponding to line AB in Fig. 14), a change in value of R_o in either direction increases distortion. Due to the knee of the I_aE_a characteristic, increase of R_o for a fixed bias voltage shows an optimum point for maximum amplification, and a similar result is found for screen voltage. Curves of amplification against load resistance for three values of screen voltage are given in Fig. 15. For low values of R_o, where $R_o \ll R_a$, mutual conductance, g_m, is the important parameter and the greater this is the greater is amplification; hence maximum amplification is obtained at high screen voltages. For high values of R_o amplification is determined by g_m and R_a, increase of both increasing amplification. Increase of screen voltage generally causes R_a to fall and it falls at a greater rate than g_m increases, so that greatest amplification for high values of R_o is obtained with low screen voltages as shown by Fig. 15.

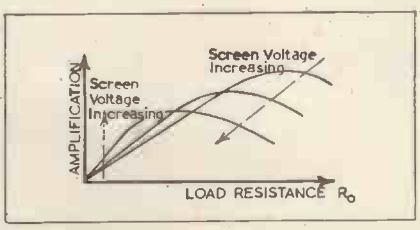


Fig. 15. Effect of screen voltage on amplification when R_o is varied with a tetrode valve.

The optimum value of grid bias for maximum amplification is often greater than that of a triode of similar characteristics, and maximum permissible output voltage is obtained without the positive peak of the input voltage approaching close to the bias at which grid current starts, *i.e.*, it is the knee of the I_aE_a characteristics which limits input voltage rather than grid current. With triodes of high amplification factor, optimum bias is the lowest

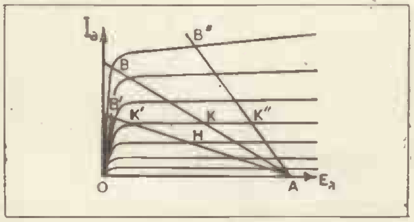


Fig. 14. Effect of varying R_o on the harmonic distortion from a tetrode.

consistent with zero grid current on peak input signals, and the bias must be adjusted to prevent grid current with the valve having the most negative bias start of grid current. This type of triode tends to show considerable variation of anode current cut-off from valve to valve so that fairly wide variations of amplification are to be expected from valves having the same nominal characteristics.

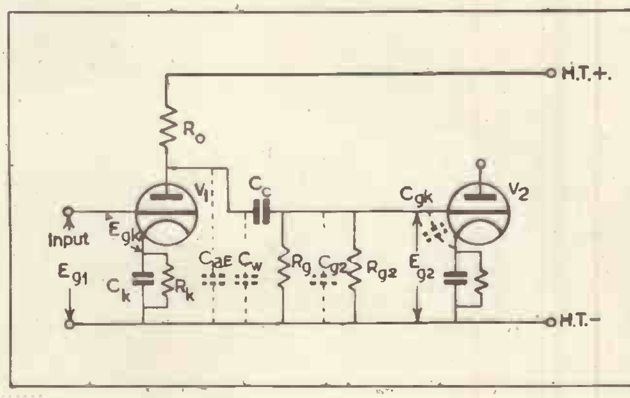
Summarising, we may say that the triode is the best type of valve for audio frequency amplification because the harmonic distortion it produces can be made small and is, in any case, less objectionable than that from a tetrode; attenuation distortion due to stray capacitance need not present a serious problem because the highest frequency required is 20,000 c/s. For television purposes the tetrode is better because comparatively high harmonic distortion can be tolerated, but attenuation and phase distortion must be small up to frequencies of the order of 2 to 4 Mc/s. For use in amplifiers having a visual output indicator (such as an electrocardioscope) either valve may be used. The tetrode has the advantage of greater amplification and the eye is comparatively insensitive to the type of harmonic distortion it introduces. On the other hand, the triode has no screen circuit complications, and the latter does create problems at very low frequencies owing to the fact that it introduces attenuation and phase distortion.

Resistance-Capacitance Coupled Low Frequency Amplifier

A typical resistance-capacitance coupled low frequency amplifier stage is shown in Fig. 16. Triode valves are shown in the diagram but they can be replaced by tetrodes, and the modifications needed to make the formulae applicable to tetrodes will be indicated as the analysis proceeds. The input voltage variations, developed in amplified form across R_o, are transferred to the next stage through the coupling capacitance C_c, which prevents the application of the D.C. component of anode voltage to the grid of the second valve V_2. The D.C. path from the grid of V_2 to H.T. negative or a suitable bias voltage is completed by the grid leak resistance R_g. Grid bias for each stage may be derived from the anode current passing through a self-bias resistance (R_k between the cathode of V_1 and H.T. negative) if the valves are indirectly-heated. Directly-heated (battery) valves require the grid bias to be inserted between the end of the grid leak and H.T. negative or earth. A potential divider carrying the total anode current of all stages, or a separate bias battery, may be provided. The self-bias resistance, R_k must be paralleled by a capacitance, C_k, if reduced amplification by degenerative voltages developed across R_k is to be prevented.

A simplified diagram of the stage when R_k is zero is shown in Fig. 17; the valve is considered as a constant voltage generator of μE_{g1}—μ is the amplification factor of valve V_1—and the output capacitance of $V_1(C_{aE})$, the input capacitance $(C_{gk} + C_{g2})$ of V_2, and the wiring capacitance C_w are repre-

Fig. 16. A resistance-capacitance coupled triode amplifier.



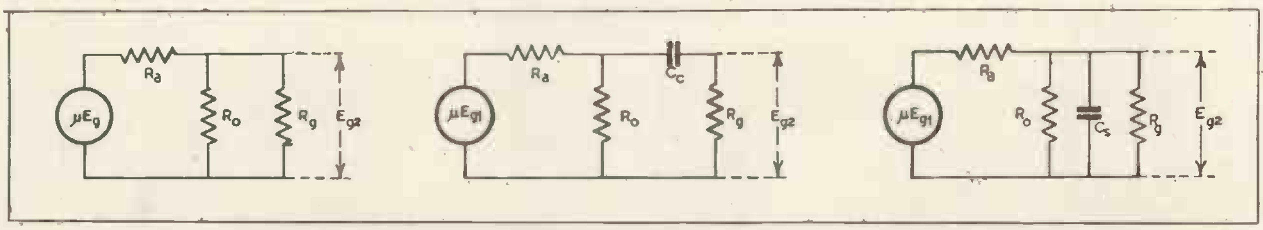


Fig. 18. (a) The equivalent circuit for medium frequencies. (b) The equivalent circuit for low frequencies. (c) The equivalent circuit for high frequencies.

sented by C_s across R_o. This is permissible because C_c is, as a rule, much larger than C_s. C_{g2} and R_{g2} are the parallel capacitance and resistance components reflected from the anode of V_2 through its anode-grid capacitance. Overall amplification is given by the ratio of the output-to-input voltage, $\frac{E_{g2}}{E_{g1}}$, and we shall calculate it first for the separately biased amplifier in which R_k is zero.

$$\frac{E_{g2}}{E_{g1}}=\frac{\mu Z_{AB}}{R_a+Z_{AB}}\cdot\frac{R_{gt}}{R_{gt}+\frac{1}{j\omega C_c}} \quad \ldots\ldots 1$$

where Z_{AB} = the impedance across the points AB looking from the generator side.

R_{gt} = the effective resistance of the grid leak resistance (R_g) and the input resistance of $V_2(R_{g2})$ in parallel.

Generally R_{g2} is much greater than R_g and in the analysis which follows we shall assume that $R_{gt}=R_g$.

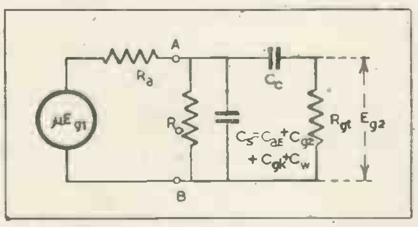


Fig. 17. The equivalent circuit for R—C coupled amplifier for $R_k = O$.

$$Z_{AB}=\frac{\frac{R_o}{j\omega C_s}\left(R_g+\frac{1}{j\omega C_c}\right)}{\frac{R_o}{j\omega C_s}+R_o\left(R_g+\frac{1}{j\omega C_c}\right)+\frac{1}{j\omega C_s}\left(R_g+\frac{1}{j\omega C_c}\right)} \quad \ldots\ldots 2$$

Hence overall amplification is

$$A=\frac{E_{g2}}{E_{g1}}=\frac{\mu R_oR_g}{R_o\left(R_g+\frac{1}{j\omega C_c}\right)+R_a\left[R_o+j\omega C_sR_o\left(R_g+\frac{1}{j\omega C_c}\right)+R_g+\frac{1}{j\omega C_c}\right]} \quad \ldots\ldots 3$$

The effect of the variables, the reactances of C_c and C_s, on the attenuation and phase distortion of the stage is best examined by dividing the pass-range into three separate bands of low, medium and high frequency. In the medium frequency band, the series reactance of C_c is negligible compared with R_g, and the parallel reactance of C_s is large compared with R_o, so that the equivalent circuit is as shown in Fig. 18a.

The amplification at medium frequencies is therefore from expression 3.

$$A_m=\frac{\mu R_oR_g}{R_oR_g+R_aR_o+R_aR_g} \quad \ldots\ldots 4a$$

$$=\frac{\mu R_o'}{R_a+R_o'} \quad \ldots\ldots 4b$$

where $R_o'=\frac{R_oR_g}{R_o+R_g}$ = effective anode load resistance to medium frequencies.

In the low frequency band, the reactance of C_c increases and becomes comparable with R_g but the reactance of C_s can still be neglected.

Fig. 18b is the equivalent diagram and the amplification at low frequencies becomes

$$A_l=\frac{\mu R_oR_g}{R_o\left(R_g+\frac{1}{j\omega C_c}\right)+R_a\left(R_o+R_g+\frac{1}{j\omega C_c}\right)}$$

$$=\frac{\mu R_oR_g}{(R_o+R_a)\left(R_g+\frac{1}{j\omega C_c}\right)+R_aR_o} \quad \ldots (5)$$

Combining 5 with 4a, we have for A_l in terms of A_m

$$\frac{A_l}{A_m}=\frac{\frac{R_aR_o}{R_a+R_o}+R_g}{\frac{R_aR_o}{R_a+R_o}+R_g+\frac{1}{j\omega C_c}}$$

$$=\frac{1}{1-j\frac{X'}{R'}} \quad \ldots\ldots 6a$$

where $X'=\frac{1}{\omega C_c}$ and $R'=\frac{R_aR_o}{R_a+R_o}+R_g$

The modulus of $\frac{A_l}{A_m}$ is a measure of the attenuation distortion, which becomes

$$\left|\frac{A_l}{A_m}\right|=\frac{1}{\sqrt{1+\left(\frac{X'}{R'}\right)^2}} \quad \ldots\ldots 6b$$

For the high frequency band the shunting effect of C_s is important but the reactance of C_c is so small that it can be neglected. The equivalent circuit is that of Fig. 18c, and the amplification at high frequencies may be written

$$A_h=\frac{\mu R_oR_g}{R_oR_g+R_a(R_o+j\omega C_sR_oR_g+R_g)}$$

$$=\frac{\mu R_oR_g}{R_oR_g+R_aR_o+R_aR_g+j\omega C_sR_oR_gR_a} \quad \ldots\ldots 7$$

Combining 7 and 4a

$$\frac{A_h}{A_m}=\frac{1}{1+\frac{j\omega C_sR_oR_gR_a}{R_oR_g+R_aR_o+R_aR_g}}$$

$$=\frac{1}{1+j\frac{R''}{X''}} \quad \ldots\ldots 8a$$

where $X''=\frac{1}{\omega C_s}$

(See foot of next page.)

A Note on Amplifiers for Electrocardiography

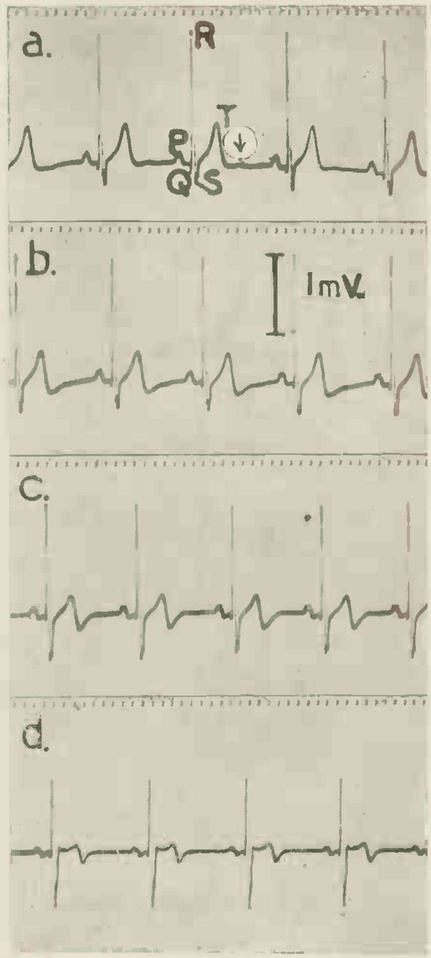
By G. D. DAWSON, M.Sc., M.B.*

IN a recent article Sturley,[1] quoting Donovan,[2] states that amplifiers for electrocardiography need to have a low frequency response from about 5 c/s. upwards. The electrocardiogram (ECG), or record of the potential differences produced by the heart during its beat, contains frequencies considerably lower than 5 c/s. and the limit of 5 c/s. is, in fact, given by Donovan[2] as the lowest frequency likely to be met in recording the heart *sounds* with a microphone. Beyond saying that "the intercoupling time constants are long, so that there is no distortion," Donovan gives no information about the response of his ECG. amplifier.

An authoritative statement on the subject of amplifiers for recording the ECG. has been made by Robertson.[3] He states that the amplifier should have an overall time constant of 1.3 to 1.5 seconds (4 seconds per stage) if the slower components of the ECG. are to remain undistorted. There seems to be no reason to revise this figure.

To show the type of distortion that occurs if the ECG. is recorded with an apparatus having an inadequate low frequency response, records have been made with amplifiers having time constants of 0.8, 0.16, 0.05 and 0.018 seconds. These time constants correspond approximately to a low frequency response to sine waves which is flat to within 5 per cent. down to 0.7, 3.0, 8.0 and 25 c/s., the records with these responses being shown in the figure in (a), (b), (c) and (d) respectively.

The waves of the ECG. are usually designated by letters; P for the first small wave of the cycle, Q, R and S for the second complex wave and T for the last wave of the cycle. The record in (a) shows these waves in a relatively undistorted form as they appear with the time constant of 0.8 seconds. As the time constant is reduced, the distortion occurring takes the form first of partial, and finally of complete differentiation of the T, P, and QRS waves in this order. It will be seen that a response which attenuates sine waves of 3 c/s. by only 5 per cent. (b), introduces a considerable distortion of the T wave. This degree of distortion is inacceptable as the shape of T wave it produces is similar to a form which may occur in disease. An amplifier for recording ECGs should therefore have a frequency response flat down to at least 0.5 c/s. The time intervals (1/10th sec.) and voltage calibration (1 mV) are marked on the records.



Lewis[4] has pointed out that if a resistance-capacity coupled amplifier, having approximately equal time constants in all its interstage couplings, is used near the lower limit of its flat response it tends to produce an oscillatory response to a single pulse input. This is due to differentiation of the signal occurring in more than one stage. There is a suggestion of this form of distortion in the record (a), taken with the 0.8 second time constant, at the point marked by the arrow. In records (b), (c), and (d) the time constant has been shortened in one stage only and left long in the others; then the effect becomes less noticeable. While this trouble would be completely avoided by the use of a DC amplifier, this type of apparatus introduces fresh troubles due to slow changes of skin potential and is not so easily stabilised against changes of battery voltage as the R-C type. Therefore, the best type of amplifier for electrocardiography would seem to be one having an overall time constant of two seconds, preferably with this all concentrated in a single intervalve coupling, the other couplings being direct.

* Neurological Research Unit, The Medical Research Council.

1 Sturley, K. R., *Electronic Engineering*, November, 1944, p. 236.
2 Donovan, G. E., *J.I.E.E.*, Part 3, June, 1943, p. 21.
3 Robertson, D., *J.I.E.E.*, Vol. 81, 1937, p. 497.
4 Lewis, W. B., *Electrical Counting*, Cambridge University Press, 1942.

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and $R''' = \frac{R_o R_g R_a}{R_o R_g + R_a R_o + R_a R_g}$, the resistance of R_o, R_g and R_a in parallel. For determining attenuation distortion

$$\left|\frac{A_h}{A_m}\right| = \frac{1}{\sqrt{1+\left(\frac{R''}{X''}\right)^2}} \quad \ldots\ldots\ldots\ldots 8b$$

It is more convenient to express attenuation distortion as a loss in decibels with reference to the amplification at medium frequencies and low frequency attenuation distortion becomes

$$\text{loss (db)} = -20 \log_{10} \left|\frac{A_m}{A_3}\right|$$

$$= -10 \log_{10}\left(1+\left(\frac{X'}{R'}\right)^2\right) \quad \ldots\ldots\ldots 9$$

and high frequency attenuation distortion is written

$$\text{loss (db)} = -20 \log_{10} \left|\frac{A_m}{A_h}\right|$$

$$= -10 \log_{10}\left(1+\left(\frac{R''}{X''}\right)^2\right) \quad \ldots\ldots\ldots 10$$

(*To be continued.*)

Swiss Television Large Screen Projector

By T. M. C. LANCE*

This description is abstracted from a paper by the author on "Some Aspects of Large Screen Television," read before the Television Society on November 28th, 1944

MANY systems of producing large television images suitable in size and of sufficient brightness for presentation in cinema theatres have been proposed.

The Baird Company in London and the R.C.A. in New York, demonstrated before the War, pictures obtained by projecting enlargements of the images formed on the screens of high intensity cathode ray tubes. Because of the high energy concentration and the possibility of light saturation of the fluorescent materials relatively large images were required, necessitating the use of specially designed projection lenses and of spherical mirrors of large aperture.

It has long been realised that there is always the possibility of other principles being employed for the production of large images which might lead to the development of devices which, while being modulated by electronic means, do not in themselves provide the luminous images, but which act as controllers or relays of the light emanating from separate sources. These sources, being fixed, can be of sufficient intensity to meet the requirements of the cinema screen as regards brightness. J. L. Baird in his demonstrations with mirror drum projection used this principle with an apparatus in which the light beam from an arc lamp was passed through a Kerr cell into the projection lens. This was the first practical application of the direct modulation of a light source by an intermediate electronic device to produce a television image.

The Scophony system employed the Debye Sears effect in the same manner, while more recently Donal and Langmuir have demonstrated what they call a new type of light valve dependent in its action on the orientation of opaque particles in a suspension when an electric field is applied to the insulating face of a cathode ray tube.

A. H. Rosenthal has proposed a system of large screen television reception based on the development of opaque areas in microcrystalline layers of ionic crystals under the action of electronic bombardment.

Now comes the description of a very interesting piece of apparatus published by Dr. Fisher of the Swiss Federal Institute of Technology in Zurich* which follows the same general lines.

* Cinema-Television, Ltd.

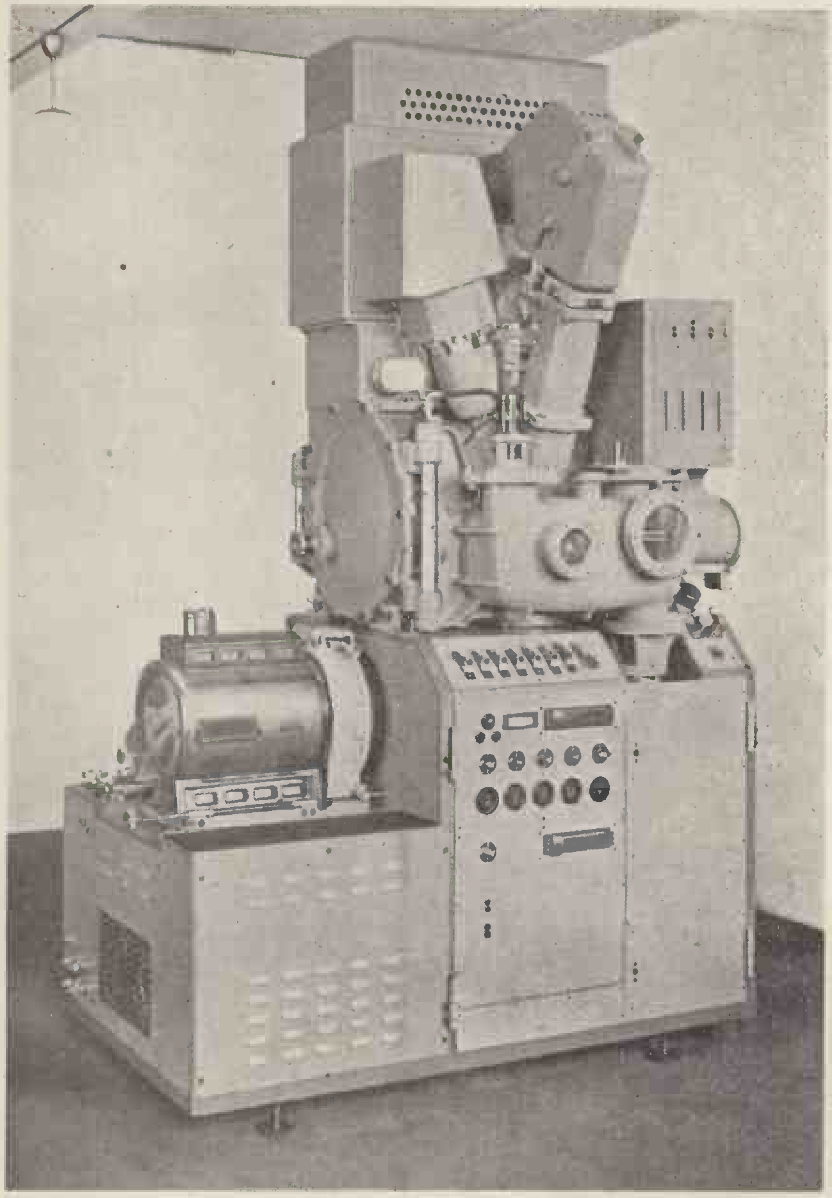


Fig. 1. The large-screen Television Projector developed by the Institute of Applied Physics, Zurich. Total height 8 feet *(from Swiss Technics)*.

The principle followed is based on the point to point deformation of the surface of a thin film of liquid by means of electrostatic forces. The light from an arc lamp passing through the liquid film is deflected by the deformation, and by means of an optical system a pencil of light rays proportional in intensity to the degree of deformation and corresponding to each deformed

* Published in "Swiss Technics," February, 1944.

point of the surface is made visible by projection.

A modulated cathode ray beam charges the surface of the liquid with electricity which gives rise to the forces needed to effect the deformation. Fig. 2, taken from the *Swiss Technics*, serves to illustrate the optical system. The liquid film (1) which in the absence of electrostatic forces has a smooth surface, is about 0.1 mm. thick. The film is spread on a glass plate (2) underneath which is a system of lenses (3) which serves to focus the light passing through the slits between the lower bars (4) exactly on to the upper bars (5). All the light rays, a few of which are represented by dotted lines on the right-hand side of the drawing, are consequently intercepted by the upper bars as long as the surface is smooth and undistorted, and hence no light appears on the screen.

The conditions are, however, considerably altered as soon as the surface of the liquid is deformed as is represented on the left-hand group of rays in the diagram by a minute indentation of the surface. All the rays of light which pass through the oblique sides of this indentation are deflected in proportion to the depths of this indentation and are able to pass between the upper bars and thus form a bright point in the television image. This figure also shows the complete schematic arrangement of the projector. It will also be seen that there is an electron gun (6) with magnetic focusing and deflecting fields (7) and (9) which scan a very finely focused electron beam over the surface of the liquid.

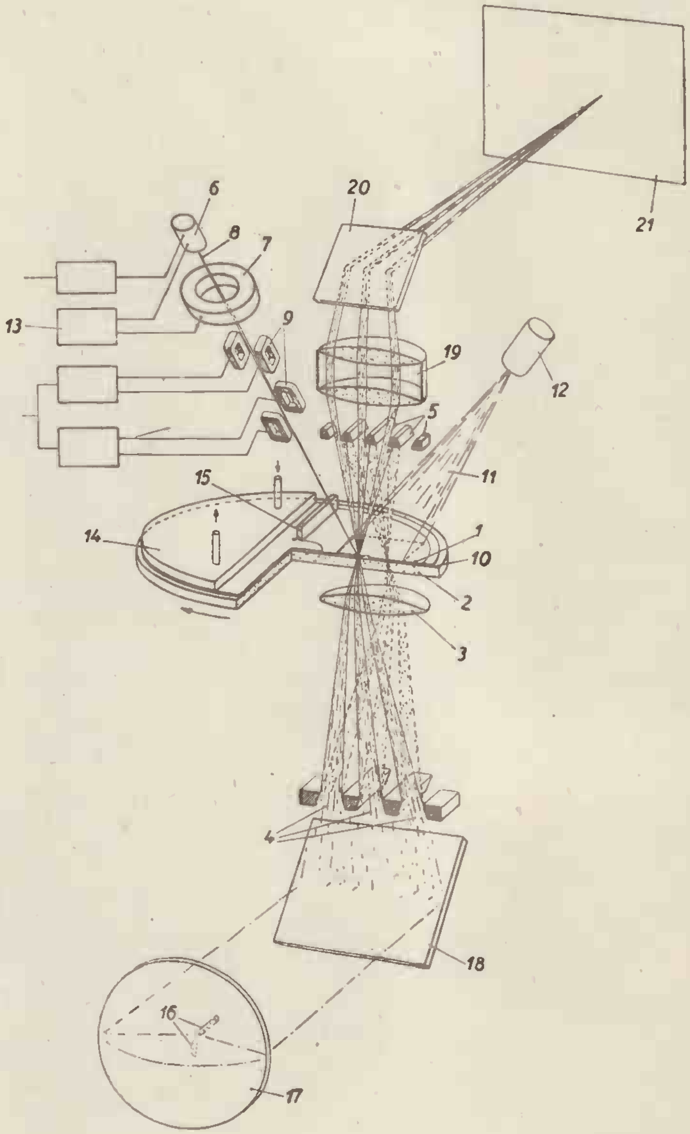


Fig. 2. Schematic diagram of the large-screen Projector.

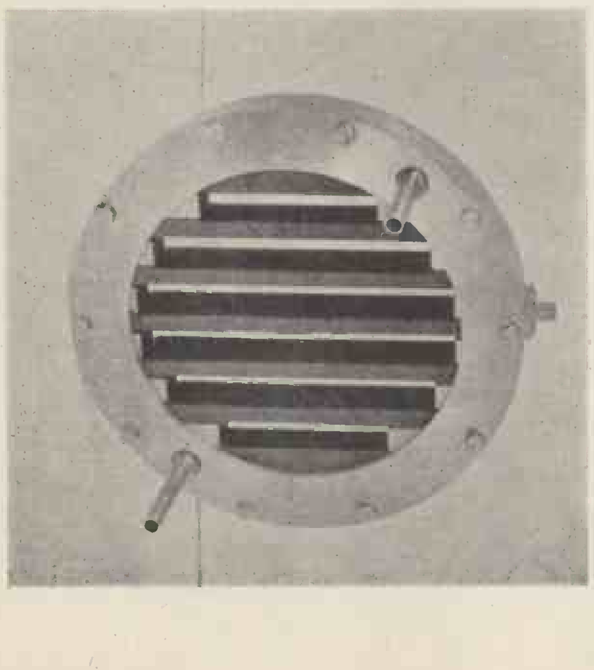


Fig. 3 (*bottom left*). **Lower bars of the optical system with water cooling.**

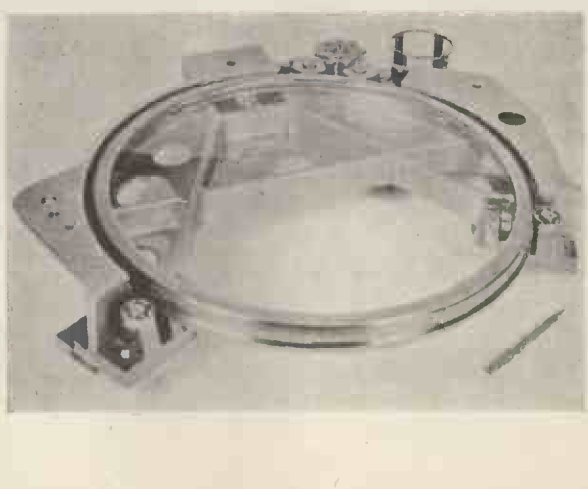


Fig. 4 (*bottom right*). **Rotatable glass plate carrying the light control liquid. An idea of the size can be obtained from the propelling pencil in the foreground** (*from Swiss Technics*).

During the scanning the beam is intensity modulated by the incoming signals which are applied to the tube as a modulation of a carrier frequency of 7.5. megacycles. In this way the surface of the liquid receives a charge image corresponding to the television image.

It is stated that the average beam current is only 20 microamps at 10 kV. which produces only a small charge at any point on the surface of the liquid with the result that a sufficiently deep indentation can only be obtained by adopting two further measures. Firstly, a thin transparent electron-conducting film (10) is deposited on the glass plate which acts as a counter-electrode for the charge existing on the surface of the liquid, and secondly, by supplying a uniform flood of electrons (11) from the gun (12) over the whole surface of the liquid.

In addition to all this elaboration the liquid is made semi-conducting so that the charges are dissipated within the time of picture repetition in order that the surface may be smooth again for the succeeding image, which is stated to be 1/50th second.

On studying the diagram further complications are noted. In the first place the whole of the above described processes occur in the vacuum of very high degree, so that the apparatus has to be continuously evacuated by pumps contained in the lower compartment of the instrument. The glass plate is rotated slowly and continuously in order to bring the film liquid under the cooling plates (14) where it loses the heat produced by the projection of the image of the arc crater. On leaving the cooling plate the liquid has to be scraped smooth by squeegee (15) and so made ready for further exposure.

No mention is made in the article in *Swiss Technics* as to any pictorial results, to the degree of contrast obtainable, or to the screen illumination realised with the apparatus.

The photographs of the completed apparatus and of the individual components, two of which are reproduced here, show the high degree of mechanical skill which has been expended in the fabrication of this instrument, and it is therefore, all the more disappointing that no indication is given of its performance.

A NOTE ON PHOTO-CELL NOMENCLATURE

By Dr. W. SOMMER

IN the writer's opinion many of the terms defined in B.S.S. 205 (part 6, Sec. 8, 1943) relating to photo-electric cells are ambiguous and misleading.

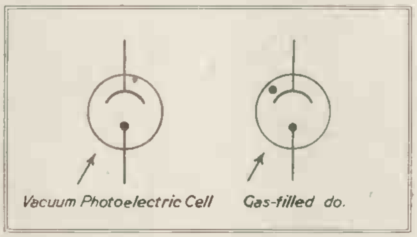
The word "photo-emissive" for example, means "light-emissive," but this type of cell does not emit light but electrons. "Photo-voltaic" does not relate to a voltaic cell, as the name might imply.

This term was rightly used by Becquerel[1], Sabine (1878), and Minchin (1893) because their particular type of light-sensitive cell was of the liquid electrolyte type, exactly as was Volta's cell.

The term "photo-voltaic" cell is, however, not confined to this group in modern practice but relates to cells described by the term "rectifier photo-electric cell."

A very good suggestion has been made for what is known in recent literature as the photo-voltaic cell. Sharp[2] suggested in 1935 making use of the term "Photo-e.m.f. cell," which is not only correct from the physical point of view but is also descriptive and euphonic. The photo-voltaic cell commands a greater variety of terms than any other photo-electric device; for example :—

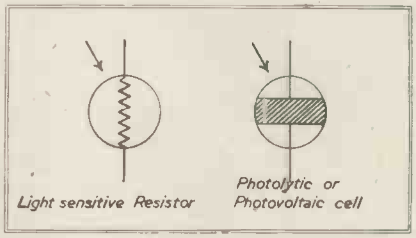
Dry-disk cell, Rectifier cell, Blocking-layer cell, Boundary-layer cell, Insulating-layer cell, Barrier-layer cell, Sandwich cell, Photo e.m.f. cell, Self-generating cell, Sperrschicht-cell.



It is suggested that photo-emissive cells might best be defined by the terms "vacuum photo-electric cell" and "gas-filled photo-electric cell," as the case may be. Photoconductive cells should not be termed "cells" but rather, and more appropriately, "light-sensitive resistors," the word "light" replacing "photo" in order to mark the difference.

Finally, the following terms are put for criticism and discussion :—

Old Terminology	*Suggested Terminology*
Photoemissive cell	Vacuum photo-electric cell Gasfilled photo-electric cell
Photovoltaic cell	Photo-e.m.f. cell
Photoconductive cell	Lightsensitive resistor
Photoelectrolytic cell	Photovoltaic cell (or) Photolytic cell



In the defence and favour of the above terms it may be said that

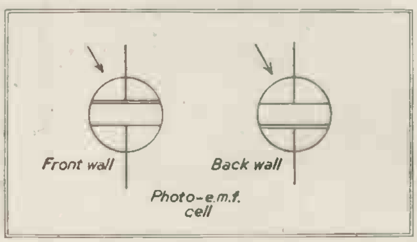
(1) each of them is a complete and unambiguous term referring to the controlling (radiant energy) as well as to the controlled agent (electric energy) and describing unmistakably the type of cell and the type of action taking place in it;

(2) they are short terms and easily recognized as what they are intended to represent.

Symbols

Agreement, or approximation to it, has been reached on the symbol for vacuum and gasfilled photoelectric cells (Col. 2). The other types of cells are represented by symbols which vary as much as the fancy of their inventors. Although the author feels he may be guilty of the same offence when suggesting new type symbols he ventures to proffer the ones shown in the text. These are self-explanatory; the arrows indicate the general direction of the incident radiant energy and are part of the symbol. The direction of incidence is essential in the case of photo-e.m.f. cells for obvious physical reasons, and necessary in the case of light-sensitive resistors as otherwise this symbol might be mistaken to represent a barretter. In the case of vacuum or gasfilled photo-electric cells they have been inserted for uniformity.

REFERENCES.
1 Edm. Becquerel, Comp. rend., 1839; 9; 561.
2 Clayton H. Sharp, J.O.S.A., 1935; 25; 165.

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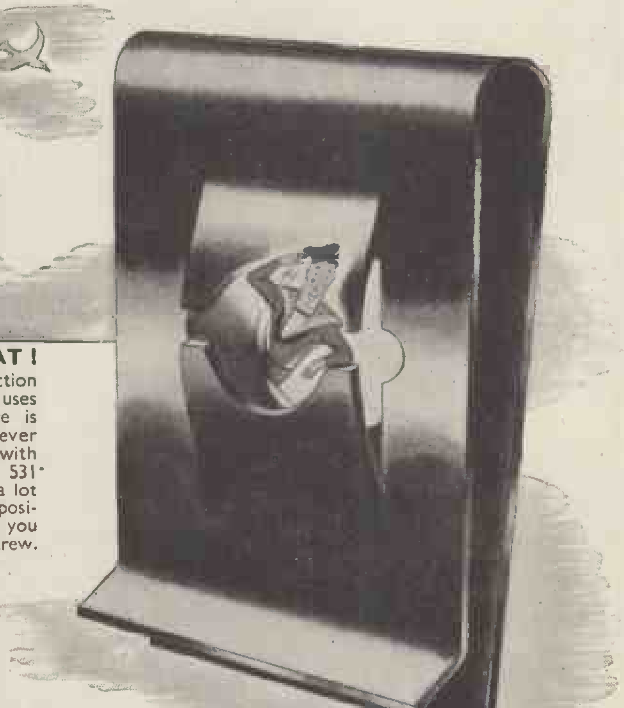

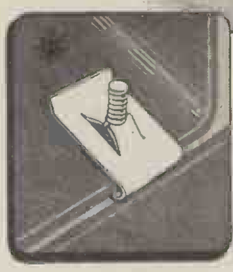

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Tensor Algebra

and its Application in the Solution of Network Problems

Part II — Tensor Analysis of Networks

By C. F. DAVIDSON*

IN the following analysis we shall consider the solution of network problems by tensor methods. Given the performance of a fundamental mesh network, known as the primitive mesh network, we shall derive from it the performance of another network formed from the primitive network by interconnexion.

Consider the impedances Z_{11} and Z_{22} arranged as shown in Fig. 1, the mutual impedances Z_{12} and Z_{21} being assumed equal and taken to be positive reactances irrespective of the direction of coupling between the coils of the impedances, and let any voltage be impressed in series with them causing current to flow as indicated. The following sign convention will be adopted:—

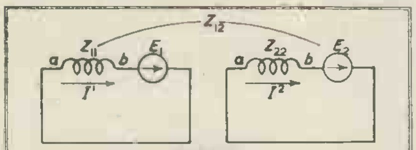

Fig. 1.

It will be assumed that positive currents flow in each impedance from a to b, and that the positive direction of the impressed voltage is the same as the positive direction of current, also when the meshes are interconnected as in Fig. 2, impedances connected in the order a-b, a-b or b-a, b-a will have their coils series aiding, and those connected in the order a-b, b-a or b-a, a-b will have their coils series opposing.

The network shown in Fig. 1 will be known as the primitive mesh network, and for this network when the coils are series aiding we have:—

$$E_1 = Z_{11}\, I^1 + Z_{12}\, I^2$$
$$E_2 = Z_{21}\, I^1 + Z_{22}\, I^2$$

or more concisely:—

$$E_m = Z_{mn} I^n \quad (m,\ n = 1,\ 2)$$

where

$$E_m = \begin{array}{|c|c|} \hline E_1 & E_2 \\ \hline \end{array} \quad (m \rightarrow 1,\ 2)$$

$$Z_{mn} = \begin{array}{|c|c|} \hline Z_{11} & Z_{12} \\ \hline Z_{21} & Z_{22} \\ \hline \end{array} \quad (m \downarrow 1,\ 2;\ n \rightarrow 1,\ 2)$$

$$I^n = \begin{array}{|c|c|} \hline I^1 & I^2 \\ \hline \end{array} \quad (n \rightarrow)$$

The quantities used in the above equations are complex quantities.

Suppose now the two networks are interconnected as in Fig. 2, the voltages impressed in series with the impedances remaining the same.

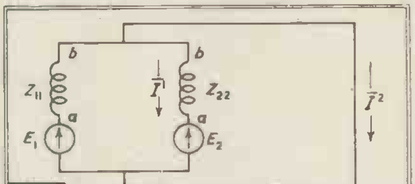

Fig. 2.

Since after interconnexion each coil is still short-circuited upon itself the current through each coil remains unchanged. However, since the added conductors introduce new current paths we can express the equation of voltage in terms of new currents $\bar{I}^r$ selected quite arbitrarily, the new currents being independent of one another, and the number being the same as the number of meshes. Equating the currents flowing through the impedances, remembering positive currents flow from a to b, we have

$$I^1 = \bar{I}^1 + \bar{I}^2$$
$$I^2 = -\bar{I}^1$$

Now I^n may be taken as the components of a contravariant vector, and we have

$$I^n = C^n{}_r \bar{I}^r \text{ where}$$

$$C^n{}_r = \begin{array}{|c|c|} \hline 1 & 1 \\ \hline -1 & 0 \\ \hline \end{array} \quad (n \downarrow 1,\ 2;\ r \rightarrow 1,\ 2)$$

Solving the system of equations for $\bar{I}^r$ we have

$$\bar{I}^r = c^r{}_n I^n \text{ where}$$

$$c^r{}_n = \begin{array}{|c|c|} \hline 0 & -1 \\ \hline 1 & 1 \\ \hline \end{array} \quad (r \downarrow 1,\ 2;\ n \rightarrow 1,\ 2)$$

$c^r{}_n$ being formed from $C_r{}^n$ in the same way in which $C^n{}_r$ is formed from $c^r{}_n$.

In both the primitive mesh network and in the new network, the power input P (including wattless power) remains invariant since the current through each impedance remains unchanged. For the primitive mesh network we have

$$P = E^*{}_m I^m$$

where $E^*{}_m$ is the conjugate of E_m, and for the new network

$$\bar{P} = \bar{E}^*{}_r\, \bar{I}^r$$

where $\bar{E}^*{}_r$ is some function of $E^*{}_m$. Now P is a scalar invariant, *i.e.*, a tensor of order zero, and as I^m is a contravariant vector, it follows by the quotient law that $E^*{}_m$, and therefore E_m is a covariant vector, and

$$\bar{E}_r = C^m{}_r\, E_m.$$

The components of $\bar{E}_r$ are

$$\bar{E}_r = \begin{array}{|c|c|} \hline E_1 - E_2 & E_1 \\ \hline \end{array} \quad (r \rightarrow 1,\ 2)$$

and it will be seen that the new voltage components are the sum of the voltages impressed around the two meshes.

Again, before interconnexion

$$E_m = Z_{mn} I^n$$

and hence after interconnexion there is a relationship of the form

$$\bar{E}_r = \bar{Z}_{rs}\, \bar{I}^s$$

It immediately follows from the quotient law that Z_{mn} is a covariant tensor of the second order and that

$$\bar{Z}_{rs} = C^m{}_r C^n{}_s Z_{mn}$$

The components of $\bar{Z}_{rs}$ are

$$\bar{Z}_{rs} = \begin{array}{|c|c|} \hline Z_{11} - 2Z_{12} + Z_{22} & Z_{11} - Z_{12} \\ \hline Z_{11} - Z_{12} & Z_{11} \\ \hline \end{array} \quad (r \downarrow 1,\ 2;\ s \rightarrow 1,\ 2)$$

$\bar{Z}_{rs}$ is the impedance tensor for the new network, and the value of its components will depend upon the arbitrary variables $\bar{I}^r$.

Consider the system Y^{mn} defined as follows. Let Y^{mn} be the cofactor of the term Z_{nm} in the determinant $Z = |Z_{mn}|$ divided by Z, then

$$Z_{rm} Y^{nr} = Z_{mr} Y^{rn} = \delta^n{}_m$$

The equations of voltage for the primitive network are

$$E_m = Z_{mn} I^n$$

Multiplying both sides of the above equation by Y^{pm} we have

$$Y^{pm} E_m = Y^{pm} Z_{mn} I^n$$
$$= \delta^p{}_n I^n$$
$$= I^p$$

or

$$I^m = Y^{mn} E_n$$

and by the quotient law Y^{mn} is a contravariant tensor of the second order, it is known as the admittance tensor.

* Post Office Research Station.

Its equation of transformation is

$$\overline{Y}^{rs} = c^r{}_m c^s{}_n Y^{mn}$$

The components of Y^{mn} and $\overline{Y}^{rs}$ are given below:—

$$Y^{mn} = \begin{array}{c|cc} & 1 & 2 \\ \hline 1 & \frac{Z_{22}}{|Z|} & \frac{-Z_{12}}{|Z|} \\ 2 & \frac{-Z_{21}}{|Z|} & \frac{Z_{11}}{|Z|} \end{array}$$

$$\overline{Y}^{rs} = \begin{array}{c|cc} & 1 & 2 \\ \hline 1 & \frac{Z_{11}}{|Z|} & \frac{Z_{12}-Z_{11}}{|Z|} \\ 2 & \frac{Z_{12}-Z_{11}}{|Z|} & \frac{Z_{11}-2Z_{12}+Z_{22}}{|Z|} \end{array}$$

where $|Z| = Z_{11}Z_{22} - Z^2_{12}$

Now $\overline{I}^r = \overline{Y}^{rs}\overline{E}_s$ and we can thus solve for $\overline{I}^r$ obtaining

$$\overline{I}^r = \begin{array}{cc} 1 & 2 \\ \hline \frac{Z_{11}(E_1 - E_2)+(Z_{12}-Z_{11})E_1}{Z_{11}Z_{22} - Z_{12}^2} & \frac{(Z_{12}-Z_{11})(E_1-E_2)+(Z_{11}-2Z_{12}+Z_{22})E_1}{Z_{11}Z_{22} - Z_{12}^2} \end{array}$$

The currents flowing in the individual impedances can be found from

$$I^m = C^m{}_r\overline{I}^r$$

and the voltages E'_m across the individual impedances are given by

$$E'_m = Z_{mn}I^n,$$

for an all-mesh network E'_m has the same numerical value as E_m.

Had the coils of the impedances been connected series aiding as in Fig. 3.

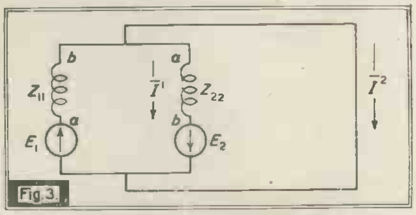

Fig.3.

it would have been found that

$$\overline{I}^r = \begin{array}{cc} \frac{Z_{11}(E_1 + E_2)+(-Z_{12}-Z_{11})E_1}{Z_{11}Z_{22} - Z_{12}^2} & \frac{(-Z_{12}-Z_{11})(E_1+E_2)+(Z_{11}+2Z_{12}+Z_{22})E_1}{Z_{11}Z_{22} - Z_{12}^2} \end{array}$$

If the sign of E_2 is reversed, then conditions are exactly the same as in Fig. 2 except that the coils are now connected series aiding instead of series opposing, and it is seen that this is equivalent to changing the sign of Z_{12}. The sign convention adopted, however, takes care of this change in sign automatically.

As a more complex example consider the three-mesh network of Fig. 4 with the primitive network given in Fig. 5. The coils of Z_{11} and Z_{44} are series aiding and those of Z_{22} and Z_{55} series opposing.

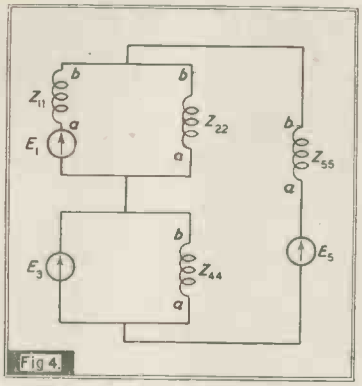

Fig 4.

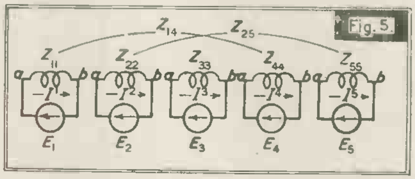

Fig. 5.

The current, voltage, and impedance tensors for the primitive network are given in the arrays below; as some of the voltages and impedances in the derived network are zero the corresponding components of the voltage and impedance tensors for the primitive network will also be zero.

$$I^m = \begin{array}{|c|c|c|c|c|} 1 & 2 & 3 & 4 & 5 \\ \hline I^1 & I^2 & I^3 & I^4 & I^5 \end{array}$$

$$E_m = \begin{array}{|c|c|c|c|c|} 1 & 2 & 3 & 4 & 5 \\ \hline E_1 & 0 & E_3 & 0 & E_5 \end{array}$$

$$Z_{mn} = \begin{array}{c|ccccc} & 1 & 2 & 3 & 4 & 5 \\ \hline 1 & Z_{11} & 0 & 0 & Z_{14} & 0 \\ 2 & 0 & Z_{22} & 0 & 0 & Z_{25} \\ 3 & 0 & 0 & 0 & 0 & 0 \\ 4 & Z_{41} & 0 & 0 & Z_{44} & 0 \\ 5 & 0 & Z_{52} & 0 & 0 & Z_{55} \end{array}$$

In the new network the impedances are no longer short-circuited upon themselves as they were in the primitive network, but it can be imagined that the impedances are short-circuited subject to the condition that no current flows through these impedanceless paths. Taking three arbitrary, but independent currents as shown in Fig. 6, we obtain the impedance currents of Fig. 7.

The current transformation is therefore

$$\begin{aligned} I^1 &= \overline{I}^2 \\ I^2 &= -\overline{I}^1 - \overline{I}^2 \\ I^3 &= -\overline{I}^1 - \overline{I}^3 \\ I^4 &= \overline{I}^3 \\ I^5 &= \overline{I}^1 \end{aligned}$$

or alternatively $I^m = C^m{}_r\overline{I}^r$ where

$$C^m_r = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 0 & 1 & 0 \\ 2 & -1 & -1 & 0 \\ 3 & -1 & 0 & -1 \\ 4 & 0 & 0 & 1 \\ 5 & 1 & 0 & 0 \end{array}$$

As the above transformation is singular, $\overline{I}^r$ cannot be expressed in terms of I^m, and $c^r{}_m$ does not exist. However, we can find the new voltage vector from

$$\overline{E}_r = C^m{}_rE_m \text{ giving}$$

$$\overline{E}_r = \begin{array}{|c|c|c|} 1 & 2 & 3 \\ \hline -E_3+E_5 & E_1 & -E_3 \end{array}$$

and the impedance tensor from

$$\overline{Z}_{rs} = C^m{}_rC^n{}_sZ_{mn} \text{ giving}$$

$$\overline{Z}_{rs} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & Z_{22}-2Z_{25}+Z_{55} & Z_{22}-Z_{25} & 0 \\ 2 & Z_{22}-Z_{25} & Z_{11}+Z_{22} & Z_{14} \\ 3 & 0 & Z_{14} & Z_{44} \end{array}$$

In this particular example $|Z_{mn}| = 0$ and therefore we cannot calculate the components of the admittance tensor Y^{mn} for the primitive network. The components of $\overline{Y}^{rs}$ for the derived network can, however, be calculated from $\overline{Z}_{rs}$ in the same way as Y^{mn} is calculated from Z_{mn}. For the derived network we have

$$\overline{Y}^{rs} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & \frac{Z_{44}(Z_{11}+Z_{22})-Z_{14}^2}{|\overline{Z}|} & \frac{Z_{44}(Z_{25}-Z_{22})}{|\overline{Z}|} & \frac{Z_{14}(Z_{22}-Z_{25})}{|\overline{Z}|} \\ 2 & \frac{Z_{44}(Z_{25}-Z_{22})}{|\overline{Z}|} & \frac{Z_{44}(Z_{22}-2Z_{25}+Z_{55})}{|\overline{Z}|} & \frac{Z_{14}(2Z_{25}-Z_{22}-Z_{25})}{|\overline{Z}|} \\ 3 & \frac{Z_{14}(Z_{22}-Z_{25})}{|\overline{Z}|} & \frac{Z_{14}(2Z_{25}-Z_{22}-Z_{55})}{|\overline{Z}|} & \frac{(Z_{11}+Z_{22})(Z_{22}-2Z_{25}+Z_{55})-(Z_{22}-Z_{25})^2}{|\overline{Z}|} \end{array}$$

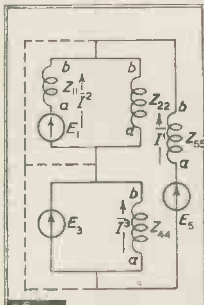

Fig 6.

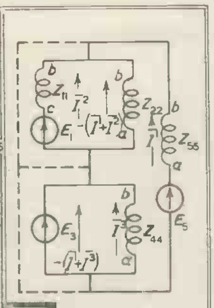

Fig 7.

where
$$|\overline{Z}| = (Z_{22}-2Z_{25}+Z_{55}) \times (Z_{11}Z_{44}+Z_{22}Z_{44}-Z^2_{14}) - (Z_{22}-Z_{25})(Z_{22}Z_{44}-Z_{25}Z_{44})$$

Having calculated $\overline{Y}^{rs}$ we can find the new currents $\overline{I}^r$ from

$$\overline{I}^r = \overline{Y}^{rs}\overline{E}_s$$

for example

$$\overline{I}^2 = \frac{1}{|\overline{Z}|}\Big[Z_{44}(Z_{25}-Z_{22})(-E_3+E_5) + Z_{44}(Z_{22}-2Z_{25}+Z_{55})E_1 + Z_{14}(2Z_{25}-Z_{22}-Z_{55})(-E_3)\Big]$$

The currents flowing in the individual impedances can be found from

$$I^m = C^m{}_r\overline{I}^r$$

and the voltages E'_m across the individual impedances from

$$E'_m = Z_{mn}I^n$$

In the examples considered, the networks have been mesh networks, but it is possible to apply the same method of attack in analysing the performance of junction and orthogonal networks. Although the method may seem laborious for simple networks, it is a very powerful one when the number of meshes or junction-pairs becomes large, the numerical working can, however, be considerably shortened by the introduction of matrices. The method is also very useful when the performance of several independent networks is given and it is required to determine the performance of a new structure formed from the independent networks by interconnexion, a complete analysis is possible by using the known results and a transformation of currents corresponding to the interconnexions without analysing the new structure as a whole.

The writer would like to express his thanks to Dr. J. C. Simmonds for his helpful criticisms and suggestions.

NOTES FROM THE INDUSTRY

Inexpensive C.R.O. Equipment

A useful cathode ray tube equipment for students and works testing has been developed by Griffin & Tatlock Ltd.

The oscilloscope uses a 3 in. tube and is supplied in a grey portable case complete with time-base for £15 15s.

The same Company have also produced a mains operated beat frequency oscillator to work in conjunction with the tube for £17 10s. Full particulars are given in Leaflet GT1220 from Griffin & Tatlock Ltd., Kemble Street, London, W.C.2.

The World's First Three-Core 132 kV. Cable

Callender's Cable and Construction Co. have recently manufactured, laid and jointed a run of three-core 132 kV. cable for underground electrical transmission. This is the first time in electrical history that three-core cable of 132,000 volts working pressure has been installed under commercial conditions.

By applying pressure to a fully impregnated paper cable, the performance of the dielectric can be greatly improved. In the normal solid type cable it is well known that, owing to the thermal expansion of the compound, the service heat cycles necessarily cause void spaces to appear in the dielectric. These spaces form a source of dielectric weakness but, if the interior of the cable is raised to a pressure of 200 lb./sq. in., the dielectric strength of the void spaces is raised to that of the impregnated paper dielectric.

Inside the three-core cable the internal gas pressure is maintained at approximately 200 lb./sq. in. and for this purpose nitrogen is introduced into the cable at one end of the route from high pressure cylinders.

The cable has a normal stranded copper conductor insulated with paper dielectric impregnated in a new type of compound that results in extremely low loss, with metal tapes to allow for the radial and longitudinal mechanical forces produced by the internal pressure. The cable is served overall with a new type of serving to avoid the remote possibility of corrosion of the reinforcement. The size of conductor is 0.4 sq. in.; the overall diameter of the three-core cable is 4.8 in.

BOOK REVIEWS

Radio Receivers and Transmitters

By S. W. Amos, B.Sc., A.M.Brit.I.R.E. and F. W. Kellaway, B.Sc. 281 pp. (Chapman and Hall, 21s.)

The style of this book is that of the physicist rather than the engineer, and the authors have largely succeeded in their aim to "bridge the gap between pure science and radio." The pre-graduate student of radio-physics will find much to interest and instruct him, and the book should appeal to teachers of radio in technical colleges. It is not intended for the use of the specialist, and there is little that will not be familiar to the experienced radio engineer, who may be irritated by the frequent use of "it can be shown that."

There are ten chapters and eight short appendices, the latter dealing with such subjects as Fourier series, the transient and steady state solution of L, C and R circuits, and the analysis of tone control circuits. Chapter I is an introduction to radio and audio waves, modulation and the types of transmitters and receivers. The direction of the lines of magnetic force of an ether (why not electro-magnetic?) wave in Fig. 1 is not very clear, and the vertical scale of Fig. 3 might be given values. In view of the glossary of symbols the use of E for power on page 6 is not very wise, and the change over from "ω" to "p" for carrier pulsatance in the A.M. and F.M. expressions on pages 10 and 11 is confusing. This inconsistency is repeated on page 132. In chapters 2 and 3, dealing with inductance and capacitance, the authors have their own idea of time constant, which should be $\frac{L}{R}$ and CR and not the reciprocal as quoted. The fourth chapter is concerned with series and parallel resonant circuits, and their use in aerial coupling, and R.F. amplifiers. There is a misprint in the caption of Fig. 55, an unsatisfactory figure because low frequency peaks in double-humped responses are generally equal to (*see* Fig. 115), or greater than the high frequency peaks. Propagation of radio waves, simple forms of aerial and their polar diagrams are described in chapter 5. On page 100, line 4 from the bottom should read "change of reactance from positive, etc."

The short paragraph on time bases seems a little out of place in chapter 6, which deals adequately with valves, A.F. amplification and detection. Chapter 7 examines the output stage in detail; the loudspeaker and negative feedback are also included. The statement on p. 149 about the triode behaving as a constant voltage generator is apt to be misleading, for the triode can equally well be represented as a constant current generator; the important point is low R_a. R.F. and I.F. amplification form the subject of chapter 8. It would be as well in this chapter to point out that valve input impedance, Z_1, if it is reactive, can be low without necessarily reducing the gain of the previous stage. A misprint occurs at the top of page 181.

The authors' best chapter is 9, where they dissect a typical superheterodyne receiver for audio reception. Television and F.M. receivers receive cursory examination. The last chapter deals with transmitters and methods of modulation. On page 254 it would be wiser to state that modulation does not affect the amplitude of the carrier component vector.

To offset this criticism the writer would state that this is the first of three books, recently reviewed, which he wishes to keep.

K. R. S.

Introduction to Valves

By F. E. Henderson (G.E.C.) 2nd. Edn. 122 pp. 140 figs. ("Wireless World" Offices, 5s. net.)

The fact that a second edition of this book has been issued within a comparatively short time shows that it has well fulfilled its purpose of providing information for those "who with little or no previous experience, are called upon to handle radio valves and cathode ray tubes and their associated devices."

All types of valves from diodes to frequency changers are described together with typical circuits, and there are sections given to gasfilled rectifiers and relays, C.R. Tubes, and specialised types such as magnetrons and electron multipliers.

The growing number of users of electronic apparatus in industry will find this a useful reference book, apart from those who do not wish to go too deeply into theory, but are not content to take radio apparatus for granted.

Physics and Radio

By M. Nelkon, B.Sc. 380 pp. 507 figs. (E. Arnold, 8s. 6d. net.)

The title page of this book states that the author is a Lecturer at the Northampton Polytechnic (which, by the way, is in London), but even without this information one would be inclined to suspect that he had experience in teaching, so thorough is the treatment of the subject.

The book is intended to be a concise elementary text-book of those principles of physics which concern basic radio and therefore contains some of the essentials of Sound and Light as well as elementary electricity and magnetism (quoting from the preface). One feature is that there is no sharp distinction between a.c. of mains frequency and higher frequencies as is so often the case in introductory text-books. The student thus obtains a truer perspective of radio engineering in relation to electrical engineering. Each chapter concludes with a summary of the contents and examples.

Valves are introduced half-way through the book, leading to the theory of amplification and oscillation. The theory of aerials follows a short section on sound and wave motion, and an introductory note on light and refraction precedes a description of the ionosphere and fading. The concluding chapter deals with the cathode ray oscillograph and its circuits.

The whole book can be recommended to both students and teachers of elementary radio theory, and the latter will find many useful suggestions for presenting facts in a clear and concise way.

G.P.

ABSTRACTS OF ELECTRONIC LITERATURE

INDUSTRY

The Principles of High-Frequency Heating
(*L. Hartshorn*)

The laws governing the basic facts of dielectric heating have been long established by many experimental investigations. The author discusses the fundamental theory of high-frequency heating and gives a brief résumé of historical development. The advantages that may be obtained by the use of this method of heating are considerable but the process is, nevertheless, subject to certain limitations. A paragraph on the future prospects of dielectric heating concludes the article.

—*Chem. and Ind.*, 9/9/1944, p. 322.*

Industrial Applications of Electronic Devices
(*F. H. Annett*)

Following an extensively illustrated review of the fundamental principles of electronic valves, commencing with the vacuum diode and including both vacuum and gas-filled types, the application of such devices for industrial purposes, as distinct from radio applications, is discussed. Rectification of a.c. constitutes one of the most important uses. Other functions, such as voltage regulation, d.c. motor speed control, flame failure protection in furnaces and smoke density indication are each discussed with diagrams.

—*Power*, April, 1944, p. 64.*

Tracking Currents in Insulating Materials
(*E. Rushton*)

Tracking is initiated by the passage over the surface of sparks which heat the surface to such an extent that it finally becomes conducting. In general, tracking occurs after the material has been in service for some considerable time, and the gradual accumulation on the surface of water or particles of soot, dust, etc., is believed to be a frequent cause since sparking between layers of the liquid (or particles) which are separated by strips of dry, uncontaminated material results in the strips becoming carbonised. The methods used for testing materials for resistance to tracking are described.

—*Chem. and Ind.*, 16/9/1944, p. 332.*

Photo-electric Industrial Controls
(*H. J. Hague*)

A summary is first given of the various types of photo-electric cells, their characteristics and their applications, stressing the advantages gained from secondary emission and positive ion bombardment in the gas-filled types of tube. Various types of equipment incorporating photo-cells are discussed, together with applications; included in the review are light relays and register-regulators and also auxiliary devices for use with the cells such as light sources, colour filters, etc.

—*Electronics*, April, 1944, p. 114.

MEASUREMENT

Comparison of Watt-Hour Meters
(*H. S. Bull*)

A device for the calibration of watt-hour meters is described, whereby phototubes, responding to speed differences, vary the degree of closure of a "magic eye." This eliminates the disadvantage of requiring special rotating standards and the necessity for characteristic markings on the disc of each test meter. The equipment is discussed in detail with the aid of circuit diagrams.

—*El. World*, Nov. 27, 1943, p. 40.*

A Photo-electric Photometer for Measuring the Light Scattered by the Surface of a Transparent Material
(*J. M. Sowerby*)

A photometer designed for measuring the light scattered at 45 deg. from the surface of a piece of transparent plastic material which has suffered abrasion is described. The abraded portion of the material is illuminated by a low-voltage lamp through a lens system and the scattered light falls on a sensitive vacuum photocell coupled to an amplifier. The amplifier drives a "tuning-eye," whose shadow is always returned to a given mark. The adjustable element is a scaled potentiometer.

—*Jour. Sci. Inst.*, Mar., 1944, p. 42.*

Moving Coil Ammeters
(*G. W. Stubbings*)

Temperature effect in shunted instruments can be mitigated by connecting in series with the instrument a resistance of negligible temperature coefficient, which is generally known as a swamp. An alternative method involving a Wheatstone bridge network is discussed in this article. The effect of the resistance of long leads is usually lessened by the use of a shunt with a higher full load drop than standard, so that extra swamping resistance can be used in the ammeter circuit. The equivalent circuit diagram in which the bridge network is connected to the shunt by leads having a specified resistance is illustrated.

—*Electrician*, 25/8/1944, p. 167.*

Thermocouple Milliammeters at U.H.F.
(*G. F. Gainsborough*)

A description is given of the calibration of commercial thermocouple milliammeters at frequencies of 100 Mc/s. and 700 Mc/s. Errors dependent on current amplitude were found and were shown to be due to the magnetic properties of the wire used for the heaters. The occurrence is confirmed of frequency errors due to the method of constructing ordinary instruments.

—*Jour. I.E.E.*, vol. 91 (pt. 3), p. 156.

An Electronic Tachometer, Accelerometer and Vibrometer

The equipment described was designed primarily to assist in adjusting and testing gyroscope rotor assemblies combining in one unit the functions of the tachometer, an accelerometer and a vibrometer, but the principles involved are applicable to a wide variety of industrial problems. The rotor under test, mounted in a fixture, is rotated by means of an air jet, and two pick-ups are so mounted on the fixture that rotation of the rotor produces varying voltages in each. Voltage from the crystal pick-up operates the vibrometer through amplifiers, while that from the electrostatic is used to operate the tachometer and accelerometer circuits. The individual circuits and their main component parts are described. Two-speed ranges are covered by the tachometer meter.

—*Electronics*, June, 1944, p. 100.

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

DECEMBER MEETINGS

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

Institution of Electrical Engineers

London Section

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

Radio Section

The next meeting of the above section will be held on December 6, at 5.30 p.m. A paper will be read by L. Essen, B.Sc., Ph.D., entitled "The Measurement of Balanced and Unbalanced Impedances at Frequencies near 500 Mc/s. and its Application to the Determination of the Propagation Constants of Cables."

On December 19, at 5.30 p.m., the meeting will take the form of a discussion on "The Sound Channel in the Television Receiver" and will be opened by Dr. D. C. Espley.

The Secretary: The Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2.

Student's Section

At a meeting of the above section to be held on December 20, at 7 p.m., a paper will be read by J. F. Stirling, B.Sc., entitled "The Condensation of Atmospheric Moisture on Insulation Surfaces."

Section Secretary: R. G. Stefanelli, 19 Effingham Lodge, Surbiton Crescent, Kingston, Surrey.

Institute of Physics

A conference will be held on December 2, at 2 p.m., in the Lecture Theatre, of the Royal Institution, Albemarle Street, Piccadilly, London, W.1, on "The Selection and Training of Personnel for Industry."

Bradford Electronics Society

At a meeting of the above group to be held on December 7, at 7 p.m., at the Technical College, Bradford, a paper will be given by F. Youle (Rediffusion, Ltd.), entitled "Radio Frequency Heating."

Hon. Secretary: G. N. Patchett, The Technical College, Bradford.

The Association for Scientific Photography

On Saturday, December 30, at the Caxton Hall, Westminster, at 2.30 p.m., a paper will be given by H. Baines, D.Sc., F.I.C., and F. J. Tritton, B.Sc., F.I.C., entitled "The Choice of Materials for Scientific Photography."

The Secretary: Association for Scientific Photography, 34 Twyford Avenue, Fortis Green, London, N.2.

British Kinematograph Society

The next meeting of the above, will be held on December 6, a 6 p.m., at the Gaumont-British Theatre, Film House, Wardour Street, London, W.1. This will take the form of a joint meeting with R.P.S. Scientific and Technical Group. A paper will be given by W. H. Clarke, A.M.I.E.E., and R. J. Engler, A.M.I.E.E., and will be entitled "Photographic Aspects of Sound."

The Television Society *

The next meeting of the above will be held on January 2, 1945.

CLASSIFIED ANNOUNCEMENTS.

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THE TECHNICA CAMERA CO., 21, William IV Street, consulting photographic engineers to H.M. Government Departments, undertake the solving of photographic engineering problems.

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ELECTRONIC ENGINEER, French, Austrian, Czech, etc., required for research work. Priority job with peace-time prospects. Box No. 691, "Electronic Engineering."

A.M.I.E.E., City and Guilds, etc., on "NO PASS—NO FEE" terms. Over 95% Successes. For full details of modern courses in all branches of Electrical Technology send for our 112-page handbook—FREE and post-free. B.I.E.T., (Dept. 337B), 17 Stratford Place London, W.1.

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Classified Announcements (Contd

PRODUCTION ENGINEER wanted by established Company, specialising in radio compo mainly variable resistances, to undertake cont manufacturing. Applicant should possess technical knowledge, long practical experience, ability to organise and control labour, about workpeople. Imagination and progressive ide production necessary. It is essential work of priority during war-time with excellent pos prospects. Box 699, "Electronic Engineering."

WANTED. 1st-class practical man with expe of sheet metal instrument case manufacture. W to spend 15/20 hours per month and advise ho reduce costs and increase production efficie Must be capable of seeing job through. Box "Electronic Engineering."

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CHIEF-OF-TEST required by firm engaged o work in S.W.5. Must have sound knowledge of pr tion testing of H.F. and U.H.F. equipment. giving full particulars to Box 705, "Elect Engineering."

HEAD FOREMAN for Instrument Section req by firm engaged on war work in S.W.5. Write g full particulars to Box No. 706, "Electronic gineering."

PHYSICIST or High Vacuum Technician wan development of Discharge Lamps. Consulting Co might be considered. Detailed application indic remuneration required to Box E/P., c/o "Scient Cliffords Inn, London, E.C.4.

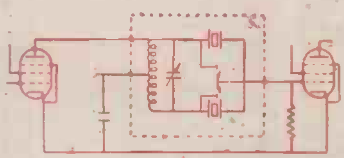
CHIEF ENGINEER required by firm engaged o work in S.W.5. Write giving full particulars to No. 703, "Electronic Engineering."

WANTED

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

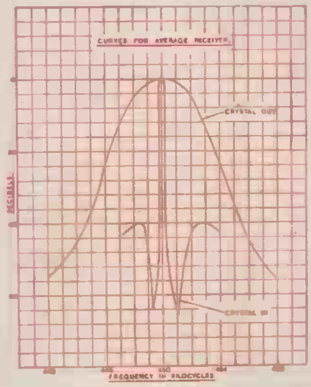
WANTED. Issues of "Bell System Tec Journal," 1938-43. Offers to Box 697, "Elect Engineering."

URGENTLY REQUIRED FOR R.A.F. Res Unit, "Electronic Engineering," Jan.-Dec., 1942 Jan.-Aug., 1943. Offers (singly or sets) to Box 702, "Electronic Engineering."



BAND-PASS FILTER CIRCUIT

Above is shown the fundamental circuit similar to that employed in the Eddystone 358X receiver. When in circuit the band-width is 300 c/s, front panel control allowing optional use of normal I.F. selectivity band-width 5 Kc/s.



SELECTIVITY CURVE "A"

shows the steep sides and flattened top response curve of the Band-pass Filter. Compare the normal crystal gate (Curve B) with its typical sharp peak necessitating constant tuning adjustment with the slightest signal frequency variation. Note the symmetrical rejection given by Curve "A" as opposed to the uneven tail effect of curve "B."

In the 358X version of this famous receiver a Band-pass Crystal circuit is employed giving high selectivity and complete rejection of unwanted adjacent signals. Furthermore the double crystal circuit avoids the extreme "peaked" effect of the conventional crystal gate, allowing easier tuning and accommodating some frequency drift of the wanted signal. These advantages are readily appreciated by operators familiar with the hair-breadth tuning of the normal filter.

The "358X" may be inspected at 14, Soho Street, preferably by appointment.

EDDYSTONE COMMUNICATION RECEIVERS ARE AVAILABLE ON PRIORITY ORDER ONLY.

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Hours of Business 10 a.m.—4 p.m. Saturdays 10 a.m.—12 noon.

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