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Metre-wave Broadcasting *Sub Judice*

THERE is nowadays a growing—and we think deplorable—tendency to postpone the discussion of an important matter with the excuse that it is "*sub judice*." That expression emphasizes an excellent principle of English law when, say, a man's life may depend on a fair trial by an unbiased and unprejudiced judge and jury, but is quite inapplicable to many of the questions of the day on which decisions may quite properly be influenced by public opinion.

Last month *Wireless World* posed a number of questions relating to metre-wave broadcasting, which we believe should be widely discussed before final plans are made for a nation-wide service. Little has been forthcoming in the way of answers; it seems to be generally believed in official circles that it is mildly improper to discuss such matters while they are *sub judice;* in other words, until the Beveridge report is debated in Parliament. That to us seems to be an indefensible attitude, involving unnecessary delay. When the debate comes, our legislators and their advisers should have the fullest possible collection of facts available to them, as well as information on technical opinion concerning debatable points.

One fact has emerged, though in a roundabout way. The Postmaster General, replying to a question in Parliament, has stated categorically that "B.B.C. proposals for a *frequency-modulated* very high-frequency broadcasting system are being examined." That confirms the view, expressed in *Wireless World* last month, that the B.B.C., as a result of the Wrotham comparative tests, would recommend frequency as opposed to amplitude modulation. Further confirmation to this has also been given by Sir Noel Ashbridge, Director of Technical Services of the B.B.C., in evidence before the Parliamentary and Scientific Committee. Speaking on the need for reinforcing our present broadcasting system, he said the Copenhagen Plan was not really satisfactory. The B.B.C. is in favour of f.m. because it gives wider coverage, and about 20 v.h.f. stations would be needed for the three-programme scheme already worked out—presumably for full national coverage.

So far so good. It might at least be thought we know where we stand on the question of modulation systems. But the P.M.G.'s replies to subsequent questions were made with great reserve: though he promised that the B.B.C. report would be considered as speedily as possible, he disclaimed full responsibility for acceptance or otherwise by stating that the Television Advisory Committee had to be consulted. From his reply it would rather seem that body is to be charged with the final responsibility of deciding on the system of modulation; the reply even accepted the possibility that the Television Advisory Committee might recommend a mixture of a.m. and f.m.! Though we believe the opinions of every interest concerned should be taken before decisions are reached, we are not convinced that the Television Advisory Committee is best qualified to be the final arbiter (as the P.M.G.'s reply suggested) on this important matter. Though some of the members have high scientific qualifications, the Committee as a body seems ill qualified to deal with the complex technical considerations involved.

Up to the time of writing the organized radio industry has not expressed its collective views on metre-wave broadcasting, though clearly nobody is more deeply concerned. Indeed, the problems involved are so complicated that unanimity must be difficult to reach, but no final decision can be reached without data on receiver design, production and maintenance. The industry at least need have no inhibitions in dealing with questions considered in official circles to be *sub judice*.

Finally, there is the question of control of e.h.f. broadcasting. There seems already a tendency to forget that the Beveridge Report left the door open for operation of such stations by independent bodies. While *Wireless World* certainly does not believe the future of British broadcasting to lie in sponsored or advertising programmes, we should greatly like to see the experiment of allowing a few stations to be run independently of the B.B.C. monopoly. Here at last is an opportunity to make an experiment that would surely please nearly everybody and offend hardly anybody.

Wrotham Aerial System

1—New Design of Slot-Radiator for V.H.F. Broadcasting

By C. GILLAM*

The Wrotham aerial is a high gain omni-directional v.h.f. radiator for horizontal polarisation. With its transmission line it is designed to handle simultaneously either three 25-kW f.m. transmissions or one 25-kW f.m. and one 18-kW a.m. transmission in the frequency band from 87.5 Mc/s to 95 Mc/s. The radiator consists of multiple co-phased slots fed by a branched transmission line. A "notch" type combining filter is installed for either two separate f.m. transmissions or one f.m. and one a.m. transmission.

THE v.h.f. broadcasting aerial system at Wrotham comprises a high gain omni-directional radiator, a rigid tube co-axial transmission line and a combining filter for two simultaneous transmissions. The radiator consists of an assembly of co-phased slots on the surface of a vertical cylinder which forms the upper part of a stayed mast. This mast has a total height of about 469½ ft above the ground level. The lower part, up to a height of about 357 ft is of lattice steel construction with a triangular cross section; near the top of this part there is a railed gallery. The upper part of the column is cylindrical with a diameter of 6 ft 6 in and right at the top there is a second railed gallery. The part of the cylinder forming the radiator proper is built up from eight cylindrical sections each 10 ft 6 in long, each section being made of four quarter-cylinder curved plates with angles welded on to all sides and ends. The plates and sections are bolted together through these angles and there are diametral cross struts at the section junctions. Each quarter-cylinder plate is pierced with a slot 8 ft long and 12 in wide; there are thus thirty-two slots in all, arranged in eight tiers of four slots equi-spaced around the cylinder, and with slots in successive tiers vertically above the lower ones. The television aerial support masts for the new high power stations, of which Sutton Coldfield was the first, are all provided with similar slotted columns for eventual use as radiators.

Inside the cylinder angle bars are fitted horizontally, forming a square cage about 4 ft 6 in on the side, the corners of which meet the cylinder mid-way between

* Marconi's Wireless Telegraph Company.

Fig. 1

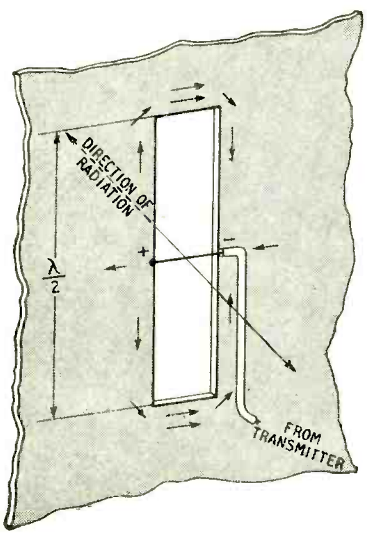


Fig. 2

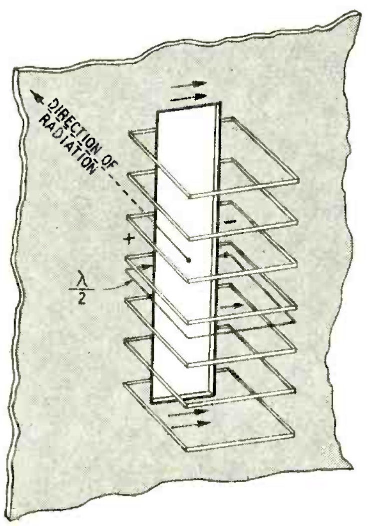


Fig. 3

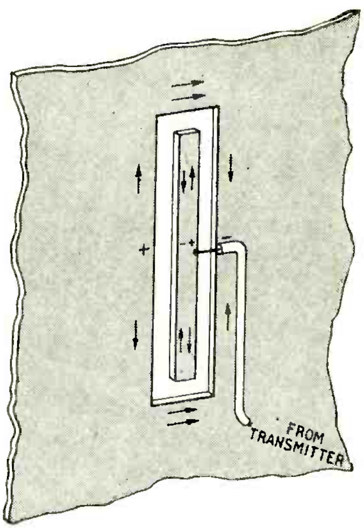
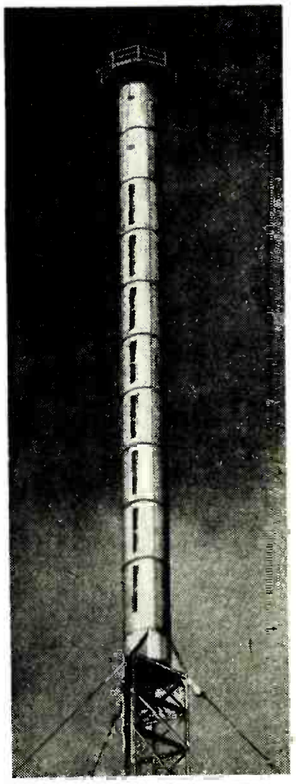


Fig. 1. Current distribution around a radiating slot in an infinite conducting plane. Fig. 2. Skeleton enclosure of horizontal loops behind a vertical slot produces uni-directional radiation and behaves as a reflector. Fig. 3. In a folded slot currents on the central bar cancel out.

the slots. The bars are spaced about 1 ft apart vertically, and they form enclosures of segmental cross-section behind each slot. The distribution feeder system is accommodated inside the square cage, and sufficient space remains for climbing up through the radiator column.

How a Slot Radiates

Slot aerials are perhaps a little unfamiliar, and at first glance it is difficult to see what they have in common with other types of aerial. The simplest view-point is to regard the slot as a means of persuading currents to flow in a desired manner in the conducting sheet in which the slot is cut, and then to consider radiation in terms of these currents. The usual slot is about half-a-wavelength long and rather narrow. It is fed by connecting a generator—or more usually the inner and outer conductors of a co-axial transmission line from a generator—across the slot lips at the centre of their length. Viewed from the feed points, the slot edges form short-circuited transmission lines a quarter-wavelength long. Such lines have a high input impedance, but a comparatively large current flows in the short-circuited ends. As will be seen from Fig. 1, rather large currents flow in the conducting sheet at the ends of the slot. There are, of course, also currents flowing in the sheet lengthwise of the slot, but as the figure shows, they flow in opposite directions on the two sides of the slot and in the upper and lower parts, so that they practically cancel each other out. The radio-frequency difference of potential across the slot lips sets up an electromagnetic field in the slot which radiates outward on both sides of the conducting sheet. This field is polarised in the plane at right angles to the slot length, that is, its electric force is in this plane. As mentioned earlier, the radiation can equally well be accounted for in terms of the currents flowing in the sheet at the ends of the slots, and it is then clear that the magnetic force is in planes lying parallel to the slot length. A slot radiator behaves in fact very much like a dipole aerial but with the planes of magnetic and electric force interchanged with respect to the length of the radiator.



A comparatively high gain in all directions is obtained with the Wrotham v.h.f. aerial by arranging the 32 slot radiators in eight tiers with four in each tier spaced equally round the circumference of the cylindrical top section.

Just as arrays of dipoles can be used to increase the directivity and gain of an aerial, so also can slots be stacked in horizontal and vertical rows for the same purpose. Another useful feature is that the slot can be turned into a uni-directional radiator by enclosing it on one side with a cavity. That this can be done is readily appreciated by considering a horizontal loop with a total length of half-a-wavelength connected from one side of the slot to the other, as shown in Fig. 2. Such a loop will have a high input impedance, i.e., it will accept very little current and so disturb only to a very small extent the conditions existing at the slot lips. Additional similar loops can be added above and below the first one, and if desired they may be put in contact with each other so that a continuous screen is formed. All radiation into the cavity so formed will then be reflected back and will reinforce the outward radiation. In fact, for this purpose the screen need not be continuous, and it is sufficient for the loops to be not more than about one-tenth of a wavelength apart. The exact cross-sectional shape of the enclosure—or skeleton enclosure—at the back of the slot is not critical; the length of path from one side of the slot mouth to the other is, however, an important factor which affects the feed-point impedance, and it needs to be near to a half-wavelength.

As would be inferred from the behaviour of a quarter-wavelength short-circuited transmission line, the feed-point resistance of a slot fed at its centre is rather high, 600 ohms being the order of value for normal proportions. However, just as the input impedance of a dipole aerial can be raised by "folding" it, so the impedance of a slot aerial can be lowered by similar means. In other words, the input *admittance* of a slot is affected by folding in the same way as is the input *impedance* of an ordinary dipole. Fig. 3 shows a folded slot, and it will be seen that the generator e.m.f. is in effect applied across only one-half of the slot width.

Returning now to the enclosed slot, the cavity behind the slot becomes filled with an electromagnetic field. This consideration leads to the converse of the previous procedure, in which a field is excited inside the cavity by any suitable means, and it then propagates out through the slot as radiation. In doing so it sets up a similar distribution of currents on the conducting sheet as would have occurred if the slot lips had been directly excited. Naturally, the field set up in the cavity must have the same character; that is, the same frequency and plane of polarisation whichever way it is produced.

Wide-Band "Folded" Slots

The Wrotham slots are fed in such a way that they behave as "folded" slots, with the result that the feed-point impedance is approximately 140 ohms, but in order to reduce the variation of feed-point impedance with frequency, a system of reactance compensation* is introduced. Each slot is fed by a co-axial feed line which terminates near the horizontal centre line of the slot in one corner of the square cage. At this point the outer conductor is earthed to the bars, while the inner conductor passes into the slot enclosure, and continues as a horizontal open conductor running just behind the cylindrical surface to a point near the horizontal and vertical centre of the slot opening. There it is joined to a vertical

* "Wide-band Folded-slot Aerials" by G. D. Monteath, *Journal I.E.E.* 97, *Part III*, p. 414.

conductor which passes upward or downward on the centre line of the slot to one end of the opening where it connects with the cylinder wall. As seen from the end of the horizontal conductor, the vertical conductor forms with the cylinder wall a half-wavelength transmission line short-circuited at its termination. At its resonant frequency, the input impedance of this line is zero, so that the end of the horizontal conductor is joined to the wall of the cylinder by a connection of zero impedance. At frequencies off resonance, this line adds a positive or negative reactance in series with the slot feed impedance. Current flows from the inner conductor of the feed line along the horizontal conductor, and returns by way of the vertical conductor to the cylinder wall and the outer conductor of the feed line. The current on the horizontal conductor sets up a radio-frequency field in the slot enclosure, which is able to emerge from the slot opening as radiation, in so far as it is horizontally polarized and the slot is resonant at the appropriate frequency.

The energy lost by radiation is supplied from the transmitter by the feed line, and there is a corresponding real term in the feed line termination impedance. Over the rather wide frequency band in which radiation is required, the feed-point impedance would vary considerably, were it not for the behaviour of the vertical conductor as a reactance compensator. Both the length and the diameter of this conductor are chosen and adjusted critically for optimum results in this respect. The horizontally polarized field is unable to pass through the horizontal bars of the slot enclosure into the square cage; but there is some vertically polarized field due to the vertical conductor, and a continuous steel strip 6 in wide is fitted to the horizontal bars behind each line of slots to prevent this entering the cage. This vertically polarized field cannot emerge from the slot opening as radiation. Because of the enclosure of the slots they have comparatively little mutual influence on each other.

Co-Phase Feeding

All the slots of the radiator are fed in identical phase. This statement, unambiguous as concerning co-planar slots, requires further elucidation when applied to slots in a cylindrical surface. It means that if observers were situated at equal distances from the cylinder axis in directions radially from each of the four slots, and if they fixed their attentions on the electric vector of the radiation emerging from the slot opening facing them, then at a given instant all observers would see the vector pointing in the same direction relative to themselves. This situation is made clear by Fig. 4. The electric vectors thus all point round the cylinder alternately in one direction and then in the other. At sufficient distance from the axis of the cylinder, the field strength is practically constant in any radial direction; that is, the horizontal radiation pattern is almost circular. If it were required to radiate a higher frequency band with a similar horizontal radiation pattern it would be necessary either to increase the number of slots around the circumference of the cylinder, or to decrease the cylinder diameter. Similarly for lower frequency bands and for the same cylinder diameter, three or two slots around the circumference would suffice, and in the limit at a sufficiently low frequency, the pattern would be nearly circular with only a single slot on one side and the radiator becomes the American-designed "Pylon."

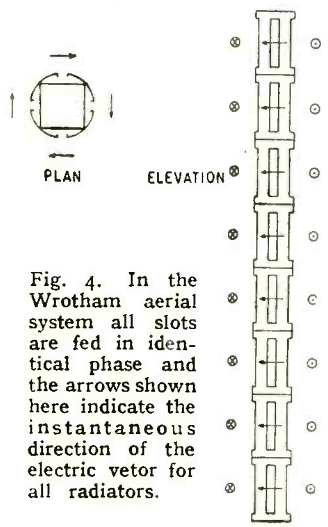


Fig. 4. In the Wrotham aerial system all slots are fed in identical phase and the arrows shown here indicate the instantaneous direction of the electric vetor for all radiators.

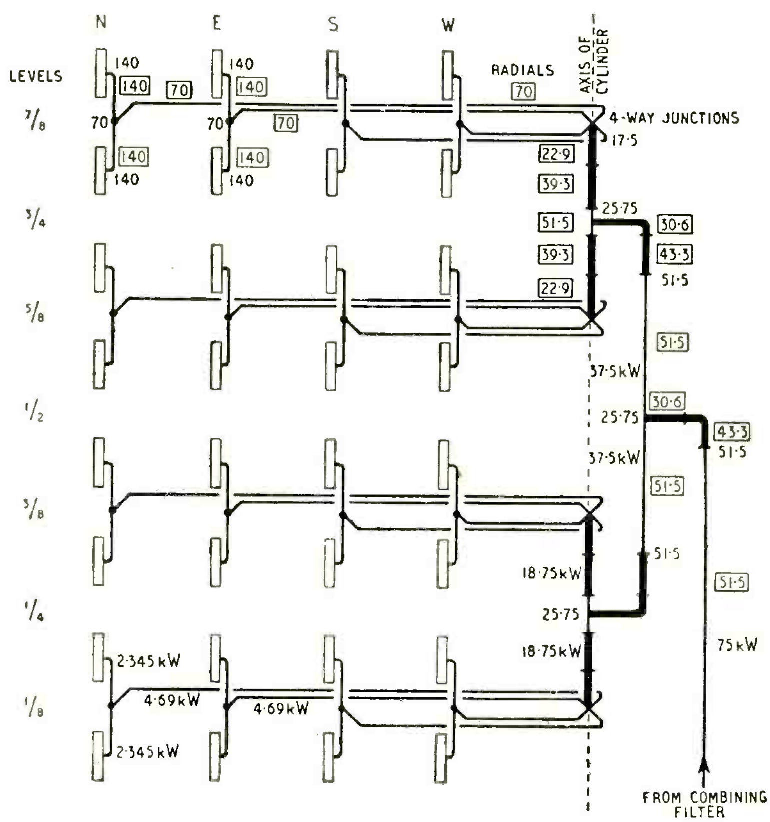


Fig. 5. Wrotham distribution feeder system with cylinder opened out into a flat plane. Radial feeders are all of equal length with point impedances shown as plain figures and characteristic impedances in "boxes."

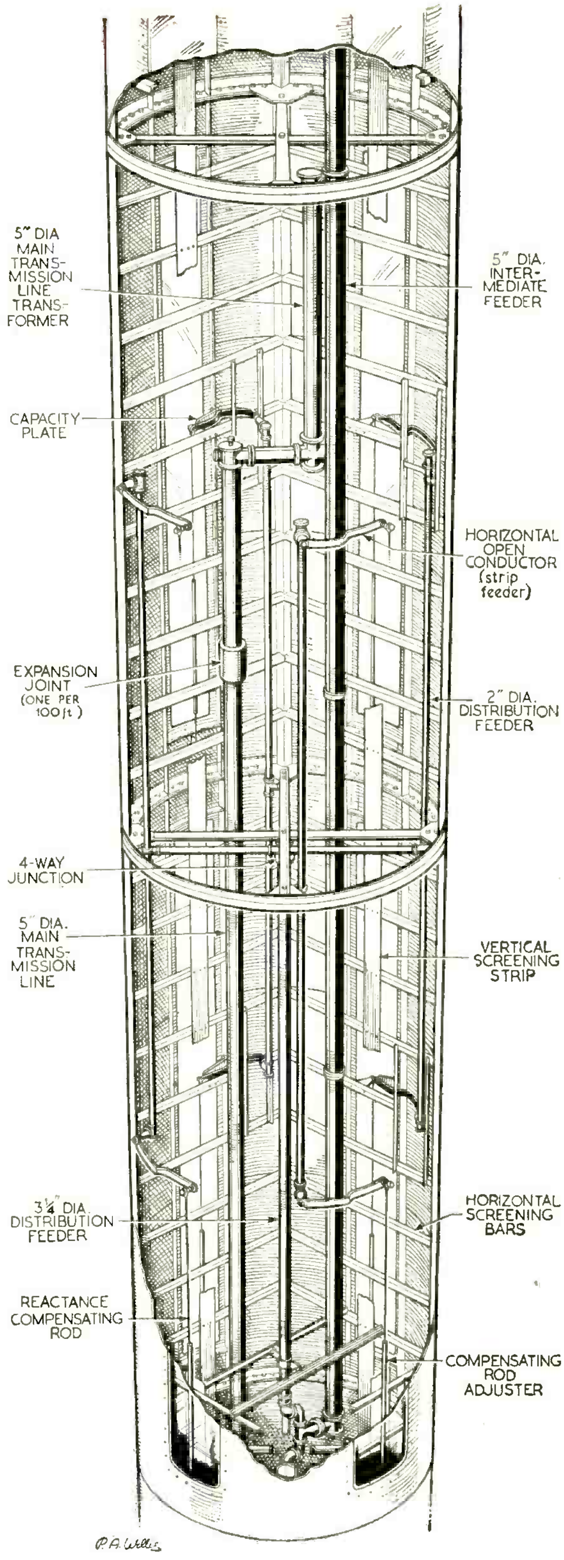
As compared to the radiation in the maximum direction from a single half-wave dipole, the assembly of four slots forming one tier of the Wrotham aerial has a gain of about unity. The stack of eight tiers then has an effective power gain of eight, or about 9 db.

The distribution feeder system is required to divide the transmitter power equally among the thirty-two slots, and to deliver it to the feed-points in equi-phase. This is accomplished by successive bifurcation of the feeder, with impedance matching at each junction, and with all paths from the first bifurcation to the slot feed-points of exactly equal lengths. There are more ways than one in which the slot feeds might have been progressively combined. At one extreme there could have been a single junction point with thirty-two feeders of equal length; apart from mechanical difficulties, an impedance transformer working from the very low resistance value of about 4.4 ohms would have been formidable. In the opposite direction, the slot feeds could have been combined first in pairs, then in fours, then in eights, and finally in sixteens, and there would still have been plenty of choice as to whether to start with vertical pairs, side-by-side pairs, or opposite pairs, and so on. The method finally adopted had little beyond a certain convenience to recommend it. It is shown diagrammatically in Fig. 5, which represents the cylinder as if it were slit down one side and opened out into a flat sheet. The individual feed-point impedances are about 140 ohms each. The slots are first combined in vertical pairs by 2-in diameter lines of 140 ohms impedance, running vertically near the corners of the square cage. At their centres these lines tee into 2-in diameter 70-ohm lines running radially from a central four-way junction box. The impedance at the input to this junction is then 70/4 = 17.5 ohms, and it feeds a group of eight slots. There are four similar junction boxes at levels corresponding to $\frac{1}{8}$, $\frac{3}{8}$, $\frac{5}{8}$ and $\frac{7}{8}$ of the radiator height.

Impedance Matching Transformers

Double quarter-wave transformer sections are joined directly to the junction boxes, and run alternately upward and downward along the axis of the cylinder; these transform the impedance to 51.5 ohms, and the lines are continued at an impedance of 51.5 ohms until they meet at tees at the $\frac{1}{4}$ and $\frac{3}{4}$ levels. These lines and transformers have an outer diameter of $3\frac{1}{4}$in. At the tees, the impedance drops to 25.75 ohms, and it is restored to 51.5 ohms again by further double quarter-wave transformers. Here again, the lower transformer points upward and the upper one downward, and they are continued by 51.5-ohm lines until they meet at the final tee at the vertical centre of the radiator. This intermediate feeder and its transformers have an outer diameter of 5in. At the final tee the main transmission line is connected through a further double quarter-wave transformer. On Fig. 5 point impedances are indicated by plain figures, and the characteristic impedances of the various parts of the feeder system, including the transformer sections, are indicated by a figure in a rectangle. All parts of the distribution feeder system are in rigid copper co-axial lines, with ceramic insulators throughout. It should be noted that the references above to the "outer" diameters of the feeders, transformers, etc., refer to the *inside* diameter of the outer conductors.

Since at every branch point the branch impedances are identical, the power divides uniformly between the



The main transmission line and part of the distribution system to the 32 slots in the aerial cylinder are shown in this cut-away view.

branches and eventually every slot receives an equal proportion of the total power. The complete aerial system was required to deal with up to three simultaneous f.m. transmissions on different frequencies in the band, each with a power of 25 kW. Thus the total power input to the radiator could be 75 kW and the power per slot 75/32 kW = 2.34 kW. These are the figures which control the conductor sizes from the view-point of r.m.s. current to be carried and heating. For example, the slot-feed-point impedance is 140 ohms, and so the r.m.s. current at that point is $\sqrt{\frac{2340}{140}} = 4.09$ A. In providing adequate flash-over distances, however, it is necessary to take account of the fact that the voltages of the separate transmissions can at particular instants add in phase to give a voltage three times as much as for one 25-kW transmission, and hence equivalent to an instantaneous power of 9×25 kW = 225 kW. All parts of the main transmission line and distribution feeder system were designed to carry voltages equivalent to this instantaneous power with an adequate safety factor. Fortunately there were no very serious problems in this respect; the corresponding r.f. voltage peak on the main 5-in 51.5-ohm transmission line is 4812, and at the slot feed point 1400.

In order to meet the very low standing wave ratio specified for the complete aerial system, it was necessary to divide the frequency range from 87.5 Mc/s to 95 Mc/s into two over-lapping parts, and to provide for separate adjustments at the slots. Thus, with one set of adjustments the range from 87.5 Mc/s to 93 Mc/s can be covered, and with the alternative adjustments from 89 Mc/s to 95 Mc/s. Over both parts of the range the standing-wave ratio measured at the input of the main transmission line transformer is less than 1.1. An explanation of the wide-band impedance compensating action of the double quarter-wave transformer is given in Appendix 1.

(*To be concluded*)

APPENDIX 1

Double Quarter-wave Transformer

If a quarter-wavelength of transmission line with a characteristic impedance of Z_o is terminated by a resistance of value nZ_o, then the input impedance of the line is a resistance value of $Z_o^2/nZ_o = Z_o/n$. Alternatively, if a resistance of nZ_o ohms has to be matched to a line of characteristic impedance Z_o ohms, a quarter-wavelength of line of characteristic impedance $Z_1 = \sqrt{Z_o \cdot nZ_o} = Z_o\sqrt{n}$ is interposed. The input impedance of this line is then $Z_i = Z_1^2/nZ_o = Z_o^2 \cdot n/nZ_o = Z_o$, i.e., the required value for match. This is demonstrated on the Smith Chart Fig. 1. Here n is taken as 0.5 and the point P_1 represents the value nZ_o; Z_1 must be made equal to 0.707 Z_o, and P_1 has to be "normalised" to this value, giving $\frac{nZ_o}{Z_o\sqrt{n}} = \sqrt{n}$ = 0.707 shown at P_2.

At the other end of the quarter-wavelength line P_2 becomes $P_3 = 1.414$. This value has to be renormalised to Z_o, i.e., $\frac{1.414 \times 0.707 \times Z_o}{Z_o} = 1$

This is satisfactory enough at the single frequency for which considerable improvement. For this, the first line has a characteristic impedance $Z_1 = \sqrt[4]{(nZ_o^3)Z_o} = Z_o\sqrt[4]{n^3}$ and the second line has a characteristic impedance $Z_2 = \sqrt[4]{nZ_o \cdot Z_o^3} = Z_o\sqrt[4]{n}$.

At the end of the first length, the impedance is then $\frac{Z_o^2\sqrt{n^3}}{nZ_o} = Z_o\sqrt{n}$, and at the end of the second length, $\frac{Z_o^2\sqrt{n}}{Z_o\sqrt{n}} = Z_o$, giving the required match.

This is shown again on the Smith Chart Fig. 3, for the values in the earlier example. P_1 is as before.

$Z_1 = Z_o\sqrt[4]{0.5^3} = 0.595\ Z_o$, so that P_2 is at 0.5/0.595 = 0.84. P_3, at the junction between the lines is, 1/0.84 = 1.19 in terms of Z_1.

$Z_2 = \sqrt[4]{0.5} = 0.84$. Renormalising P_3 to Z_2 gives $P_4 = 1.19 \times 0.595/0.84 = 0.84$. P_4 thus superimposes on P_2, and at the end of the second line, $P_5 = 1/0.84$ = 1.19 in terms of Z_2. Finally renormalising to Z_o gives $1.19 \times 0.84 = 1$.

Again consider a higher frequency, f_1, for which both

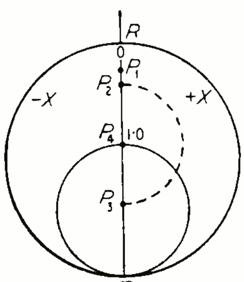


Fig. 1

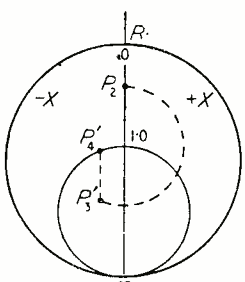


Fig. 2

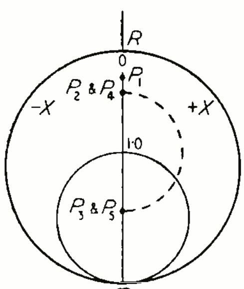


Fig. 3

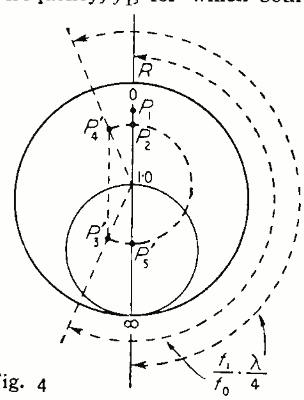


Fig. 4

the length of Z_1 line is exactly a quarter wavelength. At a higher frequency, the line has a greater length, so that the P_3 point finishes beyond the resistance axis at, say P'_3, on Fig. 2, and this when renormalised becomes P'_4, which certainly does not match Z_o.

Using a double quarter-wave transformer effects a transformer lines are above a quarter-wavelength long. P_3 on Fig. 4 is now beyond the R axis at P'_3, and when renormalised, it goes to P'_4, still to the left of the R axis. But the second line length now brings this to P'_5, almost exactly on the R axis again, and final renormalising to Z_o shows an almost perfect match.

Audio-Frequency Valve Voltmeter

Direct Readings of Inputs from Millivolts to Volts

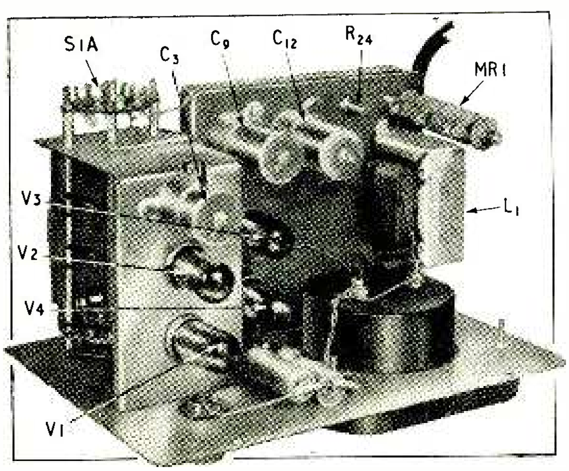
By S. KELLY*

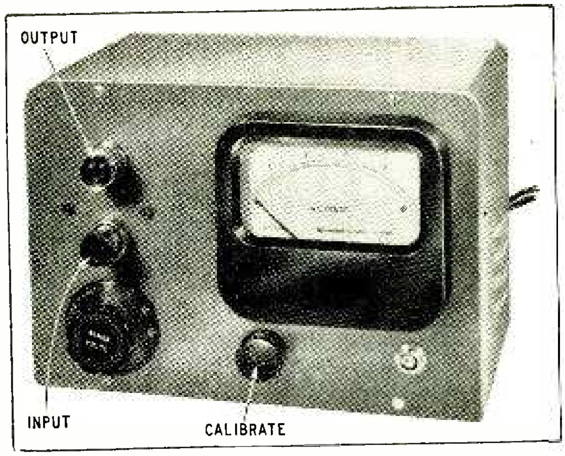
VALVE voltmeters have long been considered essential pieces of laboratory test equipment their chief merit being a high input impedance which has enabled them to be used on circuits where the loading of moving-coil, moving-iron instruments etc. draws too much current to give accurate readings. Generally, the emphasis has been towards high frequencies at moderately high voltages; and the audio engineer, with some justification may feel neglected.

The requirements of the audio laboratory are somewhat different from those predominating in the radio frequency sections. In addition to a high input impedance, high sensitivity and a very good low frequency response are necessary. For example, present day high-fidelity moving-coil pickups give outputs of only a few millivolts. the conventional valve voltmeter cannot be used unless a pre-amplifier is fitted to it, and even then there may be some doubt about the calibration at very low frequencies. There are numerous other measurements, such as measuring the insertion loss of filters, attenuators, transformers, which all demand a sensitive valve voltmeter. Investigation of loudspeaker problems can often be considerably simplified if a response curve of the acoustic output can be made in addition to the more usual voice-coil impedance tests, and even an uncalibrated microphone connected to a sensitive voltmeter will provide much useful information.

* Cosmocord Ltd.

Layout of parts is not critical, but screening should be provided between V1, V2 and V3, V4, and the switch wafer (S1C) associated with the calibrating circuit should be outside the V1, V2 screen.





General view of finished instrument.

The instrument described in this article is designed to meet the above requirements, the specification being:

Voltage Range: 1 millivolt to 10 volts in four decades of 0-10 millivolts, 0-0.1 volt, 0-1 volt, and 0-10 volts.

Input impedance: To be greater than 10 MΩ across 10 pF.

Output impedance: To be less than 500 ohms.

The unit to be self-calibrating, easily portable and capable of being built with standard components.

Design

The instrument consists, essentially, of a two-stage RC-coupled feedback amplifier, with a fixed gain of approximately 60 db, the gain being primarily determined by the feedback network; and an input and output stage, each consisting of a cathode follower; the input cathode follower being necessary to enable a high and a constant input impedance irrespective of range switching, and the output to provide a low output impedance in order to enable a wide choice of indicating instruments to be used. The complete circuit diagram is given in Fig. 1. Range switching is achieved by fitting a potential divider in the cathode circuit of the first cathode follower; it may be mentioned here that the only precision resistors required are used for range switching in this cathode circuit. An alternative system, is also described which will permit the use of standard radio tolerance resistors.

Calibration is effected by arranging for the output voltmeter to read the filament voltage (Cal. 1), and for the filament voltage then to be switched to the input of the amplifier (Cal. 2), the feedback potentiometer being adjusted until the two readings are identical. It will be seen that the accuracy of calibration will be determined solely by the output voltmeter and not the long-term stability of the amplifier.

The power supply is conventional, a 250-V half-wave rectifier system being used. The components are the same as those specified for the *Wireless World* " Midget A.C. Mains Receiver " and are obtainable from Stern Radio, 109 and 115 Fleet Street, London, E.C.4. No trouble has been experienced when using this transformer, and although the filament circuit is somewhat overrun, the temperature rise is not excessive. The power supply is not critical, and any well-smoothed unit giving 200 to 300 V at 20 to 30 mA is satisfactory. Fig. 2 shows an alternative power supply using 250-0-250-V, 30-mA transformer with a valve rectifier, the smoothing consisting of two 10-henry chokes and three 16-μF condensers in place of the 40-henry choke and the 32 + 16 μF. condenser used with a half-wave rectifier. The constructor should not experience any difficulty in obtaining the very reasonable amount of smoothing required from standard components. With either of the power supply circuits shown, the smoothing is adequate when the valve voltmeter is used with either moving coil or crystal microphones. The "humdinger" potential divider R_{21} has been found essential when operating the filament of the first two valves from a.c.; it is a pre-set unit fixed to the chassis, and should be adjusted (with the amplifier in its cabinet and a shield connected over the input socket) for minimum voltmeter reading, which should never be more than the first division of the scale.

Electrostatic Screening

The layout of the amplifier is not critical, provided that the following points are observed: The input impedance of the amplifier is extremely high and is therefore very sensitive to any stray electrostatic fields. It is essential that the whole amplifier be contained in a completely shielded metal container and that preferably V1 and V2 should be in their own shielded compartment. If the self-calibrating circuit is used, the wafer (S1C) carrying the filament supply

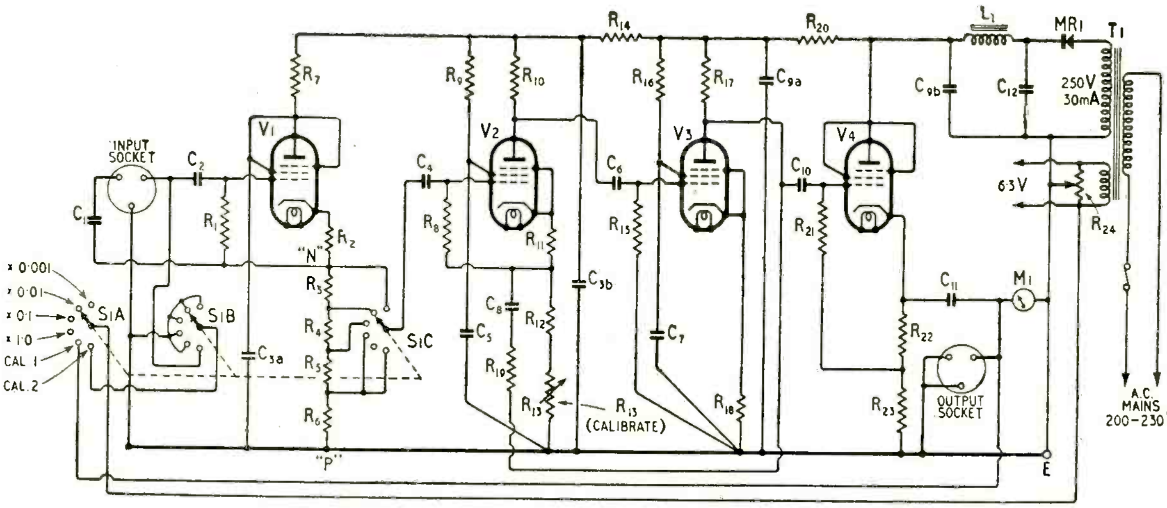


Fig. 1. Complete circuit diagram of valve voltmeter in its original form. Alternative range switching and power supply circuits are given in Figs. 2 and 3.

List of Components

Resistances:

R_1	—	$\frac{1}{4}$ W*
R_2	3.3 kΩ	$\frac{1}{4}$ W
R_3	50 kΩ	1 W* 1%
R_4	5 kΩ	1 W* 1%
R_5	500 Ω	1 W* 1%
R_6	55.5 Ω	1 W* 1%
R_7	50 kΩ	1 W(w.w.)
R_8	0.47 MΩ	$\frac{1}{4}$ W
R_9	0.47 MΩ	$\frac{1}{4}$ W
R_{10}	100 kΩ	$\frac{1}{4}$ W
R_{11}	100 Ω	$\frac{1}{4}$ W
R_{12}	50 Ω	$\frac{1}{4}$ W
R_{13}	50 Ω	Variable
R_{14}	20 kΩ	$\frac{1}{2}$ W
R_{15}	0.47 MΩ	$\frac{1}{4}$ W
R_{16}	0.47 MΩ	$\frac{1}{4}$ W
R_{17}	100 kΩ	$\frac{1}{4}$ W
R_{18}	100 Ω	$\frac{1}{4}$ W
R_{19}	100 kΩ	$\frac{1}{2}$ W
R_{20}	10 kΩ	2 W (w.w.)
R_{21}	0.47 MΩ	$\frac{1}{4}$ W
R_{22}	330 Ω	$\frac{1}{2}$ W
R_{23}	10 kΩ	2 W(w.w.)
R_{24}	50 Ω	Variable
R_{25}	39 kΩ	$\frac{1}{2}$ W
R_{26}	10 kΩ	Variable
R_{27}	2 kΩ	Variable
R_{28}	3.3 kΩ	$\frac{1}{2}$ W
R_{29}	200 Ω	Variable
R_{30}	330 Ω	$\frac{1}{2}$ W
R_{31}	20 Ω	Variable
R_{32}	39 Ω	$\frac{1}{2}$ W

Capacitors:

C_1	0.1 μF	250 V
C_2	0.01 μF	250 V
C_3	16 + 16 μF	350 V
C_4	0.25 μF	250 V
C_5	0.25 μF	250 V
C_6	0.25 μF	250 V
C_7	2 μF	250 V
C_8	2 μF	250 V
C_9	16 + 16 μF	350 V
C_{10}	0.25 μF	250 V
C_{11}	4 μF	250 V
C_{12}	16 + 16 μF	350 V

Miscellaneous:

L1	40 H, 30 mA choke
MR1	250 V, 30 mA rectifier
T1	Stern Radio 653 M.
M1	0-10 volt, a.c. meter*
V1	EF42
V2	EF42
V3	EF42
V4	EF42
V5	EZ41
L2	10 H, 30 mA choke
L3	10 H, 30 mA choke
T2	250-0-250 V, 30 mA, 6.3 V 1.2 A, 6.3 V 1.0 A
Plugs	Belling Lee L715P
Sockets	Belling Lee L715S

Tolerances, unless otherwise stated: Resistors, ± 10 per cent., paper capacitors, ± 20 per cent., electrolytic capacitors, + 50 per cent, − 0 per cent.

* See text; w.w. = wire wound.

to the calibrating circuit must be outside the shield containing V1 and V2. The photograph of the chassis illustrates this point. It will be seen that the chassis is made in two parts. This precise construction need not necessarily be followed, but it is an easy method of ensuring adequate shielding between V1, V2, and V3, V4. The cathode resistances of V1 are carried on a small panel fixed to the range switch, with a shield behind.

The heater leads should be twisted and preferably shielded, and the " humdinger " should be the only earthed point in the heater circuit. Earth leads should be short and preferably close to the socket of the valve in question and, in the interests of low noise and stability of calibration, the resistances in the cathode circuits of V1 and V4 should be wire-wound. As stated before, the accuracy of the instrument is determined principally by the potential divider in the cathode of V1 and the accuracy of the output voltmeter, and the values specified should be obtained to limits of 1 or 2 per cent. Ordinary carbon resistances should not be used, although cracked carbon high-stability or wire-wound resistances are satisfactory. R_6 can be made from a 56-$\Omega \pm 1$ per cent and a 6800-$\Omega \pm 5$ per cent in parallel.

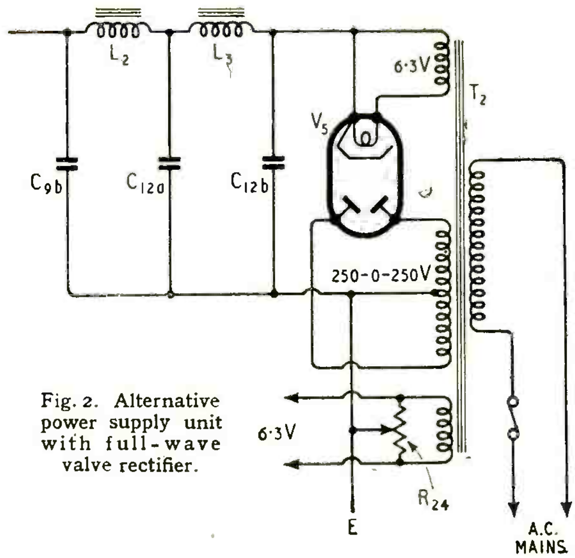


Fig. 2. Alternative power supply unit with full-wave valve rectifier.

Alternative Potential Divider

An alternative to these precision resistances is to use the circuit in Fig. 3. Here ordinary 10-per cent. carbon resistances are used, with wire-wound potential dividers of the values specified. The setting up of this resistance chain should not present any difficulty. The 10,000-Ω variable R_{26} is adjusted so that the total resistance between " N " and " P " is exactly 50,000 Ω. The 2,000-Ω resistance R_{27} is then adjusted to give 4,500 Ω between " P " and " 3 " on " S1C," the 200Ω resistance to give 450 Ω between " P " and " 4 " and the 20-Ω to give 50 Ω between " P " and " 5." If these values are set accurately, further readjustments should not be needed for setting up the range scales, but, where possible, the range calibration should be checked by means of an accurate attenuator.

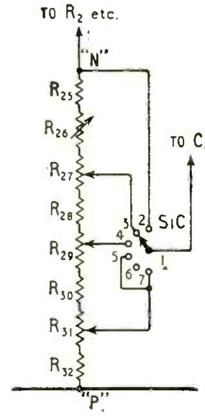


Fig. 3. Ordinary 10-per cent tolerance carbon resistors with series pre-set potential dividers can be used instead of the precision resistors used in the cathode circuit of V1 in Fig. 1.

The input impedance of the amplifier can be considerably reduced if material of high power factor is used for the insulation of the input socket, and this dielectric should consist of, preferably, polythene or high-grade low-loss bakelite. Input terminals should not be used unless the shielding is maintained over the high-potential terminal, otherwise erroneous readings will be obtained because of hum pick-up. It will be seen that the third terminal of the socket is connected through a condenser to the cathode at V1. This will enable double-shielded cable, say Telcon Type K16MYM, to be used, and thus maintain the high input impedance of the voltmeter on the end of, say, 2 or 3 ft. of cable.

The measured input impedance of the amplifier $\omega = (2\pi f) = 10^4$ was 20 MΩ in parallel with 5 pF when connected directly to the 0.01-μF input condenser and $R_1 = 0.56$ MΩ. Increasing R_1 to 1 MΩ increased the input impedance to 33 MΩ with the same input capacitance. A three-pin socket using bakelite insulation reduced the input impedance to 12 MΩ and the input capacitance to 10 pF. Connecting the wafer " S1B " of the range switch to the input further increased the capacitance to 15 pF and reduced the input impedance to 6 MΩ. Substituting a polythene input socket for the bakelite one, and a ceramic wafer in " S1B " gave final values of 75 MΩ and 10.5 pF when $R_1 = 5.6$ MΩ, and 0.15 MΩ and 10 pF when $R_1 = 0.56$ MΩ.

Valve Holders

The above results were obtained when using a mica-loaded polystrene valve socket and with the input coupling condenser freely suspended. It is essential that a low-loss plastic or a ceramic type socket be used for V1, V2 and V3. It has been found that ordinary wood-flour loaded bakelite type sockets give rise to excessive hum. Substituting an SP61 valve for V1 and taking care that the glass envelope is clean round the grid, and making the grid resistance 5.6 MΩ, resulted in an input impedance in excess of 100 MΩ and an input capacitance of 3 pF. From the foregoing it will be seen that if an input impedance in excess of 10 MΩ is required, great care will have to be exercised in the type of materials used in the input circuit of V1. Using a bakelite input socket and 0.56 MΩ grid resistance and connecting a capacitance of 1,000 pF between the grid and cathode of V1, and 1,000 pF between V1 cathode and ground, thus simulating about 25ft of double-shielded cable, resulted in an input impedance of 5.6 MΩ and 60 pF against 5.6 MΩ and 15 pF directly at the valve voltmeter. From this it will be seen that to all intents and purposes the loading effect of a double-shielded cable may be neglected.

This particular instrument uses Mullard Type EF42 valves, but the valve line up is not critical; a total of 20 instruments have been built during the last three years for use on factory production and laboratory test equipment, and EF50's, EF91's, EF80's, SP41's and SP61's have all been used successfully in various instruments without any material circuit modifications. As designed, the amplifier will be flat within 0.2 db between 20 c/s and 20,000 c/s, and the final calibration accuracy is governed almost entirely by that of the output voltmeter. The measured overall frequency response of this instrument when fed from a 600-Ω source is flat from 20 c/s to 20,000 c/s ± 0.2 db, and is 1 db down at 15 c/s and at 100,000 c/s. The low-frequency response can be improved by increasing the value of the 4 μF output coupling condenser, but an electrolytic condenser should not be used. The measured output impedance at $\omega = 10^4$ is substantially resistive and is 120 Ω.

Although a rectifier type 1,000 ohm/volt, 0–10-V. a.c. meter is specified, any similar type of instrument within reason may be used—say 0–5 V. or 0–20 V., depending on the constructor's requirements, and the instruments he has available—or the unit may be built up solely as a decade amplifier, the output being connected to a universal test set. It should be noted at this point that the meter should not consume more than 2 mA full scale, otherwise the accuracy will be affected at low frequencies due to the reactance of the coupling condenser in the output circuit. A word of warning may be uttered here: that the coupling condensers must be beyond reproach.

TELEVISION AERIALS

Two-Station Reception

WOULD-BE viewers living on the fringe of that segment of the Sutton Coldfield television area which will come within the range of the Holme Moss transmitter are naturally interested in the possibility of using a Channel 2 (Holme Moss) aerial to receive temporarily Channel 4 transmissions from Sutton Coldfield or *vice versa.*

A series of measurements have been carried out by Antiference, Ltd., to establish the difference in vision signal when aerials designed for one channel are used on another, and the figures are given in the accompanying tables.

It will be noted that with certain types of aerial the directivity is reversed and the maximum response is obtained when the reflector element is nearest to the transmitter. This is because the change in wavelength is so large that in the case of Channel 4 aerials the reflector acts more efficiently as a director. In the case of Channel 2 aerials, any director elements work more efficiently as reflectors.

It should be emphasized that the figures given relate only to the vision frequency in each case (Channel 2, 51.75 Mc/s; Channel 4, 61.75 Mc/s). The response of the various arrays over the band for which they are designed is arranged to give full picture definition. The polar diagram is also designed to provide maximum interference reduction. It is also emphasized by Antiference that when aerials are used on an incorrect channel, both bandwidth and polar diagram become greatly inferior, and some loss of both definition and directivity must be expected.

Table 1

Relative response of Channel 4 aerials when used on Channel 2—

Single dipole	− 6.6 db
Reflector and dipole	− 21.7 „
Reflector and dipole reversed	− 11.3 „
"Antex"	− 6.4 „
Reflector, dipole and director	− 16.6 „
Reflector, dipole and director reversed	− 10.9 „

Table 2

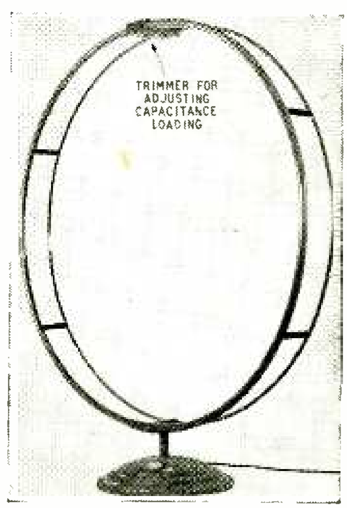
Relative response of Channel 2 aerials when used on Channel 4—

Single dipole	− 5.0 db
Reflector and dipole	− 6.5 „
"Antex"	− 15.2 „
"Antex" reversed	− 11.6 „
Reflector, dipole and director	− 17.3 „
Reflector, dipole and director reversed	− 12.6 „

Circular Indoor Aerial

THE unusual shape of the Q5R9 loop television aerial made by The Richard Maurice Equipment Company, of Portsmouth Road, Cobham, Surrey, is not an artistic feature designed to please the eye, but has a definite technical purpose in making the aerial very suitable for indoor reception. It is actually a folded dipole formed into a circle (diameter, 24in London or 19in Midlands) with a 2 to 1 conductor ratio and capacitance loading between the two ends. Apart from the reduction in size and feed impedance achieved by this arrangement, an important feature of the aerial is its marked directivity at right angles to the plane of the loop (unlike a d.f. loop), which, of course, enables interference to be balanced out. It has a figure-of-eight polar diagram and is claimed to have twice the gain of a normal indoor television aerial, permitting reception up to 25-30 miles.

Constructed from aluminium tubing and mounted on a swivel base, the aerial is supplied with 10ft of twin feeder and costs £2 18s.



London model of the Q5R9 aerial.

LETTERS TO THE EDITOR

The Editor does not necessarily endorse the opinions expressed by his correspondents

Broadcasting of Records

IN recent months "Diallist" has been mildly indicting the B.B.C. on two counts:

(a) that an excessive number of gramophone recordings is broadcast, and

(b) many of these recordings are of indifferent quality.

I believe there is a considerable body of opinion against the present excessive employment of recordings; some of the objections have been articulated in the lay press, usually on psychological grounds.

It is apparent that the programme-building authorities have been persuaded that recordings are quite indistinguishable from "live" broadcasts, and that the presence of a recording is not a factor which need weigh in organizing programme layout.

Nothing could be further from the truth. With a high-quality equipment, good to say 12 or 14 kc/s, it is possible to detect, without exception, when a recording is being used, even when the recording is the best which the B.B.C. can achieve. I have also made tests with the co-operation of non-technical friends, and they also have achieved a remarkably high proportion of successes in judging whether or not the programme was recorded. Even with a commercial set of fairly good quality it is possible to detect recordings in nearly all instances.

This detection is not a matter of hypercritical analysis; it is usually only too evident, manifesting itself even to the non-technical listener as "roughness" or "lack of intelligibility." This loss of intelligibility is often quite serious during plays, discussion programmes and the like.

It is not only at higher frequencies that the defections of recordings are evident; with a good low-frequency reproducer I have often found it necessary to insert l.f. attenuation to counteract motor rumble. The transmitted quality of commercial recordings falls far short of what one can achieve in the home.

Finally, let me plead for a greater measure of co-ordination between the artistic and engineering functions in the playing of commercial recordings. Quite frequently we are condemned to listen to bad pressings of recordings when it is known from personal experience that good copies do exist.

Again, we often find that indifferent old recordings of standard works are used when several excellently recorded modern versions are available. I am not impressed by excuses that might be advanced to explain this away.

Singapore. E. JEFFERY.

"Bass Without Big Baffles"

WITH reference to the article by K. A. Exley in your April issue, my reaction is that the surest way of producing realism is to render to the ear that which it should naturally hear.

In the old days of short horn loudspeakers, one could readily follow organ pedal passages from the harmonics which filtered through and could even tell when drums were being banged. No one would say that these results were either realistic or pleasant. Organ builders, for many years, have produced 32-ft effects by employing pipes speaking at harmonic pitches, but, as far as I know, it has never been claimed that these are equivalent to the real thing. They are effects which, owing to the harmonics so produced, class themselves into the 32-ft category. A "resultant bass" is often produced by several pipes sounding at harmonic intervals (not in unison, by the way) and the result is a 32-ft subjective effect, but without the "weight" which it would have were the fundamental present. An "acoustic bass" is normally just 2nd and 3rd harmonics only. Certain tones such as trombones, strings and other reeds have little or no fundamental in their make-up, but with tubas, diapasons and flutes a sounding fundamental is necessary. One of the defects of certain makes of electrophonic organs is that the 16-ft basses are practically devoid of fundamental.

The ear is sensitive to difference tones which are innocuous at normal strength; unnatural sub-tones, however, are most disagreeable. With the use of the tempered musical scale the modulation products of two or more notes (other than octaves) would be dissonant.

The circuit given by Dr. Exley, however, is very interesting and worth trying out, as, who knows, a curious pseudo bass may be better than none at all.

The John Compton Organ Co., London, N.W.10. L. E. A. BOURN.

"Grouped Component References"

L. BAINBRIDGE-BELL'S efforts (your March issue) to obtain clearer circuit diagrams are always interesting. With regard to the location-strip method, it may not be known generally that this has been used consistently by Philips and Mullard for a long time. The earliest example known to me is the circuit for the Philips 575A receiver, dated May, 1935. Other firms may have used this method before 1939, but I have not found any examples.

The component references are grouped in three lines: inductors, capacitors, resistors. This emphasis on inductors may seem strange, but somewhere in the Philips design team there has always been a love of inductors (of high degree). These are used to good effect, in greater numbers than in many conventional designs.

The total of inductor references is increased by Philips in another way, which is worthy of general consideration. Every winding is given a separate reference, whether forming part of a tuned circuit, an r.f. or a.f. choke, a power transformer, speaker transformer or speech coil. A tapped secondary of an i.f. transformer is referenced as two inductors in series, thus enabling data in text to be applied to the correct part of the winding without ambiguity. A tapped resistor is dealt with similarly as two or more resistors in series, though in the special case of a carbon track volume control with an additional fixed tapping, the parts are usually referenced, for example, as R9, R9A.

There are thus no circuit references for chokes or transformers as such, and the miscellaneous references are much reduced. In the Philips 575A the inductor references total 40, and the only miscellaneous items are lamps, switches, tuning meter and valves.

In present-day Philips and Mullard data, similar location strips are used for chassis layout diagrams, and with the compact and complex nature of modern designs, these are a great help in identifying small components.

West Mersea, Essex. W. H. O. BANHAM.

Over-Centralization?

I AM a Glaswegian, and I have always thought that Glasgow was as enterprising as any other city. However, I have now to modify my ideas somewhat, in regard to wireless matters.

I intend buying a high-quality amplifier and a tuner unit, such as are advertised in the *Wireless World*, and while all of the manufacturers to whom I have written have provided me with adequate data regarding their products, reading a pamphlet is an entirely different matter from actually hearing an instrument.

With one exception, I have been unable to find a firm in Glasgow where I can hear any or even one of the well-known high-class amplifiers and/or tuners, whereas I see advertised in your journal shops in London where *all* the above instruments can be heard and compared.

To what then can we attribute this situation? Are the manufacturers themselves to blame for not ensuring that their products are displayed, by suitable agents, in a city as large as Glasgow?

Glasgow, N. L. MACNAUGHTON.

Cathode Follower Circuit

REFERRING to S. H. Finn's letter in the May 1951 issue, I have for the past three years been using a home-built receiver in which the diode detector precedes a cathode follower. The arrangement has all the advantages he describes. In fact, as pointed out in an article by W. T. Cocking in the same issue, the importance of a high ratio of a.c. to d.c. load impedance is often exaggerated, but it is worth while making this ratio as large as possible.

A few other details of the receiver may be of interest. It employs four tuned circuits (500-1,500 kc/s), with two EF50 r.f. amplifier valves, the diode is an EA50, while the cathode follower is another EF50 (triode-connected). The audio frequency amplifier employs a tone control system previously described in *Wireless World* by G. N. Patchett, and the output stage consists of a pair of DA30 valves capable of delivering an output of 25 W to a matched load. The output valves are transformer coupled to the preceding stage (push-pull 6SN7 valves), and a large amount of negative feedback is employed.

I have not bothered to make particular measurements on the receiver. The quality of reproduction is quite reasonable, the selectivity is adequate except sometimes after dark on the Light Programme frequency, while the hum and noise levels are so low as to be quite negligible.

London, S.W.15. F. BUTLER.

Television Licences

THE suggestion of "Free Grid" (your March issue) about gradual payment of the television licence has been practised in Holland for several years.

Every listener has a card with space for 12 stamps, which can be bought at any post office for approximately 2s each. Every month a stamp must be bought and at the end of the year the card should be taken to the post office for renewal. M. J. J. BRONS.

Southsea, Hants.

A.M. and F.M. in Mobile Services

I WOULD like to comment on two letters in your recent issues

In a previous letter I pointed out that Major Armstrong's statement that f.m. was universal in mobile services was not correct. I pointed out that f.m. was anything but universal in the land mobile field in Great Britain, that it was not universal in the marine mobile field, and that, on the contrary, a.m. was universal in the air mobile field.

In defence, Major Armstrong says that his original statement was addressed to the American reader, and dealt with conditions in the U.S.A. The statement did not make this clear, and it did not confine itself, as it should have done, to the land mobile field in the U.S.A.

I can only express my surprise that it did not occur to either Major Armstrong or to the editor of *Tele-Tech* that the statement would be widely read, and, consequently, misinterpreted in countries other than the United States.

H. N. Gant in his letter (your March issue) has not given the correct reason for the overwhelming predominance of a.m. in the mobile field in Britain. At least two leading British manufacturers have been offering mobile f.m. in the home market for the past five years. If the advantages of the system are to take longer than this to assert themselves, they must, in my opinion, be rather obscure. Over that period f.m. has had every opportunity to prove its virtues to the hundreds of users who have demanded and received competitive trials. I do not know of any such demonstration where a.m. had the advantage of higher power. Contrary to what Mr. Gant says, a.m. has been slightly cheaper than the equivalent f.m., but I do not think that price has been a main factor.

I would conclude by assuring him that my firm does not screen vehicle wiring in a.m. installations. One suppressor is sufficient. J. R. BRINKLEY.

Pye, Ltd.,
Cambridge.

What is a Polar Diagram?

IN your March issue on page 105 appears a graph with the caption "Polar diagram of radiation." This, strange to say, is plotted in Cartesian co-ordinates with decibels as ordinates and abscissæ as angles.

May I protest against this indifference to the meaning of words? A polar diagram is plotted by setting out radial distances from a *pole* (whence the name): It does *not* mean any type of graph in which the independent variable is an angle.

L. BAINBRIDGE-BELL.

Haslemere, Surrey.

"Thermal Soldering Shunt"

REFERRING to P. F. Duncan's article in your February issue, I always use an old jeweller's trick for localizing the heat and stopping it from running up the connecting wire. A radial slit is made in a slice of potato, and the slit is passed over the wire. I have even done brazing by this method. JOSEPH CLEGG.

Woodford Green, Essex.

Television Picture Quality

G. H. BALL raises, in his letter in the March issue of *Wireless World*, an interesting point. I can support his view that the link to Sutton Coldfield is not to be blamed, for there is a high incidence of poor picture quality here in the London area.

The explanation appears to be simply one of poor signal-to-noise ratio in the cameras and the apparatus immediately associated with them. In this district there is such a strong signal available that it is child's play to keep receiver noise off the screen. Nevertheless, high noise levels are often visible, and these come and go as cameras are changed in the course of programme presentation. What other explanation can there be?

It seems also that the camera amplifier channels at the A.P. studios are generally more noisy than those in the O.B. equipment, although why this should be is not apparent. It cannot be argued that the O.B. gear is cleaner because it is more modern; the signal from Lime Grove is often very poor.

An even more pronounced comparison is often possible when the programme is faded from camera to film-scanner. Mr. Ball may be able to make some interesting observations by comparing the average quality of film transmissions with direct presentations. He can take it for granted that film transmissions are generally of good quality, after making allowance for unsuitable subject matter. G. L. STEPHENS.

Enfield, Middx.

How to Choose a Valve

The Revealing Story Told by a Single Characteristic

By THOMAS RODDAM

SIX times a week, and twice on Sundays, for the last thirty years, someone, somewhere, has introduced a new type of valve. The designers of wide-band amplifiers have attempted to deal with this vast variety by introducing a factor of merit based on the mutual conductance and the capacitances. By the use of this factor of merit the designer can say that valve A is better than valve B. At very high frequencies a new factor, the noise resistance, appears to be the most suitable criterion. The audio designer is left to choose his valves by intuition. In this article I shall point out the merits of two different figures of merit for use by audio designers.

It is, of course, time that the designer is not confronted by the possibility of using any one of the thousand odd valves listed in the valve books. The valves are already classified and sub-classified. Foreign customers, for example, often demand that valves of American type should be used: they say that replacements to fit the new Welsh nine-pin octal are difficult to find in their local suppliers. The use of miniatures makes them think that they really are getting an up-to-date design. Standardization of heater supplies makes it necessary to keep to the 6.3-volt valves except in the most abnormal circumstances. But finally we are faced with the problem of internal standardization: if sections of a complete system are designed by different people, it looks better if the final equipment uses one valve type for one function. We must have our domestic standard. In deciding this from the short list of, perhaps, half-a-dozen valves, the figure of merit can be invaluable.

Very often, the final choice is a matter of chance. The man who is quickest off the mark announces that he is committed to such and such a valve: the man with the loudest voice overrides the discussion: the only type which happens to be available in the local shop is used, because no one wants to wait while an order goes through. But if a single factor of merit can be used to assess the claims of the different valves, there is just a hope that the best type will be chosen.

Characterizing Curve

The basis on which we can best work is the use of a single curve which characterizes the valve, instead of the set of characteristics which are usually used. This set, of course, really represents a three-dimensional surface, and there are quite real difficulties in appreciating the full significance of the normal characteristics. The single curve conveys its meaning much more directly: for some reason, however, the standard text-books seem to have overlooked its merits.

In the discussion of the figure of merit it will be assumed that we are concerned mainly with pentodes. I am fully aware of the advantages of using positive feedback triode pairs, but the problem of type selection is not so acute here, because there is not really a wide range of choice. The pentode valve characteristic can be written in the form

$$I_a = I_o + Ae_g + Be_g^2 + Ce_g^3 + \ldots \quad (1)$$

where I_a is the anode current, I_o the steady component with no signal applied, and e_g the alternating component of the grid voltage. A, B, C etc., are parameters which are fixed by the valve construction.

Differentiating this equation, we have

$$dI_a/de_g = A + 2Be_g + 3Ce_g^2 \quad \ldots \quad \ldots \quad (2)$$

which goes to

$dI_a/de_g = A$ if e_g is made small enough. This means that A is simply the mutual conductance of the valve. Let us plot a graph of mutual conductance against grid bias We can measure this ourselves, and some valve manufacturers give us this graph for some of their valves. Such a graph is shown in Fig. 1. Since $g_m = dI_a/de_g$, we can write

$$I_a = \int_{-\infty}^{e_{go}} g_m de_g \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

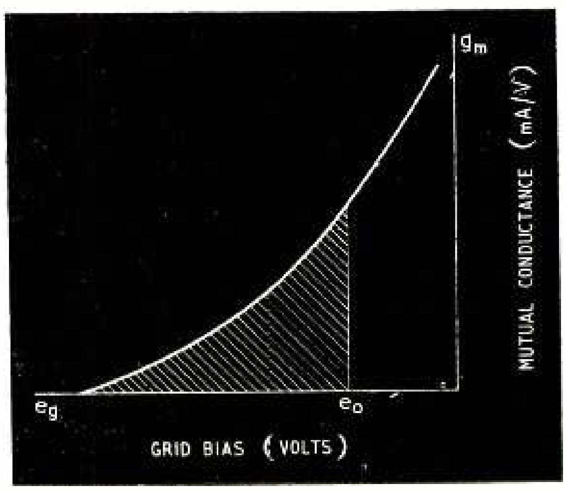
$= I_o$, the current at some bias e_{go}. The integral of eq. (3) is the area under the $g_m - e_g$ curve, which is shown shaded in Fig. 1. The single curve of Fig. 1 thus tells us both the standing current and the mutual conductance at any particular bias.

Going back to equation (2), we can differentiate again, and we have

$$\frac{dg_m}{de_g} = 2B$$

This is the slope of the curve shown in Fig. 1, and it is actually a measure of the second harmonic dis-

Fig. 1. The basic valve characteristic, showing mutual conductance as a function of bias. The shaded area is the anode current.



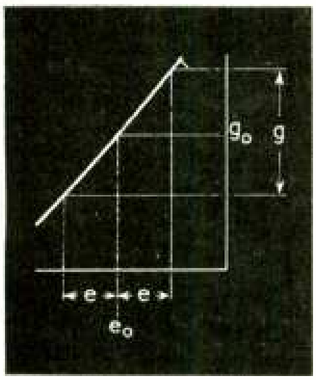
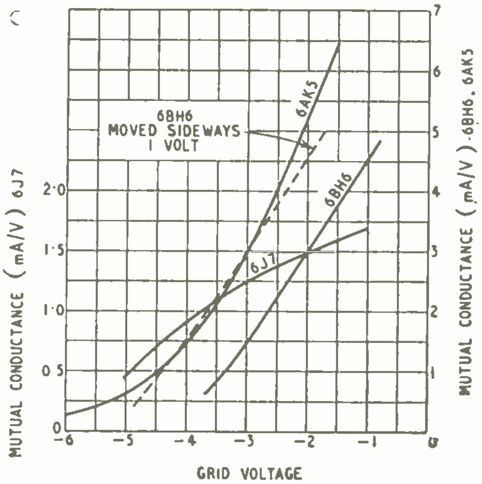


Fig. 2. The slope of the characteristic is specified by *g* and is a measure of the second harmonic.

Fig. 3. Characteristics of three pentodes, showing linear $g_m - e_g$ characteristic for 6BH6 and parabolic characteristics, 6AK5 and 6J7.



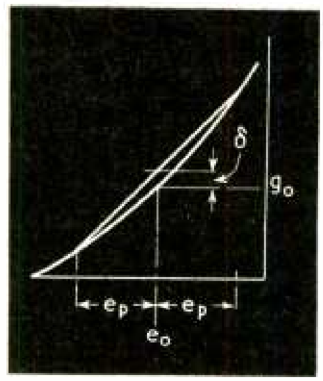


Fig. 4. The sag of a curved characteristic is a measure of the third harmonic distortion.

tortion. We can see this by putting $e_g = e \sin \omega t$ so that

$$I_a = I_o + g_m e \sin \omega t + Be^2 \sin^2 \omega t \ldots$$

$$= I_o + g_m e \sin \omega t + \frac{Be^2}{2}(1 - \cos 2\omega t) \ldots$$

The second harmonic distortion is therefore

$$\frac{Be^2}{2g_m e} = 100\% = \frac{B}{2g_m} . e .100\%$$

Looking at Fig. 2, we see that $B = g/2e$, as B is the slope of the $g_m - e_g$ characteristic: putting g_o for the value of the mutual conductance at the working point, the distortion is

$$(g/4g_o) . 100\%$$

From the single curve of $g_m - e_g$, we can therefore derive the following information.

(1) The mutual conductance, and thus the gain, at any particular working point. This is read straight off the curve.

(2) The anode current. This is the area under the curve, and can be obtained by counting squares, or by any other convenient method of graphical integration, such as a planimeter.

(3) The second harmonic distortion for a given working level, or the working level for given distortion. This is given by reading off g_o and g from the graph, and calculating $(g/4g_o) . 100\%$.

If the valve $g_m - e_g$ characteristic is a straight line, we need only concern ourselves with the second harmonic distortion, because the factor C in equation (1), which is a measure of the third harmonic, will be zero. Two types for which this is true are the 6BH6 and the 6AG7. We shall not use $(g/4g_o)$ as a figure of merit, however, for reasons which must be discussed. Provided that the designer is sufficiently skilful, the distortion can be reduced by the use of negative feedback, and the price to be paid is in the gain of the system. The gain reduction and the distortion reduction are directly proportional, so that the important quantity for the audio designer is

(gain)/(distortion).

This is clearly proportional to $g_o/(g/4g_o)$, and dropping the factor 4 we have as a figure of merit the quantity g_o^2/g.

The *best* valve to use in an audio amplifier is the valve which has the highest value of (g_o^2/g), provided that gain and distortion are the criteria of choice. To indicate how we can make use of this rule, the characteristics of three different pentodes, the 6AK5, 6BH6 and 6J7 are plotted in Fig. 3. If we consider these valves for low-level applications, we can tabulate the values of g_o and g for a peak swing of 0.25 volts. We have:

	g for $e = 0.25$	g_o	Fig. of merit	I_o
6AK5	1.3	5.8	26	9
6BH6	0.75	3.35	15.2	4.5
6J7	0.125	1.5	18	3.3

It will be seen that the 6AK5 is the best of the three, and that the 6J7, in spite of its low mutual conductance, is better than the 6BH6. Unfortunately, as any critical reader can check for himself, I have not been quite fair here. The curves shown are published characteristics, and they apply for different supply voltages. It is, however, not necessary to make the comparison under identical conditions, because if we get better results from the 6AK5 at 180 volts (the maximum) than from the 6BH6 at 300 volts, we shall choose this valve.

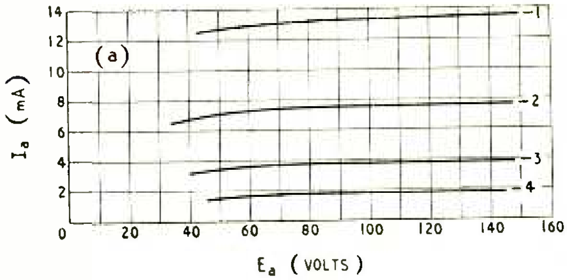
Sometimes we have other requirements for our valve. We may say that all the distortion occurs in the output stage, and demand only high gain in the previous stages. Then, of course, g_o is the factor which decides which valve we are to use. For the designer who really wants the best possible result, however, this is only part of the story, because he can add positive feedback to the early stages, and it is easy to see that with the design worked out for the best performance, the figure of merit already quoted is the one to use. With the increasing demand for miniaturization, another criterion may be needed: we may want to get as much gain as possible for each milliamp of anode current. It is necessary to take account of the tail which appears in some valves, and to compare the characteristics closely. By shifting the 6BH6 characteristic sideways in Fig. 3, it can be seen that the 6AK5 has a longer tail, and so will take rather more anode current for the same gain. It is much more difficult to provide a single figure of merit for this application, because the relative merits of two valves may differ as the working level is altered. The $g_m - e_g$ characteristic, however, contains the complete story.

Some valves, of course, have a curved $g_m - e_g$ characteristic. The simplest form of this is shown in Fig. 4. This parabolic characteristic is due to the fact that the coefficient C in equation (1) is not zero. The result in practice is that there is a third harmonic term in the distortion. I am not going to work out the distortion in detail, because the mathematics is quite straightforward, but I will just quote the results. The third harmonic for any peak level is obtained by joining the two points on the curve corresponding to the maximum working peak level, $(e_o \pm e_p)$. The dip of the curve below the straight line, measured at e_o, is δ, and is a measure of the third harmonic. For any signal peak level e_s less than e_p, the third harmonic is given by the formula

$$\frac{3\delta}{g_o} \cdot \left(\frac{e_s}{e_p}\right)^2 \cdot 100\%$$

When $e_s = e_p$, this reduces to $3\delta/g_o$ .100% which may be compared with the expression for the second harmonic, $g/4g_o$ .100%. Which harmonic dominates depends on whether δ is greater than $g/12$. It is easy to test this on any particular characteristic.

The reader who wishes to apply this method of assessing valves will encounter one very serious difficulty. Some valve makers consider it sufficient to announce that Venus valves are Versatile, and support this claim with a photograph of an attractive young lady—the same one who uses a well-known soap, eats chocolate and drives the most expensive motor cars. True, engineers, unlike editors, like these pictures, but we are also interested in the anatomy of the valves and would like to see some of their curves too. In theory the $g_m - e_g$ characteristic can be derived from the ordinary $I_a - E_a$ characteristics, but if you look at Fig. 5 you will see that this does not seem to be a very reliable method. The only ways out of this are, either measure the characteristics yourself, using methods given in the standard text-books, or say to the maker, "no tell, no buy." Even after all these years I still cherish the hope that one day we shall have a uniform base and numbering system: but by then we shall probably all be using transistors instead.



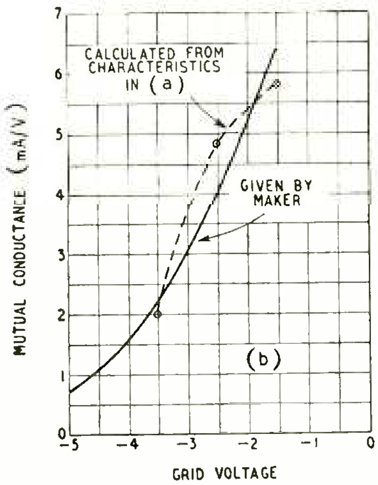


Fig. 5. Characteristics of 6AK5, showing failure of agreement in data.

To sum up what I have said, the most useful single valve characteristic is the mutual conductance-grid bias curve, and from this we can immediately determine the anode current, the stage gain and the distortion. To compare two valves for audio amplifier service we can make use of a figure of merit which is easily calculated.

STEREOPHONIC SOUND

Demonstration in the Telekinema

A THREE-CHANNEL system has been adopted for the demonstration of stereophonic sound in the Telekinema. Reproduction is through the main B.T.H. sound film installation and separate loudspeaker units have been placed at right, left and centre of the stage. Magnetic tape is the recording medium, and a special machine has been developed in conjunction with E.M.I. for use with stock 35mm. film base, which has been coated with oxide. In addition to the three tracks for the main groups of speakers, there is a fourth track for special effects from loudspeakers at the back of the hall.

The use of wide film has brought many problems not associated with standard 0.25in. tape. Pressure pads are necessary on each of the recording, replay and wipe heads, and heavy Mumetal screening has been provided to prevent ingress of hum into the comparatively large volume of the recording head assembly.

Pre-emphasis and complementary de-emphasis of high frequencies to a law equivalent to a circuit time constant of 40μsec has been adopted. The figures given for the final overall frequency response are 30c/s to 15kc/s; signal/noise ratio is 55 to 60db, and total harmonic distortion less than 2 per cent.

The microphone used for recording stereophonic sound is of the twin ribbon type in which the ribbons are mounted at 90 degrees to each other in a common magnetic field. Each ribbon has a figure-of-eight polar diagram and the relative amplitudes of the signal in each channel are determined by the position of the source. Cross talk between the two channels is less than −45db and has been found to be quite satisfactory.

WORLD OF WIRELESS

Festival Conventions : Notes and News : Personalities

Engineering Conference

AT the afternoon session of the Joint Engineering Conference, arranged by the Institutions of Civil, Mechanical and Electrical Engineers (June 4th to 15th), on June 8th, Sir Noel Ashridge will speak on "The British Television Service." At the telecommunications session at 10.0 on June 11th Sir Stanley Angwin will be the speaker. "Radio Masts and Towers" is the subject to be dealt with by C. O. Boyse at 10.0 on June 12th. These three meetings will be held at the I.E.E., Savoy Place, London, W.C.2.

At an alternative meeting on June 12th at 10.0 at the Institution of Mechanical Engineers, Storey's Gate, London, S.W.1, Air Comdre. C. S. Cadell and Dr. B. J. O'Kane will speak on "Forty Years' Progress in Air Radio."

During the conference visits will be made by delegates to a number of works, research establishments, etc., including E.M.I. Factories, N.P.L., Alexandra Palace, S.T.C., G.E.C., G.P.O. Radio Terminal, and B.B.C. Lime Grove Studios.

Details of the conference, which is open to members of the three convening institutions and of certain other institutions and societies, are obtainable from the Secretariat, Institution of Civil Engineers, Great George Street, London, S.W.1.

Brit. I.R.E Convention

THE first two of the six sessions of the Convention being organized by the British Institution of Radio Engineers during the period of the Festival of Britain will be held at University College, Gower Street, London, W.C.1, from July 3rd to 6th.

The first two days will be devoted to "Electronic Instrumentation in Nucleonics," and the chairman will be Dr. Denis Taylor, of A.E.R.E., Harwell. Seven papers will be presented.

"Valve Technology and Manufacture" is the subject being covered at the second session (July 5th and 6th), at which J. W. Ridgeway (Edison Swan Electric Co.) will be the chairman. The papers to be read include:—

"Triode Amplifiers in the Frequency Range 100 Mc/s to 450 Mc/s," by D. C. Rogers (S.T.C.).

"Aluminium-Backed Screens for Cathode-ray Tubes," by R. W. Dudding, B.Sc. (G.E.C.).

"Dynamic Measurements on Receiving Valves," by A. J. Heins van der Ven (Mullard).

"Rare Metals in Electron Tubes," by D. A. Wright, M.Sc. (G. E. C.).

"A Survey of Quality and Reliability Standards in Electronic Valves for Service Equipment," by G. L. Hunt, B.Sc. (Ministry of Supply).

"The Production of Miniature Valves in France," by M. Martinoff (Société Française Radio-Electrique).

"The Application of Image Converters to High-speed Photography," by J. A. Jenkins, M.A. (Hons.), and R. A. Chippendale, B.Sc. (Mullard).

"Vacuum Technique: Its Application to Radio and Electronics," by D. Latham, B.Sc., and B. D. Power, B.A. (W. Edwards and Co.).

"Line Scanning Valves and Circuits," by B. Eastwood, B.Sc., and C. C. Vodden, M.Sc. (Edison Swan).

Further details of the Convention, which is open to non-members, are obtainable from the General Secretary, Brit. I.R.E., 9, Bedford Square, London, W.C.1. The registration fee for each session is 10s 6d.

Indian "Beveridge"?

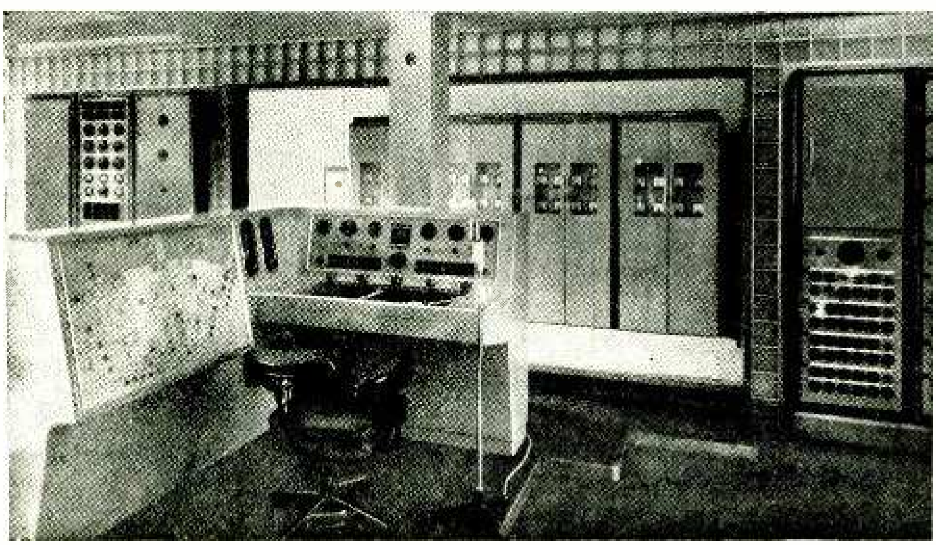
PLANS for the International Radio and Electronics Exhibition of India, mentioned in our last issue, have been carried a stage further by a proposal for an "Asian Conference on Broadcasting" to coincide with the exhibition. By Western standards, Asia is very poorly served, and the purpose of the conference is to examine technical and organizational possibilities for extending broadcasting throughout the Continent.

Y. A. Fazalbhoy and his associated organizers of the Indian Exhibition, who have been discussing their plans with various bodies in this country and elsewhere in Europe, are returning to England on May 29th and will be staying at the Savoy Hotel, London, W.C.2.

Indexes

THE index to the 1950 volume of *Wireless World* is now available from our Publisher, price 1s (postage 2d). Cloth binding cases for the volume are also obtainable, with index, price 6s 5d by post. The binding of readers' own issues can be undertaken by our Publisher; the cost, including binding case and index, being 17s 6d, plus 9d for the postage on the bound volume.

Readers may like to know that copies of the 1950 index to the Abstracts and References section of our sister journal *Wireless Engineer* are still available. The author and subject sections cover the 3,221 abstracts published in *Wireless Engineer* during last year. The index, which costs 2s 8d by post, also includes a list giving the names and addresses of the 160 journals of the world regularly scanned for abstracting.

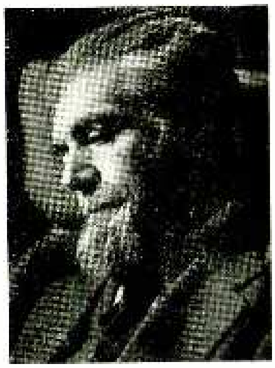


SOUTH BANK SOUND SYSTEM. Four 1.5-kW amplifiers, seen in the background, are used in the Rediffusion sound system at the South Bank Exhibition. Pre-selection of groups of the 700 loudspeakers in the various buildings and open spaces is provided by the switch buttons on the illuminated map at the control position.

Amateur Television

A TELEVISION Convention is to be held by the British Amateur Television Club on June 23rd from 10 a.m. to 6 p.m. at the Cinematograph Exhibitors' Association, 164, Shaftesbury Avenue, London, W.C.2. The morning session will be devoted to a discussion of transmitting standards, licensing, etc., and the afternoon to demonstrations of equipment. A charge will be made for admission. Particulars are obtainable from the Hon. Sec.: M. Barlow, 8, Primrose Street, Cambridge.

The date of the Convention coincides with the R.S.G.B. National Convention (to be held from June 21st to 24th—see April issue) and has been chosen to enable interested amateurs to attend both functions.



DR. T. L. ECKERSLEY, B.Sc., F.R.S., who, owing to illness, was unable to travel to London, received the Faraday Medal from the President of the I.E.E. at a private ceremony at the Marconi Works, Chelmsford.

Television Bandwidth

THE main objection to the adoption of a high-definition television system, such as that introduced in France, has been the very wide bandwidth required (14 Mc/s). It has been suggested by the Editor of our French contemporary *La Télévision Française* that so long as there is good vertical definition unbroken by the line structure and good contrast, viewers are content. It is of interest, therefore, to note that regular test transmissions of 819-line television from the "low-definition" Eiffel Tower transmitter, which operates on 46 Mc/s and has a pass band of about 4 Mc/s, are being undertaken by Radiodiffusion Française.

PERSONALITIES

Sir Stanley Angwin, K.B.E., who, as announced in our April issue, relinquished the chairmanship of Cable and Wireless, Ltd., to act as technical adviser to the Commonwealth Telecommunications Board, has now been appointed chairman of the Board. Before his appointment in 1947 as chairman of Cable and Wireless, Ltd., Sir Stanley was for eight years Engineer-in-Chief of the Post Office. He is also chairman of the Radio Research Board.

A. H. Mumford, O.B.E., B.Sc. (Eng.), M.I.E.E., has been appointed Assistant Engineer-in-Chief G.P.O., on the retirement of Capt. J. Legg. He joined the Post Office Engineering Dept. as a probationary assistant engineer in 1924 and by successive promotions took charge of the Radio Branch in 1938.

C. Buckle, A.M.I.E.E., has been appointed Engineer-in-Charge of the television station now being built at Holme Moss. He joined the staff at Alexandra Palace in 1938, and became successively Engineer-in-Charge of the broadcasting stations at Blackburn and Middlesbrough when the television service closed down in 1939. He was appointed to the staff of the Corporation's Engineering Training Department as an Instructor on transmitters in 1944. Mr. Buckle's Assistant at Holme Moss will be **J. P. Broadbent**, who is at present one of the senior engineers at the Droitwich transmitting station.

W. J. Chalk, B.A., has joined the staff of the Overseas and Engineering Information Department of the B.B.C. to deal mainly with the allocation of wavelengths for broadcasting, and to take part in international and other conferences on this and related subjects. During the war he held staff appointments as Radio Planning Officer for Special Forces Signals in the Middle East, Europe, and the Far East, and was a member of various frequency allocation committees.

L. W. Turner, A.M.I.E.E., has been appointed Assistant Head of the Engineering Services Group of the B.B.C. He joined the Corporation in 1936 from the International Marine Radio Co. In 1949 he was seconded to the Colonial Office in order to carry out a broadcasting survey of the West African colonies.

IN BRIEF

Receiving Licences current in the United Kingdom at the end of March totalled 12,403,950, including 763,750 television licences. Our contributor, "Free Grid," who recently pleaded for the introduction of some means whereby licences could be purchased by weekly instalments will be interested to learn that the P.M.G. has pointed out that the Stamps Saving Scheme allows money to be accumulated in small amounts for encashment later.

Television Society. — A Summer Meeting for members of the Society will be held at the Norwood Technical College on June 2nd. A demonstration of large screen television will be given at the Penge Cinema during the morning and in the afternoon a series of short papers will be read.

Telearchic Lighthouses.—The possibility of controlling remotely situated lighthouses by radio is well demonstrated at the South Bank Exhibition by the lighthouse on the Shot Tower, which is automatically switched on and off from a distance of three miles. A 5-watt v.h.f. transmitter is installed at the St. James's Square offices of Chance Brothers, who made the lighthouse, and a four-element Yagi aerial on the roof directs a coded signal to the Shot Tower when the equipment is operated by a time-switch. All the radio equipment is supplied by Marconi's.

"Radio Valve Data."—A new and up-to-date edition of this useful reference book will shortly be available from our Publisher. Although it has been completely revised and enlarged and now includes characteristics of some 2,000 valves and cathode-ray tubes, the book is still priced 3s 6d (postage 3d).

Williamson Amplifier.—Copies of the reprint of the articles describing the Williamson Amplifier, which has attained international repute, are again available and may be purchased from booksellers, price 3s 6d, or, in cases

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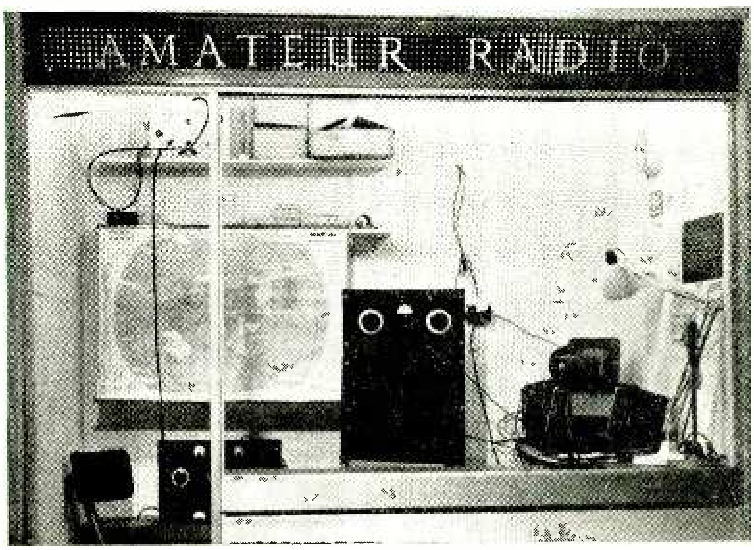


AMATEUR RADIO STATION at the Land Travel Exhibition which, after visiting Manchester in May, will be in Leeds from June 23rd to July 14th. The transmitter was provided by Webb's Radio and the aerial equipment by Belling & Lee. A Cosmocord crystal microphone is used.

Television Relay Systems

Distributing Programmes by Wire

TWO companies are now operating television relay systems in conjunction with the ordinary sound relays. The methods used by each are alike in their essentials and in both four audio-frequency channels are provided, the distribution being along a quad cable at audio-frequency. One of these four channels carries the television sound signal and the other three give the Light, Home and Third programmes.

The television signal is superimposed on the same wires using carrier frequency. The attenuation of such cable at this carrier frequency is naturally fairly heavy, but it is claimed that up to a mile can be used before a repeater becomes necessary.

In the case of the system installed by Link Sound & Vision Services Ltd. at Gloucester, the receiving station is some three miles outside the town on high ground and the signal is conveyed to the distribution point over a centimetre-wave relay link. A metre-wave receiver, also installed at this distribution point, plays a double role; it provides a check on the operation of the link and it acts as a stand-by so that a service can be provided from it in the event of a failure of the link. Reception, whether direct or via the relay link, is from Sutton Coldfield.

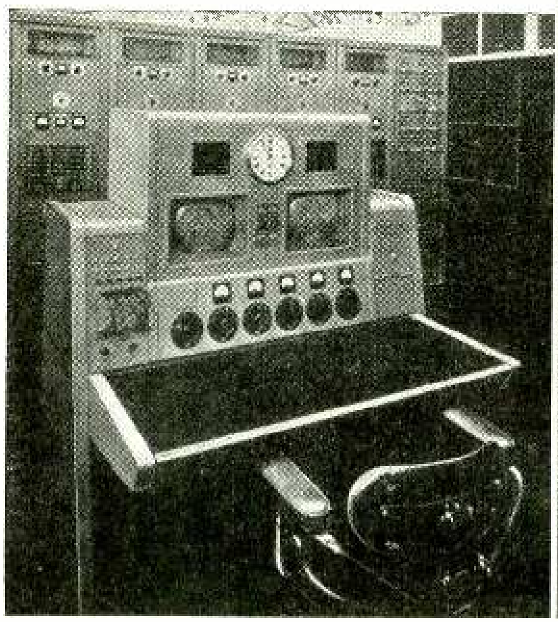
Each subscriber has a television unit which includes the cathode-ray tube, scanning and e.h.t. circuits, and a video receiver designed for the carrier-frequency employed. It is, of course, somewhat simpler than the ordinary television receiver in that the conventional sound channel at radio-frequency is unnecessary, as are also sound-channel rejectors and interference-suppression circuits. The sound side is the purely a.f. circuit of the conventional relay system. Provision is made in the design for the distribution of a second picture programme should this ever become necessary.

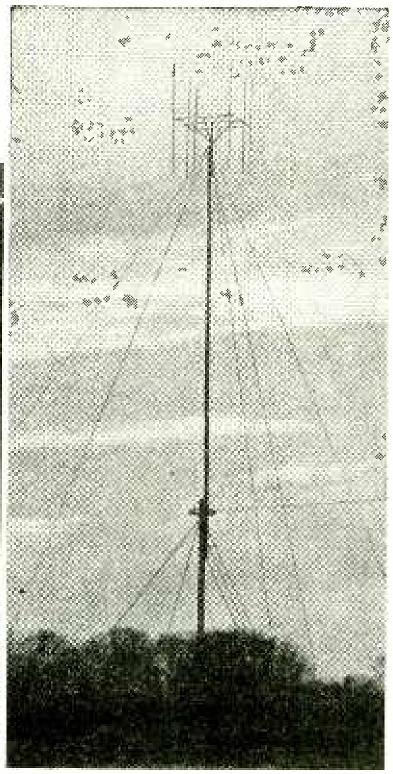
At Margate the aerial array of Central Rediffusion Services' installation is outside the town on an open site and is supported by a 60-ft mast. The receiver has five r.f. stages and five i.f. and the first stage is a low-noise earthed-grid triode. The output signal at a level of about 2 V is carried by 2,000yd of quad cable to a repeater station where an amplifier compensates for the line attenuation. From this repeater the signal is distributed to subscribers and, when the service is extended, it will feed further repeaters.

The signal is received from Alexandra Palace and is stated to vary from about 15 μV to 150 μV according to propagation conditions. An a.g.c. system will consequently be fitted to the receiver.

(Right) Rediffusion aerial system at Margate.

(Below) Control desk of the Link installation at Gloucester.





World of Wireless . . . . concluded

of difficulty, by post from our Publisher, price 3s 9d.

"R.S.G.B. Call Book."—The Radio Society of Great Britain has decided to publish a book under this title giving the call signs, names and addresses of all licensed amateurs in the United Kingdom. Amateurs wishing to have particulars of their stations in the first edition, to be published towards the end of the year, are asked to write their call sign, name and address on a postcard and send it to J. P. P. Tyndall, 174, The Drive, Ilford, Essex.

South Bank Radar.—The harbour supervision radar equipment in use in the Transport Pavilion at the South Bank Exhibition, which includes a 12-ft scanner mounted on a boom extending from one corner of the building, was supplied by Cossor Radar, Ltd.

Gramophone Turntable Speeds

What is the Best Speed for Microgroove Recording?

By G. F. DUTTON,* Ph.D., D.I.C., A.M.I.E.E.

THE history of the disc gramophone shows that there has been a great variety of turntable speeds and of groove dimensions. The early discs were of about 7in to 8in in diameter and it will be shown later that the turntable speed of about 78 r.p.m. was justified at that time. The groove dimensions and amplitude of cut were dictated by the need for direct mechanical reproduction through a horn system. The development of the more delicate electrical pickup mechanisms has naturally changed these requirements, but mechanical gramophones are still used by many people throughout the world. A very important aspect of the gramophone record was its universality. Except for slight variations of frequency characteristics a record made in this country could be played wherever there was a pickup or a portable gramophone. The introduction into the commercial market of the microgroove and at least two alternative speeds robs the disc of its universal application.

It has been stated on good authority that of the sales of the standard 78-r.p.m. records throughout the world, 40 to 50 per cent go to customers who have the portable mechanical type of machine only. It is also interesting to note that though the number of portable mechanical gramophones exported from this country greatly exceeds the home consumption, the latter has shown a distinct rise since the end of the war. The U.S.A., being a highly electrified country, has no mechanical gramophone problem. It is to be expected, therefore, that a firm in the U.S.A. can embark on new standards of speed and groove dimensions with less embarrassment than firms in this country.

It must be clear, therefore, that whatever alternative speeds and groove dimensions are eventually adopted, the standard 78-r.p.m. record must continue for a considerable time.

The playing of a gramophone record is a very personal form of entertainment; one has the choice of a number of artists performing any one work and one can play it when one likes. Perhaps the mention of the broadcast programme called "Desert Island Discs" will illustrate the personal choice of a variety of short items together with the portable gramophone angle. I presume that the desert island is not electrified.

We should perhaps at this stage state the specification for the performance of a gramophone disc. There is no doubt, however, that it will be the public who will finally choose the specification, but we may usefully list what we think to be the items which could be discussed here on technical grounds. Before we do that we should bear in mind that the buying public can, I suggest, be roughly divided into two age groups —14 to 30 and 50 to 70. The first group, 14 to 30, is the romantic group, requiring dance music, hot jazz, crooning, etc., with a fair demand for the more serious classical music. They have little money to spend and probably prefer to spend only a little at a time. The second age group, 50 to 70, is the connoisseur group with more money to spend and more time to listen to long operatic works. One age group would tend to sway the gramophone industry to concentrate on short five-minute records and the other to adopt long-playing records. The use of long-playing records to string together whole series of dance tunes would, I think, be ridiculous. It is difficult enough, with the 10-in, 78-r.p.m. record, to choose suitable coupling items for the two sides of the disc. I must also mention that there are many lengthy classical works covering, say, a dozen 12-in discs, and the sales of one or two discs from the series far exceeds the sale of the complete work.

Record Materials

It would seem, therefore, that the record of short duration, say up to five minutes, is a definite requirement. Does the standard 78-r.p.m. record fulfil the requirements of a short-duration record? To a large extent it certainly does, but we must consider whether the size of the record player, the storage of records, the economical use of low surface noise and high-grade plastic moulding material are items which would swing the development towards small diameter lower-speed discs. Shellac is an ideal resin for moulding, since it flows freely at a moderate moulding temperature and pressure. Its great drawback is its dimensional instability without the use of a large percentage of mineral filler. This filler is the cause of most of the so-called surface noise. The record, however, stands up well to the variable treatment that it may experience by reason of the great variety of needles and pickup playing pressures used throughout the world.

The unfilled vinyl co-polymer resins can only be used with safety by the modern lightweight pickup with precision needle points. The plastic is expensive, and, like most high molecular weight resins, requires high moulding temperatures and pressures. This in its turn is liable to cause strain which may lead to warping. When using vinyl plastic, therefore, the small disc is to be preferred.

Can long playing be fulfilled by the 78-r.p.m. standard disc? History shows that there have been many attempts and some quite successful. For instance, the World Record Company in 1910 brought out a disc claiming to play from 10 to 100 minutes employing a constant groove speed. A sample record is extant which plays for 12 minutes, the turntable speed varying from 30 r.p.m. on the outside to 80 r.p.m. on the inside. The use of constant groove speed is the most

* E.M.I. Engineering Development, Ltd.

efficient way of operating a disc, since the quality can be kept constant at a predetermined value. The mechanism to produce this constant groove speed and at the same time avoid "wow" and "flutter" is something of a mechanical problem.

The $33\frac{1}{3}$ r.p.m. speed was introduced for 16in discs to be used in conjunction with films. With these large-diameter discs $33\frac{1}{3}$ r.p.m. is justified. In recent years it has been used by broadcasting concerns both for processed transcription records and for lacquer recordings. The groove dimensions are the same as for 78-r.p.m. standard. The 16in disc is, of course, too large for domestic use. If we examine Fig. 1 we see a family of curves showing the relation between playing time and disc speed for various overall diameters. The minimum groove speed is 16in/sec and there are 100 grooves per inch.

The playing time of a record is determined by the width of the recorded area on the record, the spacing between individual grooves, and the angular speed of the turntable. The average groove spacing depends very largely on groove width, which in turn is controlled by the size of the needle point, and to a slightly lesser degree on the amplitude of the recording cut. The turntable speed and the total width of recording allowed are related together by considerations which involve the overall diameter of the record and the least permissible tangential groove speed; the latter depends in turn on the same two quantities, that is to say the needle size and the amplitude of cut, which are involved in groove spacing. Since these two features control playing time in two distinct ways, they merit the first consideration.

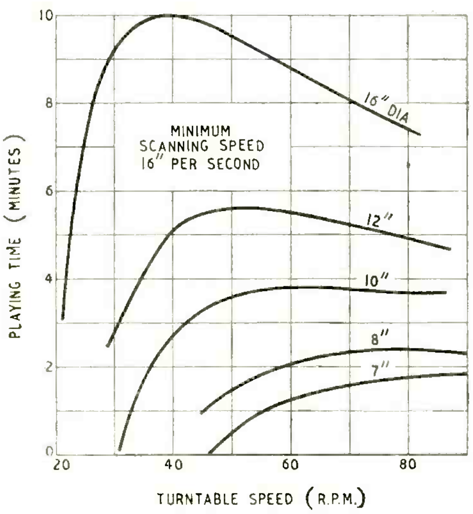
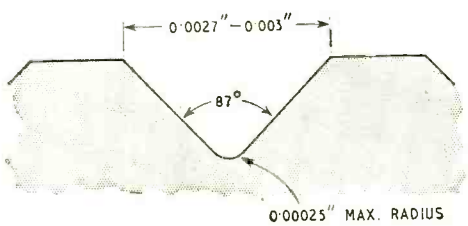


Fig. 1. For a given minimum groove speed there is an optimum turntable speed for maximum playing time with any given outside diameter of record.

Fig. 2. Principal groove dimensions in microgroove recording.



For use on microgroove records, the radius of the hemispherical tip of the needle has been reduced from the value of 0.0025in, associated with standard records, to 0.001in. To avoid excessive wear or major damage to either the needle or the record, it has been necessary to reduce the needle pressure and stiffness by at least the square of this ratio. This has been achieved partly by reducing the mass of the pickup head, and partly by some degree of counterbalancing: further reduction of needle pressure would almost inevitably have to be achieved by increased counterbalancing alone.

If the radius of the needle point were reduced below the new figure of 0.001in,

(a) the uniformity of performance between needles would deteriorate seriously,

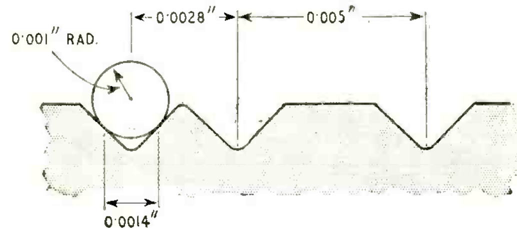
(b) the needle tip would be too susceptible to accidental damage,

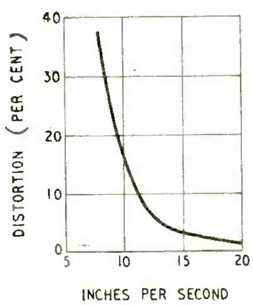
(c) the counterbalancing would become critical and would involve individual adjustment, and

(d) the ratio of the residual moment to the moment of inertia would be so low that the needle might fail to maintain proper contact with records which are slightly warped.

In all proposed microgroove records, the amplitude of the lateral cut has been reduced in, at least, the ratio of the needle-tip reduction, at the lower frequencies, which determine the greatest amplitude. Further decrease would not give a proportionate increase in playing time, particularly if the groove pitch is made variable. On the other hand, with pre-emphasis the amplitude of cut at high frequencies is only slightly below the standard (78 r.p.m.) records.

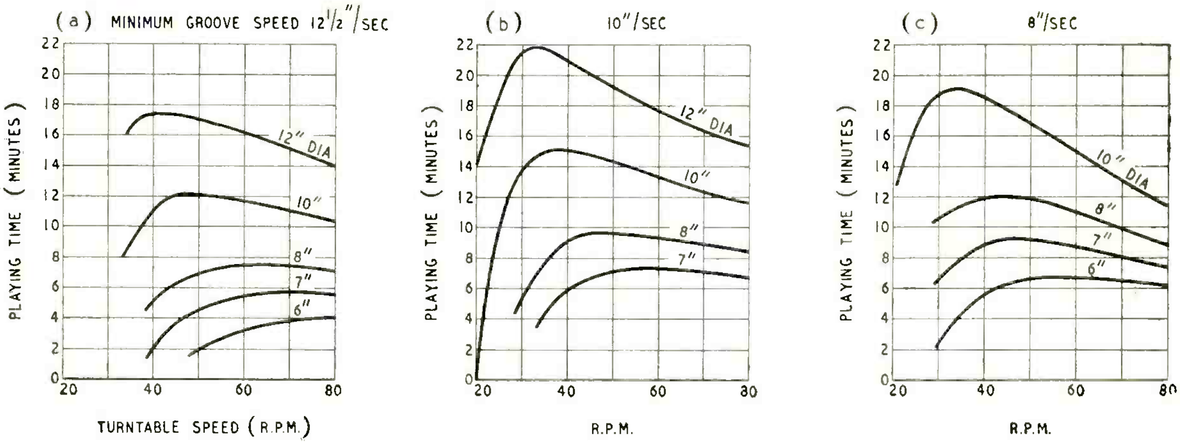
Fig. 2 shows the dimensions of cross-section of the groove. The best position for the needle to engage the groove wall is half-way up the wall where there is the least danger of distortion of the wall by rounding. It will be clear from Fig 3 that the width of the needle at the point of engagement is 0.0014in and that the absolute minimum groove spacing is, in consequence, 0.0028in. In extremely quiet passages, a record could theoretically be cut to 350 grooves to the



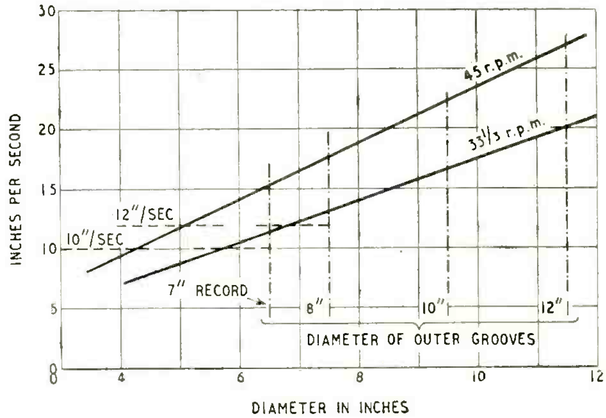


Above: Fig. 3. Using the groove of Fig. 2, the theoretical minimum spacing without modulation is 0.0028in (about 350 grooves per inch). In practice an average of 250 g.p.i. is rarely exceeded.

Left: Fig. 4. For a given stylus radius and lateral velocity of cut, distortion is inversely proportional to the fourth power of the tangential (linear) groove speed.



Above : Fig. 5. Playing time, for 250 grooves per inch, in terms of minimum groove speed, external diameter of disc and turntable speed.



Right : Fig. 6. Relationship between linear groove speed and groove diameter.

inch, but in practice an extra tolerance has to be allowed to ensure that grooves do not cut into one another. An allowance for this effect leads to a groove-to-groove minimum spacing of 0.0035in, and a maximum of 280 grooves per inch in silent and fairly quiet passages. Heavy recording will require an increase of spacing of at least 0.0015in, making 0.005in in all, but, as loud passages do not in general predominate, it is thought that a variable groove-pitch system would allow an average of 250 grooves per inch. All the following calculations of playing time are made on this assumption.

The distortions which arise in following a groove with a needle point of finite size have been analysed in detail by Pierce and Hunt[1], Lewis and Hunt[2], and others. Briefly, the expression for distortion contains terms of the form:

$$\frac{r^2 V^2}{S^4}$$

where r is the needle-tip radius, V is the lateral cut velocity, and S is the tangential velocity. This means that, in order to produce similar distortion conditions S^2 varies directly with rV.

In considering harmonic distortion of lower frequencies, or intermodulation between low and high frequencies, both r and V have been reduced by 2.5 to 1 from their values with standard records, and hence the minimum tangential speed may be reduced in the same ratio for the same amount of distortion. Harmonic distortion of high-frequency notes, or intermodulation between high notes, however, involve values of V which are unchanged from the standard record, and here a reduction of S in the ratio of the square root of 2.5, or only about 1.6, is justified. Taking into account the importance of the various types of distortion, it is probable that the permissible decrease of tangential velocity, from that of the standard record, is in the ratio of 2 to 1.

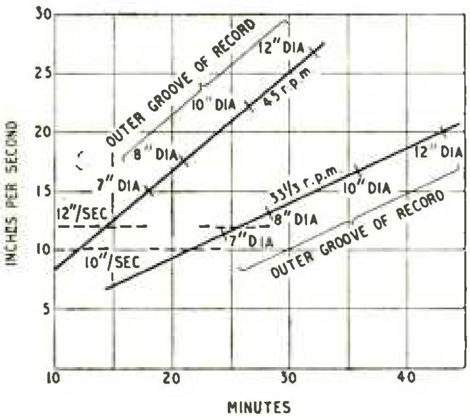
Existing standard 78-r.p.m. records in extreme cases play to a tangential velocity as low as 16 inches per second, and distortion is apparent at the inner grooves, if the amplitude of cut is high. In fact the quality in loud passages is not noticeably impaired at 22 inches per second. On this basis we should recommend that microgroove records should preferably be terminated at 12 inches per second, and certainly never allowed to play beyond 10 inches per second.

Experience has shown that the distortion which sets in at a certain point in the playing of the record, increases at a rate which appears to be out of all proportion to the change of radius. It cannot be too strongly emphasized that this is completely justified in theory by its dependence on the reciprocal of the fourth power of the speed. Similarly, we are quite justified in drawing a strong distinction between speeds differing as little as 12in and 10in per second, because this small difference accounts for more than a two-fold increase of distortion. This is illustrated in Fig. 4.

Playing Time

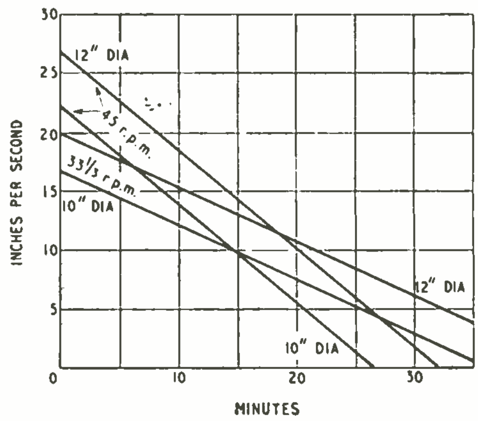
On the assumption of an average of 250 grooves per inch, the playing time can be calculated for various sizes of record, minimum groove velocities, and turntable speeds. From Fig. 5 it will be seen that for each record size and minimum groove velocity there is actually an optimum turntable speed; at this speed the outermost groove is played at twice the minimum groove velocity, and the music occupies just one half

[1] *J. Acous. Soc. Amer.* Vol. 10, July, 1938.
[2] *J. Acous. Soc. Amer.* Vol. 12, January, 1941.

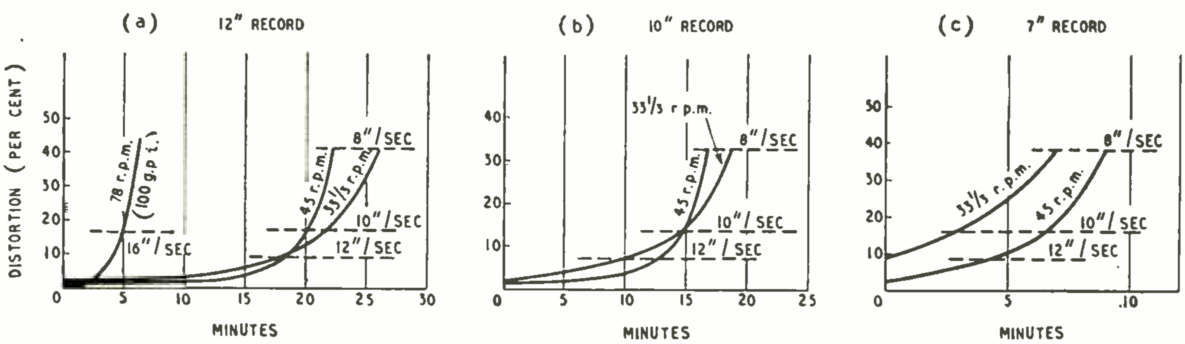


Left : Fig. 7. Groove speed as a function of time, with zero time at the centre of the record.

Right : Fig. 8. Data for 10in and 12in discs replotted from Fig. 7 with zero time at start of outer groove.



Below : Fig. 9. Limitation of playing time by distortion at the inside groove diameter for discs of 12in, 10in and 7in. external diameter at alternative turntable speeds.



of the radius of the record. The curve of playing time plotted against turntable speed is, however, very flat near its maximum and change of speed by 20 per cent in either direction from the optimum only results in reducing the playing time by 4 per cent from the maximum. For this reason, it is only necessary to consider the two figures of $33\frac{1}{3}$ r.p.m. and 45 r.p.m. which have already been adopted: if the optimum for any given set of conditions falls centrally between these two, no great loss can arise from adopting either.

It is obvious that linear speed, which has a marked effect on quality, is greater at the starting groove of a record turning at 45 r.p.m. than on one of the same diameter turning at $33\frac{1}{3}$ r.p.m., but equally clear that, as the needle moves into the centre more rapidly in the faster record, the linear speed falls off more rapidly. Actually, there is a time at which the two records, started at the same instant, will be moving at the same linear groove speed and, after this point, the record which is rotating at only $33\frac{1}{3}$ r.p.m. will actually have the higher linear speed and therefore give the better quality. This critical point occurs at about 15 and 18 minutes from the start on 10in and 12in records respectively, and occurs at linear speeds of about $9\frac{1}{2}$ and $11\frac{1}{2}$ inches per second.

In Fig. 6, the variation of groove velocity is plotted against the diameter of the groove which is being played. The diameter of the inner groove is given by the intersection of the appropriate line with the limiting groove velocity chosen: from this the useful area of the record can be deduced. In Fig. 7, the tangential speed is plotted against time, and as a matter of convenience, zero is the time when the needle reaches the axis of the record. To compare the performance at the two speeds for a particular outer groove diameter, the curves are shifted laterally to align the points corresponding to the outer groove diameters, and the zero is shifted to this actual starting point. The pairs of lines corresponding to 12in and 10in records resulting from this operation are shown in Fig. 8, and indicate the critical points already mentioned. Graphs of this kind have been used, in conjunction with the inverse fourth power conversion, to calculate the curves of distortion for various record diameters shown in Fig. 9. In each case, the starting groove is taken as having a diameter half an inch less than the nominal outside diameter of the record.

Summarizing, it can be stated that:

(a) 12in records can be played at either $33\frac{1}{3}$ or 45 r.p.m. with good quality to 18 minutes. At 45 r.p.m. the 10 inches per second limit is reached at just over 20 minutes: at $33\frac{1}{3}$ r.p.m. this limit is extended nearly to 22 minutes. The rise of distortion is illustrated in Fig. 9(a).

(b) 10in records can, in the extreme, be played to $14\frac{1}{2}$ minutes at either speed, but the last 4 minutes of playing will have noticeably better quality on the 45-r.p.m. record. The lower distortion in the latter case is indicated in Fig. 9(b).

(c) For smaller records, the higher turntable speed is unquestionably better: by this means popular 5-minute recordings can be made comfortably on 7in discs. The advantage is clearly shown in Fig. 9(c).

In deducing the minimum groove velocity we have tacitly assumed that the techniques of recording and

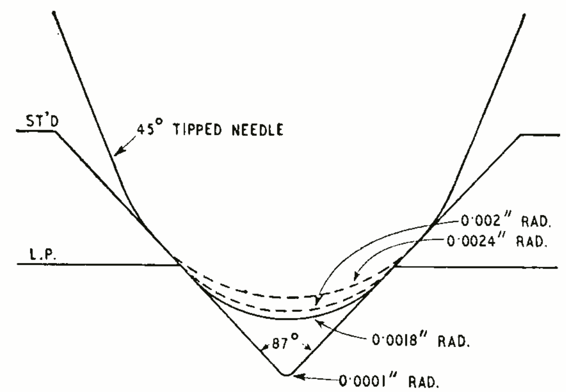


Fig. 10. Standard and microgroove sections superimposed with needle tips of different radii.

processing have kept pace with the reduction of needle size. Results already achieved show that this is in fact possible, but the process requires an increase in skill and supervision, and adds considerably to the production difficulties.

If the choice of turntable speeds were completely free, it would still be difficult to arrive at a definite optimum, because the relative commercial importance of short and long recordings exerts so much control on the choice.

It is impracticable to use the optimum speed where the record is smaller than 8in, because this, after allowing for a run-off groove, would leave an inadequate label diameter. For an 8in record, the optimum varies from 60 r.p.m. to 50 r.p.m. according to the quality permitted. The higher speed should be deprecated, however, partly because it allows no margin for squeezing a little more on to a record (which is quite justifiable where the record ends with a quiet passage), and partly because it is very uneconomical for 12in records. The highest speed that should be considered is therefore 50 r.p.m.

At the other end of the scale, the optimum for 12in records varies from 40 r.p.m. to $33\frac{1}{3}$ r.p.m. according to quality, but the loss due to using 40 r.p.m. is, in any case, small. The range of choice therefore lies between 40 r.p.m. and 50 r.p.m. It should be biased to one end or the other of this range according to the relative importance of large and small records respectively.

The Use of Universal Needles

In this report no account has been taken of the American proposals for truncated or other universal needles, although we appreciate the practical convenience of such a needle. Most recording companies are now cutting the 78 r.p.m. type of record with a radius at the bottom of the groove of 0.001in, but it must be remembered that there are a large number of records in circulation which have a bottom radius of at least 0.002in. A universal needle will not necessarily ride on the straight walls of a groove unless the width at the points of engagement is less than 0.0024in (for microgroove records) and simultaneously greater than 0.0028in (for the older 78 r.p.m. records). It follows that, in one case or other, the needle will ride on surfaces which are not accurately controlled, and noisy results will be obtained. These points will be clear from an inspection of Fig. 10.

Apart from this noise, a needle with a tip of radius 0.002in, playing a microgroove record, will give four times the tracing distortion of the standard (0.001in radius) microgroove needle.

An elliptical cross-section point with a small radius of curvature at the contact edge would reduce the distortion, but with a principal radius of 0.002in would contact the microgroove at the shoulder, which is not desirable.

I would like to thank Mr. R. E. Spencer for collaboration in its preparation.

FREQUENCY TEST RECORDS

Calibration Methods Discussed by the B.S.R.A.

IN the past, standard test records have been taken more or less for granted as the basis for comparison of pickup performances. The use of vinyl plastic materials for pressing new test records has, however, shed some doubt on the validity of many earlier assumptions, and to ventilate the matter thoroughly, a discussion was held in London on March 16th by the British Sound Recording Association.

In opening the discussion, H. Davis, M. Eng., M.I.E.E. pointed out that the voltage output from the terminals of a pickup represented the performance of the combined system of pickup and record. When a record groove is traced by a spherical stylus tip, the pressure at the point contact is theoretically infinite; in practice some deformation of the groove wall always takes place until the contact area is sufficient to reach equilibrium. One consequence of this deformation is that a compliance is added to the equivalent mechanical circuit of the system, and the top resonance frequency is usually lowered. In addition to deformation due to the weight of the pickup head, there is the driving force working against the mechanical impedance at the needle point. This force could be very high, and at high frequencies accelerations of the order of 100*g* were possible, even though the groove deflections were small.

Unless mechanical impedances were known to be negligibly small, it would be better to specify a pickup by a family of curves taken in a variety of test record materials and to say that the performance lies within these limits.

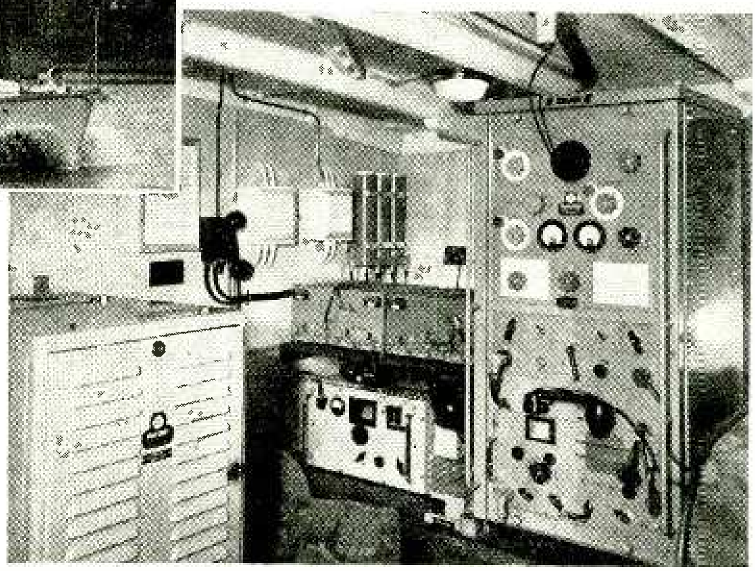
In the discussion which followed, various basic methods of measuring the depth of modulation were discussed, including microscopic examination (difficult at high frequencies where amplitudes may be as small as 10^{-6}in); exploration at low speed with light stylus pressure and a displacement micrometer; measurement of voltage output from a pickup at the resonance frequency of the armature and its supporting compliance where mechanical impedance is a minimum, the speed of the turntable being varied inversely as the nominal frequency (working at one frequency eliminates the pickup characteristic); and the Buchmann and Meyer optical reflection method. Several speakers underlined the importance of adhering to the basic conditions of this test which was applicable only to sine waves and required parallel light from a narrow source. From experience one speaker suggested a single-filament motor lamp bulb at 5 or 6ft, and an observing telescope of small aperture.

Comparison of results obtained by Buchmann and Meyer images and electrical methods, using a high-grade pickup, showed close agreement in the case of the new frequency test records issued by the British Sound Recording Association, and members were satisfied that the calibration figures represented the highest accuracy attainable in measuring the lateral velocity of recording.

A NEW *ELETTRA*

Sea-going Research and Demonstration Yacht

Marconi Marine research and demonstration yacht "*Elettra II.*"



"Transarctic" transmitter - receiver (right) "Seaphone" v.h.f. and "Oceanic" sound reproducing equipment (centre) and transmitter cabinet of "Radiolocator IV" radar (left) as installed in the forward saloon.

TO perpetuate the name of *Elettra*—Marchese Marconi's famous steam yacht in which many of his early experiments with short waves were carried out—the Marconi International Marine Communication Company have put into commission a new diesel-engined yacht, *Elettra II,* which, in addition to providing similar facilities for original experimental work at sea, will also serve as a floating showroom for the latest Marconi Marine equipment.

The new vessel, which was built by J. Samuel White and Company of Cowes, is 72ft overall and is driven by twin Gardner diesel engines each rated at 150 h.p. The cruising range at 10 knots is 1500 miles.

Standard radio equipment at present carried by *Elettra II* includes the "Mercury" long- and medium-wave, and "Electra" medium- and short-wave marine communication receivers, conforming to G.P.O. specifications for ships' general-purpose receivers, "Lodestone" direction finder for the 550-1200 metre range, "Transarctic" telephone/telegraph transmitter/receiver, "Seaphone" v.h.f. radiotelephone transmitter receivers (one for use with the Thames telephone link via Monarch exchange and the other for communication with the Marconi Marine Company's East Ham Depot.)

Radar is represented by the latest "Radiolocator IV" in which the display unit is carried in a compact trunnion mounting for fixing in any of the usually required positions on board ship. An interesting feature of this equipment is that pulse length is automatically varied by the range switch, giving 1 μsec for the long ranges (up to 40 miles) and 0.2 μsec for greater discrimination at short ranges (minimum one mile). The aerial scanner incorporates a built-in performance monitor, and extensive facilities are provided for checking working conditions by means of plug-in meters. The main transmitter cabinet also contains a small c.r. tube for observing all essential waveforms in various parts of the equipment.

Echo-sounding gear is also carried, the permanent installation being the "Seagraph" recording echometer. A new visual depth indicator working on the principle of a rotating arm carrying a flashing neon bulb is undergoing trials and will shortly be put into production. It will be known as the "Visette" and will have a range up to 130 fathoms, suitable for the needs of inshore fishermen and others requiring soundings inside the 100-fathom line.

It is a tribute to the compactness of design that all this equipment has been tucked away in this comparatively small ship, without unduly restricting living accommodation or the amenities offered to visitors. *Elettra II* will be at Oslo during the conference of the international association of radio marine operating companies and has a full programme of visits to other ports on the Continent and this country.

Intermodulation Testing

Some Pitfalls of "Simplified" Routine Methods

By E. W. BERTH-JONES,* B.Sc.

IN recent years the conviction has grown that the most important single factor in the assessment of the quality of audio-frequency apparatus is the absence of what is often called "non-linearity distortion," "amplitude distortion," or "harmonic distortion." A curve may be plotted for the apparatus of instantaneous output against the instantaneous value of the input producing it. In the case of a purely electrical device, such as an amplifier for instance, this could represent instantaneous output voltage versus instantaneous input voltage. If this graph is a perfectly straight line over the working range, then the equipment is distortionless; but if it departs from a straight line, then distortion is introduced, hence the term "non-linearity distortion." The amplification (or loss) of the equipment under test is given by the slope of the graph, and if this is a curved line, the slope (and thus the amplification) changes with the amplitude of the applied signal. From this effect the term "amplitude distortion" is derived.

The curve itself may be expressed as a power series of the form :—

$$y = a + bx + cx^2 + dx^3 + ex^4 + \dots \text{ (to infinity)} \qquad (1)$$

where y is the instantaneous output voltage, x is the instantaneous input voltage, and a, b, c, etc., are numerical coefficients. If these coefficients are correctly estimated, and the graph of the above expression is drawn, it will coincide exactly with the curve derived from the apparatus. However, their exact assessment is so tedious in most cases, that the exercise is not recommended. If we wish to know what happens to the output waveform when a sine wave is applied to the input, we must replace the "x" in the series by some expression defining the input wave, such as :—

$$x = A \cos \omega t \qquad (2)$$

(The cosine wave is chosen rather than the sine, simply because it makes the mathematics rather simpler. As everyone knows, the two waves have the same shape, so it is immaterial which we choose for analysis.)

The output voltage e_0 is equal to y, and the graph of the output waveform against time is obtained by substituting equation (2) in equation (1), thus :—

$$e_0 = y = a + bA \cos \omega t + cA^2 \cos^2 \omega t + dA^3 \cos^3 \omega t + eA^4 \cos^4 \omega t + \dots \qquad (3)$$

By means of well-known identities, which any good trigonometry book will prove to the satisfaction of one and all, the quantities $\cos^2 \omega t$, $\cos^3 \omega t$, etc., may be expressed in terms of $\cos 2\omega t$, $\cos 3\omega t$, and so on, which are waves at twice, three times, etc., the frequency of the original wave, and are known as the second, third, and higher harmonics.

Making the necessary substitutions in equation (3) gives a somewhat lengthy expression which may be simplified by collecting together all the coefficients of $\cos \omega t$, $\cos 2\omega t$, etc., and which then reduces to the form :—

$$e_0 = (a + \tfrac{1}{2}cA^2 + \tfrac{3}{8}eA^4) + (bA + \tfrac{3}{4}dA^3) \cos \omega t + (\tfrac{1}{2}cA^2 + \tfrac{1}{2}eA^4) \cos 2\omega t + (\tfrac{1}{4}dA^3) \cos 3\omega t + (\tfrac{1}{8}eA^4) \cos 4\omega t + \dots \qquad (4)$$

The first term is a constant, independent of $\cos \omega t$. This represents a direct current, and is normally filtered out from the output by a blocking condenser or transformer, so it is of no further interest here.

The second term is the fundamental, at the original frequency, and succeeding terms are second, third, etc., harmonics. An interesting point to note is that even-order harmonics derive entirely from even powers of "x," and odd harmonics entirely from odd powers.

Two-tone Testing

A parallel effect becomes significant when we come to consider intermodulation distortion. In order to measure the intermodulation distortion of a piece of apparatus, it is necessary to introduce into the input two tones of different frequencies, f_1 and f_2. If there is any distortion present, we shall obtain from the output the original two frequencies, and in addition certain spurious tones which were not present at the input. These tones are the harmonics of f_1 and f_2, and others which are generally said to occur at frequencies equal to the sum and difference of f_1 and f_2. It might be worth while to investigate this statement to see if it is invariably true.

In the interest of simplicity in this example, the fourth and all higher powers of "x" in the power series

TABLE 1

Expansion of the first four terms of the power series $y = a + bx + cx^2 + dx^3 + \dots$ when $x = B \cos \omega_1 t + C \cos \omega_2 t$

$e_0 = a + \frac{1}{2} cB^2 + \frac{1}{2} cC^2$ (direct current term)	
$+ (bB + \frac{3}{4} dB^3 + \frac{3}{2} dBC^2) \cos \omega_1 t$ $+ (bC + \frac{3}{4} dC^3 + \frac{3}{2} dB^2C) \cos \omega_2 t$	(fundamental terms)
$+ \frac{1}{2} cB^2 \cos 2\omega_1 t$ $+ \frac{1}{2} cC^2 \cos 2\omega_2 t$	(second harmonic terms)
$+ \frac{1}{4} dB^3 \cos 3\omega_1 t$ $+ \frac{1}{4} dC^3 \cos 3\omega_2 t$	(third harmonic terms)
$+ cBC \cos(\omega_1 + \omega_2)t$ $+ cBC \cos(\omega_1 - \omega_2)t$ $+ \frac{3}{4} dBC^2 \cos(\omega_1 + 2\omega_2)t$ $+ \frac{3}{4} dBC^2 \cos(\omega_1 - 2\omega_2)t$ $+ \frac{3}{4} dB^2C \cos(2\omega_1 + \omega_2)t$ $+ \frac{3}{4} dB^2C \cos(2\omega_1 - \omega_2)t$ + higher order terms.	(intermodulation terms)

* E.M.I. Studios Ltd.

may be omitted, and since the input now consists of two tones, we must write :—

$$x = B \cos \omega_1 t + C \cos \omega_2 t \quad \ldots \quad (5)$$

where B + C = A of equation (2).

Since the two waves are, in the general case, of different frequency and not multiples one of the other, they will eventually come into phase with each other instantaneously, and this point may be taken as the instant when $t = 0$. This artifice enables us to omit any initial phase angle from expression (5) and further simplifies the mathematics without invalidating the argument.

Substituting for "x" from (5) in equation (1), expanding, and collecting coefficients, the output can be expressed in the form shown in Table 1.

It is perhaps convenient to consider the harmonics as being merely a special case of intermodulation, due to each fundamental tone beating with itself. In this connection it is interesting to see what happens when the two tones approach one another in frequency until in the limit, they are equal. Then :—

$$\omega_1 = \omega_2 = \omega \quad \ldots \quad (6)$$

We have already stated that B + C = A, and it will simplify the arithmetic if we make $B = C = \frac{1}{2}A$. In order that the peaks shall reach the same point on the distortion curve in each case, it is also necessary to stipulate that the two waves are in phase.

If we now write ω for ω_1 and ω_2, and $\frac{1}{2}A$ for B and C, in Table 1, and collect together and simplify the coefficients of each of the resultant frequencies, we are left with :—

$$e_0 = (a + \tfrac{1}{2}cA^2) + (bA + \tfrac{3}{4}dA^3) \cos \omega t + (\tfrac{1}{2}cA^2) \cos 2\omega t + (\tfrac{1}{4}dA^3) \cos 3\omega t + \ldots \quad (7)$$

Compare this with equation (4) for the single tone. In the case of the intermodulation analysis we have agreed to omit the fourth and higher powers of "x" in the series, for simplicity's sake, so that the coefficient e in equation (4) becomes zero, if we are to get a direct comparison. Rewriting equation (4), omitting all terms containing e, results in an expression identical with equation (7).

This result may be said to be obvious, but sometimes obvious results do not work out when subjected to analysis : and sometimes they are not obvious until they have been pointed out. The interesting point to be noted is that harmonic distortion and intermodulation distortion are not two entirely different kinds of distortion, as some people seem to think, but are merely two symptoms of the same complaint, namely non-linearity of the transfer characteristic. Provided enough terms are taken, measurements of either will tell the whole story, but there are many cases when it is not possible to measure enough terms.

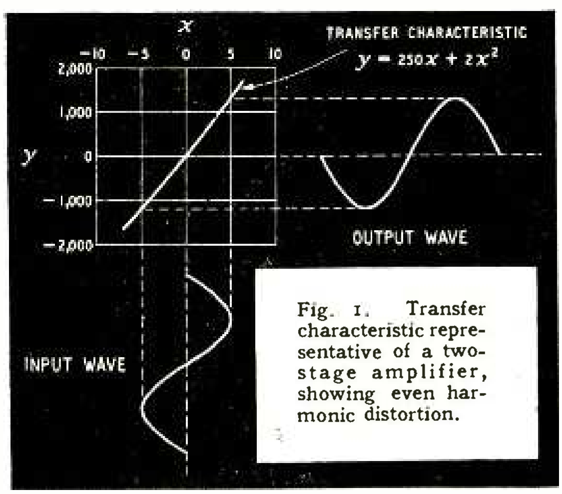


Fig. 1. Transfer characteristic representative of a two-stage amplifier, showing even harmonic distortion.

For example, if we want to assess the distortion of a typical audio amplifier at 10 kc/s, we shall be lucky if we can measure even the second harmonic. But by letting the 10 kc/s note drive the amplifier to the required level, and adding a second note of lower level and frequency, say 400 c/s, 12 db down in level, we can produce intermodulation tones within the pass band of the amplifier, which can be measured, as described previously in this journal[1] and elsewhere. With most audio-frequency apparatus, the intermodulation percentage usually exceeds the harmonic percentage, so that for low distortion levels, it is easier to measure, and probably is directly responsible for most of the annoyance value of the distortion.

The method generally employed for measuring the intermodulation is to mix the two tones and put them through the apparatus under test. The lower frequency tone is filtered out from the output, and the high-frequency tone, which becomes the carrier, together with the principal intermodulation products in the form of sidebands, is passed to a detector of known efficiency (sometimes !). The output of the detector will contain the low-frequency tone, together with the modified carrier and sidebands, and higher-order products. All but the low-frequency tone are filtered out, and the latter is measured and compared with the amplitude of the carrier which produced it. The ratio is expressed as a percentage of the carrier, and generally refers to peak values. The r.m.s. or arithmetic value sometimes measured and quoted cannot be inferred from this, as the sum of all the intermodulation products is far from sinusoidal.

To get an idea of the magnitudes to be expected, let us take a very simple case as a practical example. Suppose that in equation (1) we make $a = 0$, $b = 250$, $c = 2$, $d = e = f$ etc. $= 0$

$$\text{Then } y = 250x + 2x^2 \quad \ldots \quad (8)$$

is the equation of the transfer characteristic, and the curve is shown in Fig. 1. This might represent a two-stage amplifier, having an amplification of 250 times, and perhaps in need of a little feedback. Into this amplifier we put a 400-c/s sine wave (or cosine wave) of amplitude 5. Then A = 5 and $\omega = 2\pi \times 400$ in equation (2). We shall write the symbol cos (400) to represent $\cos (2\pi \times 400)t$, etc. Substituting these values in equation (4), we obtain $e_0 = (0 + 25 + 0) + (1{,}250 + 0) \cos (400) + (25 + 0) \cos (800) + (0) + (0) +$ etc. The 2nd harmonic amplitude is 25 when the fundamental is 1,250, i.e., there is $\frac{25 \times 100}{1{,}250} = 2$ per cent 2nd harmonic, and no 3rd or higher.

Suppose now that we apply two tones simultaneously, namely 400 c/s at amplitude 4, and 4,000 c/s at amplitude 1. Then

$$B = 1, C = 4, \text{ and } B + C = A = 5.$$

Substituting these values in Table 1, and simplifying we obtain

$$e_0 = 17 + 250 \cos (4{,}000) + 1{,}000 \cos (400) + 1 \cos (8{,}000) + 16 \cos (800) + 8 \cos (4{,}400) + 8 \cos (3{,}600).$$

From this, filter out all frequencies below, say, 2,000 c/s (taking care that the filter coils do not intro-

[1] "Intermodulation Distortion," by Thomas Roddam. April, 1950, p. 122.

duce more intermodulation than the amplifier under test) leaving :—

$$250 \cos(4{,}000) + \cos(8{,}000) + 8\cos(4{,}400) + 8\cos(3{,}600).$$

The last two terms of this expression are

$$8[\cos(4{,}000 + 400) + \cos(4{,}000 - 400)]$$
$$= 8[2\cos(4{,}000)\cos(400)] \quad .. \quad .. \quad .. \quad (9)$$

The signal thus consists of

$$250\cos(4{,}000) + 16\cos(4{,}000)\cos(400) + \cos(8{,}000)$$
$$= 250\left[1 + \frac{16}{250}\cos(400)\right]\cos 4{,}000 + \cos(8{,}000) \quad .. \quad .. \quad .. \quad .. \quad (10)$$

As is well known, the first part of this expression represents a 4,000 c/s carrier modulated to a depth of $\frac{16}{250}$ = 6.4 per cent by a 400 c/s tone. If this combination is passed through a detector, and all frequencies above, say 600 c/s are filtered out, we shall be left with a 400 c/s tone whose magnitude will be 6.4 per cent of the carrier level measured at the detector input, provided that the detector efficiency is 100 per cent.

To get the true value, the measured level must be divided by the detector efficiency, and as this is liable to be variable with carrier strength, measurements should always be made at a fixed carrier level. The problem of measuring accurately the detector efficiency is probably the most difficult one to be solved in making up an intermodulation test set, and is one frequently overlooked. A diode detector operated at 10 volts or more input, with a condenser of optimum value in parallel with a high-resistance load, has a fairly high efficiency (about 92 per cent with practical component values, for a frequency ratio of 10 : 1), but even so it should be checked if good accuracy is desired.

The question of detector efficiency has been very fully treated in the literature[2], and it is not proposed to go more fully into it here, except to emphasize its importance. For example, it sometimes happens that the two frequencies are so chosen that an important intermodulation product falls within an octave or so of the carrier. Under these conditions, it is not safe to use a reservoir condenser after the detector, and the efficiency falls to $\frac{1}{\pi}$. Unless allowance is made for this, the amplifier under test will appear about three times better than it really is ! The filter may modify the detector behaviour considerably, and it is advisable to use a buffer valve between detector and filter.

It has been shown that in the case under discussion, the intermodulation product is 6.4 per cent of the carrier, and we started with a 4,000 c/s carrier of one-fifth of the total amplitude. The intermodulation product is thus only $\frac{6.4}{5}$ or 1.3 per cent of the total input wave, and, on the face of it, would appear more difficult to measure than the 2 per cent harmonic in the single tone case. However, after filtering, it is permissible to amplify the carrier and sidebands considerably, even at the risk of some distortion, without the intermodulation depth being materially affected. This gives the intermodulation test method a slight advantage.

One further practical example is of considerable interest. Using exactly the same process as in the previous example, let us introduce, in equation (1)

$$a = 0, b = 250, c = 0, d = -2, e = f = \text{etc.} = 0.$$

[2] "Radio Receiver Design," by K. R. Sturley Part 1. p. 369. (Chapman & Hall.)

Then the equation of the transfer characteristic is

$$y = 250x - 2x^3 \quad .. \quad .. \quad .. \quad .. \quad (11)$$

and its shape is shown in Fig. 2. This might represent a poor gramophone pickup, an overloaded transformer, or a well-balanced push-pull amplifier driven up to overload point. We shall again put in a single 400 c/s note of amplitude A = 5. Substituting these values in equation (4) we have

$$e_0 = (0 + 0 + 0) + (1{,}250 - 187.5)\cos(400) + (0) - (62.5)\cos(1{,}200) + (0) + \ .. \quad (12)$$

The 3rd harmonic term is 62.5 when the fundamental is 1,062.5 and the 3rd harmonic is therefore about 5.9 per cent of the fundamental. For the intermodulation case, we apply the same tones as before, and again B = 1, C = 4 and B + C = A = 5. Substitute in Table 1, filter out all frequencies below, say 2,000 c/s, as before, and simplify, and we get

$$e_0 = 200.5\left[1 - \frac{48}{200.5}\cos(800)\right]\cos(4{,}000) - \tfrac{1}{2}\cos(12{,}000) - 12\cos(8{,}000)\cos(400) \ .. \quad (13)$$

The last term has no carrier, so only the first term will be demodulated in the detector. But in this expression there is no 400 c/s term in the modulation bracket, so nothing will pass through the 600 c/s low-pass filter, and no distortion will be measured on the intermodulation meter ! From the harmonic distortion test, however, we already know that the distortion is somewhat fearsome, nearly 6 per cent of third ! Obviously one up to harmonic testing.

Design Precautions

Of course, if we are aware that the principal intermodulation tone occurs at 800 c/s we can alter the cut-off frequency of the low-pass filter so that it will pass. Even so, the reservoir condenser of the detector, which has been made of optimum value to give the highest possible detector efficiency for a modulation tone of 400 c/s, will bypass the 800 c/s tone partially, with the result that the effective overall efficiency of the detector will fall to about 75 per cent. If we redesign the detector for 800 c/s with a carrier of 4,000 c/s, the optimum overall efficiency becomes about 90 per cent. But we should be lucky if the equipment under test had a transfer characteristic represented by as simple a power series as the one we have chosen, and maybe there are important intermodulation products at 1,200 and 1,600 c/s. It is these factors

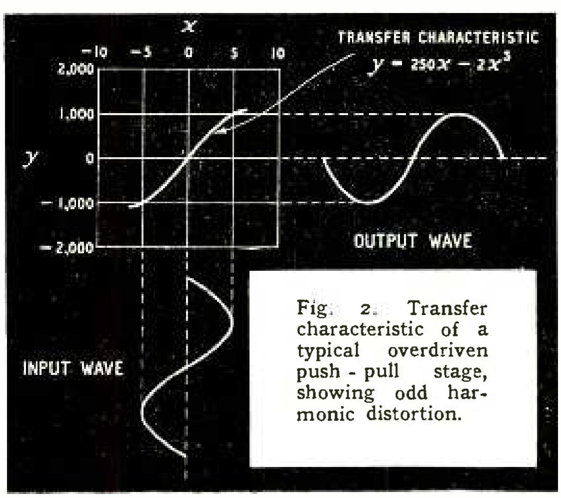


Fig. 2. Transfer characteristic of a typical overdriven push-pull stage, showing odd harmonic distortion.

which cause the wide divergences of intermodulation reading as measured on different measuring sets.

The great danger lies in the fact that, in the push-pull amplifier example just considered, there would in practice almost certainly be some second harmonic distortion, and therefore some 400 c/s, intermodulation present in the output—say 5 per cent. With the original 600 c/s filter, this would be measured, and might well be quoted as the intermodulation figure for the amplifier. Equation (13) has shown us that the principal intermodulation tone is at 800 c/s, and its modulation depth is $\frac{48}{200.5}$, or nearly 24 per cent! To generalize, it may be said that, in cases where second harmonic distortion predominates, the principal intermodulation product will occur at the difference frequency of the two tones, but where third harmonic is greater, it will fall at $(f_1 \pm 2f_2)$ or $(2f_1 \pm f_2)$, depending on the values of the coefficients. If higher order harmonics are present in any great magnitude, it is safer to measure all the separate intermodulation products with an analyser.

The moral of this story is that, while intermodulation testing is a very useful tool, always make sure that the test equipment fully covers all the requirements. And that is not as simple as we are sometimes led to believe.

General reference: "An Analysis of the Intermodulation Method of Distortion Measurement," by W. S. Warren and W. R. Hewlett. *Proc. I.R.E.*, Vol. 36, No. 4, April, 1948.

APPENDIX

The following trigonometrical identities are useful in deriving the equations, and Table 1.

$$\cos(\theta + \phi) = \cos\theta\cos\phi - \sin\theta\sin\phi$$
$$\cos(\theta - \phi) = \cos\theta\cos\phi + \sin\theta\sin\phi$$

Whence, adding, $\cos(\theta + \phi) + \cos(\theta - \phi) = 2\cos\theta\cos\phi$

or if $\theta = \phi$, $\cos 2\theta + 1 = 2\cos^2\theta$

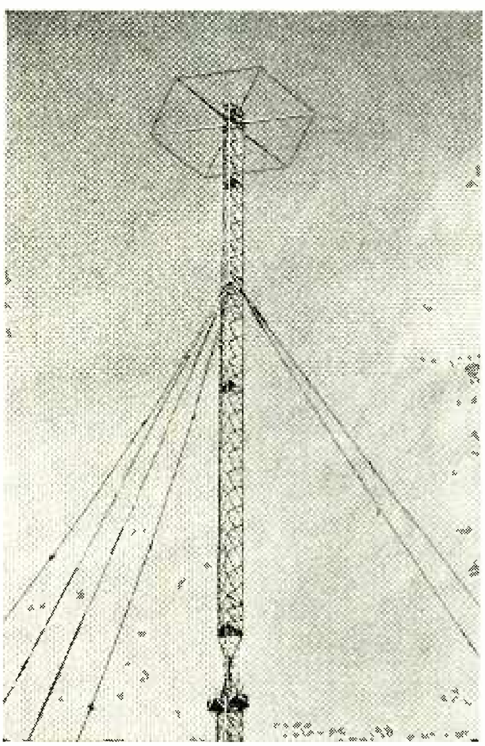
It follows from this that

$$\cos^2\theta = \tfrac{1}{2}\cos 2\theta + \tfrac{1}{2}$$
$$\cos^3\theta = \tfrac{3}{4}\cos\theta + \tfrac{1}{4}\cos 3\theta$$
$$\cos^4\theta = \tfrac{3}{8} + \tfrac{1}{2}\cos 2\theta + \tfrac{1}{8}\cos 4\theta.$$

New Daventry Station

200-kW Transmitter Designed for Unattended Working

By R. W. HALLOWS, M.A. (Cantab.), M.I.E.E.



Top section of the Daventry mast, showing the insulated "break". The radiator is fed at this point through a concentric line.

THE first question that a visitor to the B.B.C.'s new "Third Programme" station at Daventry feels inclined to ask is: "Where's the transmitter?" For he is taken to begin with to a large field in which the only visible radio feature is a 725ft lattice mast and no building save the small aerial tuning house is to be seen. The transmitter is in fact a mile away on the other side of an intervening hill. The reason for this unconventional layout is that the transmitter occupies the hall which originally housed the old 5XX. Near this there are now numerous aerial arrays belonging to the shortwave transmitters; interaction between these and the new station's vertical radiator would have been inevitable, had it been erected on the site.

The transmission line, which is actually 2,640 yards in length, is of the open-wire unbalanced type. The inner conductor consists of four No. 6 gauge copper wires spaced round the circumference of a half-inch circle; the outer conductor has eight wires of the same gauge spaced round an 18in circle. The line is carried on 18ft steel poles at 50yd intervals. A remarkable feature is that the loss over this great length of line is rather less than 0.35 db: to obtain an aerial output of 150 kW the input needed from the transmitter is 162 kW.

The vertical radiator normally operates as a virtual dipole, the feed being to its nodal point. The mast is divided into two sections by an insulator at 460ft from the ground. The upper section has a "capacitance top" consisting of six 35ft horizontal spokes, with their outer ends inter-connected by wires, and the two sections are balanced by high-Q loading inductances in the aerial tuning house. Centre-feed has been adopted with a view to minimizing high-angle radiation due to feed-current effects; with a comparatively feeble sky-wave a large fading-free service area is ensured.

It was expected that this first-class service area of the new station would have a radius of the order of 100 miles and this expectation seems generally to have been fulfilled.

The aerial may also be fed from the bottom as a stand-by measure, in which case it functions as a normal series-loaded mast radiator. The switches controlling the centre-feed and bottom-feed coupling equipments in the aerial tuning house are remotely controlled from the main transmitter building.

It seems almost uncanny that a high-powered station should have been designed for unattended working; yet, once the Third Programme station has been run in, it is intended that there should normally be no one in the transmitter hall while it is operating. Automatic monitoring apparatus will keep an untiring electronic eye on the quality, continuously comparing the signal radiated from the aerial with the signal at its point of origin in London, and sounding an alarm bell in the nearby short-wave transmitter building on the occurrence of a defect serious enough to cause any kind of distortion noticeable to the ears of listeners. This is the first application of automatic monitoring to a high-power transmission.

It is likely that the station will eventually be operated entirely by remote control, either from another building at Daventry or from London. Experiments are in progress with apparatus which enables the transmitter to be switched on or off from a distant point and connected either to the aerial or to a test load. There is, however, one difficulty here: the transmitter is a "twin", consisting of two 100-kilowatt plants working in parallel, and the necessary phasing must be done by engineers on the spot.

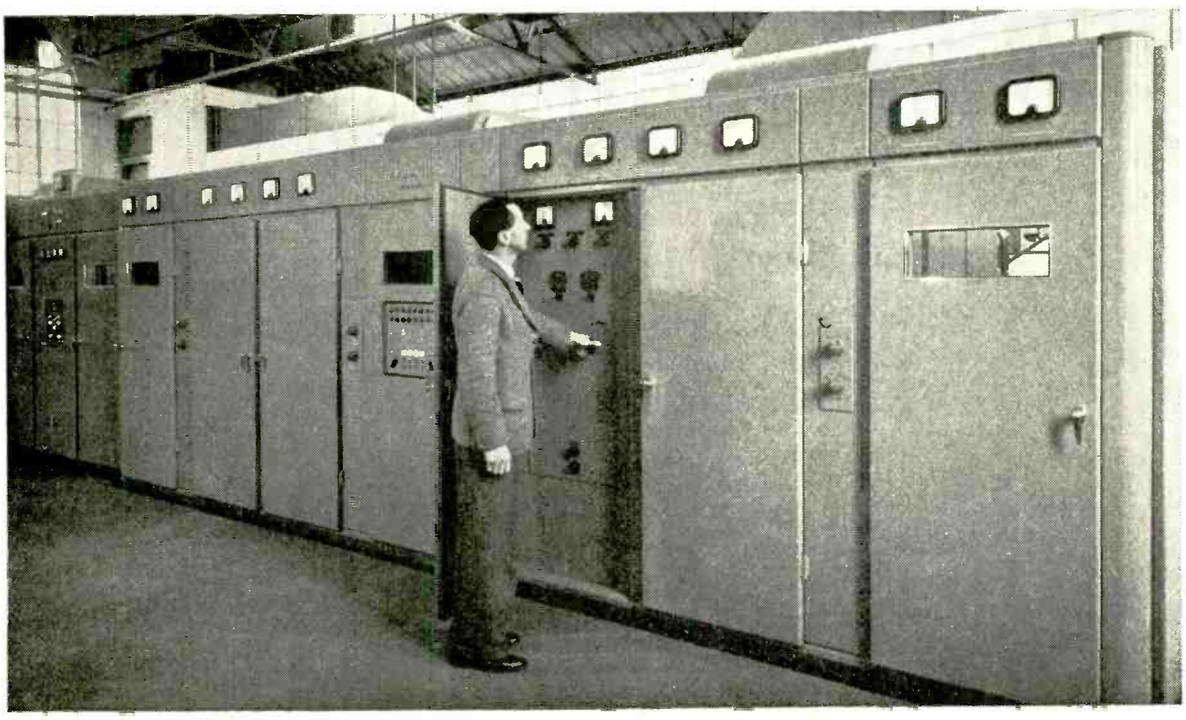
Though the available output power is 200 kW, only 150 kW can be used at present, owing to the limitations imposed by the Copenhagen Plan. The advantage of using coupled transmitters for broadcasting is that, should one of them break down the other carries on the service; in the present instance the power of the transmitter left in action could presumably be run up to 100 kW and there should be no serious fall in signal strength.

There are many points of interest about the two transmitting sets. Not so many years ago the construction of the first transmitters to use water-cooled valves was hailed as a great advance in wireless technique, as indeed it was. To-day, the Third Programme transmitter marks an even greater step forward by using air-cooled valves throughout! The anomaly is, of course, only apparent. Water-cooling, when it was introduced, made really high-powered broadcasting possible by providing the only means then known of dissipating heat sufficiently rapidly. The necessary water circulating apparatus is, however, expensive besides occupying a great deal of space and involving the use of rotating machinery. Air-cooling on the grand scale (each 100 kW section of the transmitter requires some 12,000 cubic feet of air per minute) is a greater advance, since it is cheaper to install, needs far less space and contains no rotating machinery except the blower. It also lends itself readily to remote control. The air-blower, by the way, is the only rotary machine in the transmitter building, for the filaments of all valves are heated by a.c.

The use of air cooling has been made possible partly by special valve design and partly by sharing out the load amongst a considerable number of valves. In either half of the transmitter there are four BR126 triodes in parallel push-pull in both the final amplifier and the final modulator stage. Sixteen valves, therefore, take part in providing the normal 150 or possible 200 kilowatts of modulated output power.

The 12,000-V h.t. supply for the modulator and modulated amplifier is provided by six single-anode mercury-arc rectifiers in a full-wave three-phase circuit. The system is more compact than those using

One 100-kilowatt unit (with combining unit at extreme left) of the high-power Marconi air-cooled transmitter at the new Daventry station.



multi-anode rectifiers and enables a h.v. transformer of ordinary type to be used.

The control desk is striking by reason of its neat and convenient layout and of the completely temporary-mental-aberration-proof arrangement. When the station is being controlled manually the engineer in charge can see the transmitter through the large windows in front of him. The controls—reminiscent of those of some wartime radar sets—are interlocking, with automatic time-delay contactors where necessary. Thus the filaments cannot be switched on until the air-blower has been started; after the filament button has been pressed there is an appropriate warming-up time before a pilot lamp lights up to show that the full voltage has been applied; h.t. voltage cannot be fed to the anodes until the grids have their proper biasing voltages.

Either half of the transmitter may be connected to the aerial or to a water-cooled artificial load, a conspicuous green arrow on the front of the transmitter concerned lighting up and indicating unmistakably which connection has been made.

Can we see in this Third Programme transmitter the shape of things to come in the design and lay-out of broadcasting networks? I believe that we can. Giving one's imagination play, one sees each network of the future as a number of high-, medium- and low-powered "slaves", all remotely controlled by a central "master" station and all virtually unattended. Rapid developments are taking place in remote-control methods and the system seems certain to have wider and wider applications as time goes on. If all new stations (except, possibly, those of very small power) are to be of the twin-transmitter type, as I believe will be the case, remote control may eventually be able to take charge of the phasing. And may not the automatic monitor develop into something more than a warning device? It appears well within the bounds of possibility that the "automatic controller" of some years hence may be able to "interpret" the signals of its monitoring section and to set on foot in its controlling section the action necessary to correct the defects to which they call attention without any human intervention.

Electromagnetic Gramophone Pickups

Design Problems Discussed by the B.S.R.A.

UNDER the title "The Design of Magnetic and Dynamic Pickups," H. J. Leak, M.Brit.I.R.E., gave a lecture and demonstration to the British Sound Recording Association on April 20, on the relative merits of moving-iron and moving-coil types. After describing the principles underlying their operation, he gave demonstrations using intermodulation and square-wave test records in conjunction with a large-diameter demonstration c.r. oscilloscope in support of his preference for the moving-coil type. He pointed out the possibility of non-linearity in moving-iron pickups arising from the square-law variation of attraction as the armature was deflected from the mid-position towards either of the pole pieces, and also from hysteresis arising from the cyclical change of flux in the armature.

In the discussion which followed defenders of the moving-iron principle, while admitting the existence of these potential sources of distortion, showed that by choice of suitable materials and proper design they could be reduced to levels comparable with distortions which might arise from non-uniformity of the field in moving-coil pickups. In the moving-iron pickup it was pointed out that the non-linearity was of opposite sense on each side of the mid-position and that for small amplitudes the response was linear.

Reference was made to the rustling noise which is often heard when the armature of a moving-iron pickup is moved from side to side, slowly by hand. This was attributed to Barkhausen noise which arises from the discrete orientation of particles in the crystalline structure of the magnetic material. There is a threshold value below which this effect is not observed, and, as in the case of distortion, the obvious solution would be to design for operation at low levels.

R.I.C. Components Specifications

IN order to cover all radio requirements it is recommended by the Radio Industry Council that components be classified under three headings, red, yellow and green in descending order according to their ability to withstand extremes of temperature and humidity.

Specifications covering the classifications, dimensions, conditions of use, types, tolerances, methods of storage, electrical and mechanical tests, where appropriate, of a number of different components have been issued so far, and it is proposed to deal with all components in a like manner in future publications.

Among the latest specifications issued by the R.I.C. are those for variable capacitors (RIC/141), fixed paper capacitors (RIC/136), small power transformers (RIC/214), plugs and sockets for use up to 1 Mc/s (RIC/321), and for use above 1 Mc/s (RIC/322).

A colour code for fixed capacitors has at long last been agreed. This is the same as that used for resistors, the values indicated being in picofarads. The alternative numerical method of marking is optional.

Copies of these specifications, which are intended for use within the radio industry only, and of all earlier issues, can be obtained from The Radio Industry Council, 59, Russell Square, London, W.C.1, the price being 5s each.

FROM AERIAL TO LOUDSPEAKER

A STEP-BY-STEP survey of the superhet is given by W. E. Miller, Editor of our associate journal *The Wireless & Electrical Trader,* in his book, "Radio Circuits," the third edition of which has recently been issued by the Trader Publishing Company. This edition includes a new chapter on the "all-dry" portable and band spread and automatic tuning. This 120-page book, which has 64 diagrams, costs 5s (postage 4d).

Frequency Modulation

2—Sidebands and Noise

By "CATHODE RAY"

BEFORE we start on what is bound to be rather less simple than last month's general review of f.m., let us be quite clear about the various frequencies involved:

Carrier-wave frequency, f_c. The frequency of the radiated waves, usually reckoned when they are not being modulated. Commonly of the 100-Mc/s order.

Modulation frequency, f_m. The frequency at which f_c is "wobbled" by modulation; e.g., for sound, anything up to 10-20 kc/s.

Frequency swing, f_s. The amount of the "wobble" each side of unmodulated f_c. For example, if f_s is 30 kc/s and f_c is 90 Mc/s, the carrier frequency wobbles between 89.97 and 90.03 Mc/s (Fig. 1). It is a measure of the depth of modulation.

Frequency deviation, f_d. The maximum frequency swing allowed at a particular station. A standard f_d for broadcasting is 75 kc/s.

The ratio f_s/f_m is the *modulation index* (M) and f_d/max. f_m is the *deviation ratio*. Whereas the deviation ratio is part of the fixed specification of a station, the modulation index refers to what is actually happening at any given moment, and is continually varying during a normal programme. Since the effect of modulation is to vary the radiated frequency between $f_c - f_d$ and $f_c + f_d$ as extreme limits, it probably seems obvious that the bandwidth occupied by the station is $2f_d$. Actually that is true only when the frequency is varied infinitely slowly. When it is varied at the frequency f_m, and f_m is comparable with or greater than f_d, the frequency band is considerably broadened. In fact it is rather more than either $2f_d$ or $2f_m$ or even $2(f_d + f_m)$.

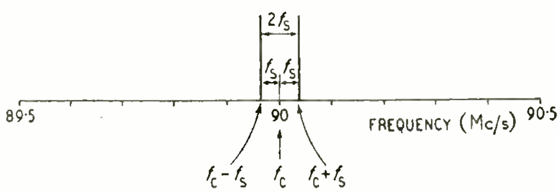


Fig. 1. Frequency diagram illustrating the meaning of frequency swing, f_s. The carrier-wave f_c, in this example is 90 Mc/s, and f_s is 30 kc/s.

Another thing about frequency modulation—and this may seem even more incredible—is that although modulation by a constant f_m causes the carrier frequency to slide continuously to and fro between its limits, it is the same thing as a number of fixed frequencies, just like the carrier-wave and sidebands in amplitude modulation but rather more complicated. This statement probably sounds as sensible as saying that a man journeying to and fro every day between home and work is no different from the same man standing still all the time at a number of points *en route*. The mathematical proof of the above facts is more difficult than the corresponding proof for amplitude modulation, and it is far more difficult—I would be inclined to say impossible—to visualize. But it is quite easy to get a picture of both by a simple vector diagram. In case you are not already familiar with the vector diagram for a.m. I will begin with that.

The length of a vector, you will remember, represents the magnitude of an alternating voltage (or current), and the frequency is represented by the number of anticlockwise revolutions the vector makes per second. So an unmodulated carrier wave is represented by a single vector rotating at f_c revs. per second. Since f_c is a radio frequency, it is rather difficult to see what it is doing when it is turning so fast. But if we climb on to it so that we are rotating at the same speed it will seem to be standing still, relative to us, and we can study it closely. If it is to represent amplitude modulation it must alternately lengthen and shorten f_m times per second without altering its own frequency of rotation. But it is not in the nature of vectors to lengthen and shorten just by themselves. However, a vector can be lengthened by adding another vector to it in the same phase, or shortened by adding another one to it in opposite phase. A single extra vector, if it rotates relatively to the first, comes alternately into phase and opposite phase, so when added to it does give a resultant that alternately lengthens and shortens.

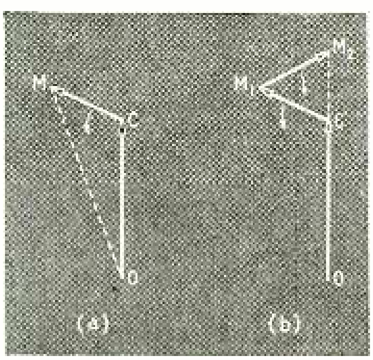


Fig. 2. (a) When a carrier wave, represented by the vector OC, and a single side frequency, represented by CM, are added together, the resultant (OM) alternately lengthens and shortens (amplitude modulation) and also wags from side to side of OC. (b) But if there are two side frequencies, equally lower and higher than f_c, so that their vectors CM_1 and M_1M_2 rotate in opposite directions relative to OC, the resultant (OM_2) shows pure amplitude modulation.

But unfortunately the resultant also wags from side to side, like the connecting rod in an engine (Fig. 2(a)). This undesired complication can be avoided if instead of adding a single extra vector we add a pair of them, both rotating at the same speed relative to the carrier-wave vector, but in opposite directions. If all three start off in the same phase, the vector sum of the three is always in phase with the carrier-wave vector, but is alternately longer and shorter; and if the two extra vectors rotate at constant speed, the lengthening and shortening follow a sine-wave law. (You can demonstrate this for yourself by drawing Fig. 2(b) with CM_1 and $M_1 M_2$ at $\pm$ 0°, 30°, 60°, 90°, 120°, etc., up to 360°, relative to OC, and plotting the length of OM_2 against angle). If their speed relative to OC is $+f_m$ and $-f_m$ respectively, then their actual speed is $f_c + f_m$ and $f_c - f_m$. What we have done, therefore, is to show that this group

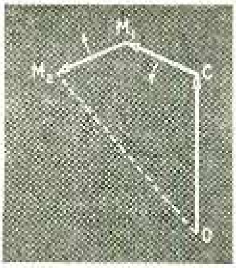
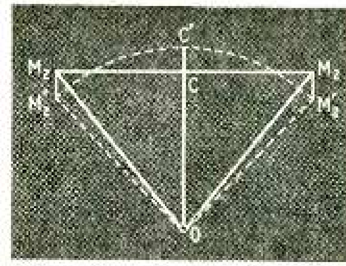


Fig. 3. If M_1 M_2 in Fig. 2(b) is reversed in phase, the result is phase and frequency modulation, mixed with a little a.m.

Fig. 5. With a wider angle COM_2 it is necessary to correct for the difference in length (amplitude modulation) between OM_2 and OC by a second pair of side frequency vectors, which add to OC in the centre position (CC′) and subtract from it at the extremes (M_2 M'_2).



of three vectors, all of constant length, adds up to a single vector of alternating length—which clearly represents an amplitude-modulated carrier wave. (And in case you feel that this is only a pretty picture on paper, it should be said that if you actually take three oscillators and adjust their frequencies, phases, and amplitudes suitably and add their outputs together the result cannot in any way be distinguished from the result of amplitude-modulating a single oscillator).

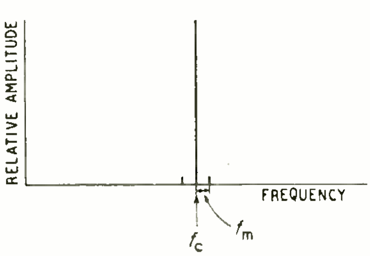
Frequency modulation can be demonstrated by a surprisingly slight modification of Fig. 2(b). All you have to do is reverse one of the " sideband " vectors. The resultant of the two is then at right angles to the carrier-wave vector, instead of being in the same phase (positively and negatively in turn). The resultant of all three, OM_2 in Fig. 3, then wags from side to side f_m times per second. When it coincides in position with OC it is moving at its fastest relative to OC, alternately to left and right. During its leftward wag it is rotating faster than OC, and during its rightward wag slower. This represents an alternating voltage (or current) whose frequency alternately increases and decreases. So now we see that the same fixed-frequency carrier and sideband frequencies, by a change in phase relationship, add up to a frequency-modulated carrier wave.

The only flaw in this second demonstration is that the resultant OM_2 not only gains and loses in frequency but also lengthens and shortens somewhat ; in other words, we get some a.m. mixed with our f.m. The effect is small so long as the sideband components CM_1 and M_1M_2 are much shorter than OC, *making the angle COM_2 always quite small.* I have emphasized those words because they are an important clue to the significance of M, the modulation index. The official title of the angle COM_2 is *phase swing*, but I am going to stick to my highly unofficial term, " angle of wag."

Of the several important matters arising at this point, the first that should be noted is that the usual modulation sidebands, $f_c + f_m$ and $f_c - f_m$, still appear, entirely regardless of the extent to which the carrier-wave is wobbled. So bang go the dreams of the would-be inventors who hoped to keep down the bandwidth by narrow frequency deviation. The only objection that could be raised to this conclusion is that what has been demonstrated in Fig. 3 is not pure f.m. but a mixture of f.m. and a.m. Any faint hope that the measures necessary to eliminate the remaining a.m. might somehow narrow the frequency band is doomed to worse than disappointment. To start with, it is obvious that the more the frequency swing is reduced, the more the angle of wag is reduced, and the more nearly one approaches pure f.m. It is easy to see, by considering Fig. 3, that if f_s is made very much less than f_m, the result is almost pure f.m., in which the sideband waves are equal to $f_c + f_m$ and $f_c - f_m$ and are very small compared with the carrier wave. This situation can be depicted as in Fig 4. The $2f_m$ bandwidth can only be narrowed by stopping modulation altogether.

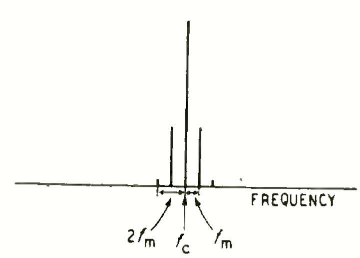
Balancing out the A.M.

The next thing is to find how to eliminate the a.m. when the angle of wag is *not* extremely small. What we have to do is to shorten the resultant vector at the limits of its wag, and perhaps lengthen it in its centre position. Fig. 5 shows the Fig. 3 diagram at its extreme limits with a fairly wide angle, and obviously the resultant vector OM_2 is considerably longer in those positions than in the centre, where it is equal to OC. But if an extra bit is added to OC in the centre position, making the resultant OC′, and taken off from it at the extremes, making it OM'_2, it is possible to make OC′ and OM'_2 the same length. Note that this necessitates *two* lengthenings and shortenings for every one modulation cycle. So we can get it by adding another pair of comparatively small vectors, rotating like CM_1 and M_1M_2 in opposite directions to OC, but at twice the frequency (i.e., $2f_m$). The phases of these two new vectors will have to be the same as those in Fig. 2 (because we want to balance out an unwanted a.m. without introducing any more f.m.), and their combined length must be half the difference between OM_2 and OC, so that when they are added to OC and subtracted from OM_2 the result will be equal. We can now see that with increased frequency



Left : Fig. 4. When frequency modulation is such that the phase angle represented by COM_2 in Fig. 3 is kept very small, the carrier and one pair of side waves are all that are present in appreciable strength, and the frequency diagram is like this (angle = $\pm 6°$).

Right : Fig. 6. The frequency diagram (or spectrum) when the angle of wag is nearly $\pm$ 30°.



swing Fig. 4 will turn into something like Fig. 6. The bandwidth of the transmission is double what it would be with undistorted a.m.

It is obviously going to be a more complicated business finding out if these " second-order " vectors neutralize the unwanted a.m. completely at all angles and not just at the centre and extreme positions. If you are sufficiently energetic and interested you will draw another set of vector diagrams very accurately to find out. If not, you will probably take my word for what you may have instinctively suspected—that they do not. The approximation is quite good up to about 45°, but beyond that it is necessary to recognize the existence of what had previously been negligibly small third-order vectors, spaced $3f_m$ in frequency from the carrier wave. The greater the angle, the larger the number of these side frequencies and the greater the bandwidth occupied by the transmitter. The exact amplitudes can be calculated mathematically by the use of Bessel functions. This sounds very highbrow, but fortunately graphs or tables of Bessel functions are given in most engineering reference books and (as Dr. E. K. Sandeman put it in a remark that deserves to become a classic) " the fact that these (graphs) are called Bessel functions does not make the curves any more difficult to read."

Angle of wag and f_s

Up to now we have been accepting the angle of wag as a measure of the frequency swing f_s, but have not yet discovered exactly how the two things are related. We do know that f_s is represented by the rate at which the vector OM_2 is gaining or losing on OC when it coincides in position with OC. The greater f_s, the greater the angle it will make in a given time. The given time, of course, is one quarter of a modulation cycle. So the angle can also be increased by increasing the time occupied by the modulation cycle—in other words, by reducing f_m. As a matter of fact, if the angle of wag, which we can denote by ϕ, is reckoned in radians (1 radian $=180/\pi$ degrees), and the modulation waveform is sinusoidal, it is related to f_s and f_m in the following simple manner:

$$\phi = \frac{f_s}{f_m}$$

But we have already defined f_s/f_m as M, the modulation index. So $\phi = M$, and this is why M is significant—the sideband structure of an f.m. transmission depends entirely on it.

The Bessel functions that give the relative amplitudes of the component waves in f.m. are in fact functions of M. They are denoted by J, and a graph or table for $J_n(M)$ shows how the amplitude of the nth side frequencies ($f_c \pm nf_m$) varies as M is varied. I have not reproduced any graphs or tables here, but anyone interested can look them up; for example in Sandeman's " Radio Engineering " Vol. 1, p. 550.

Fig. 4 was drawn for M = 0.1 (ϕ = nearly 6°) and Fig. 6 for M = 0.5 ($\phi = 29°$). Fig 7 extends the picture gallery to include M equal to 1, 2.5, and 10. The last of these shows sidebands something like 14 times as wide as with a.m. And the last two show another interesting difference from a.m.—the amplitude of the carrier wave itself is very much affected by depth of modulation. For any M it is given by J_0 (M), relative to 1 for no modulation.

This may be the right moment for saying something about phase modulation. What one actually sees, looking at Fig. 3 in motion, is phase modulation rather than frequency modulation. The phase of the resultant vector OM_2 is quite plainly shifting to and fro relative to OC. We know that in order to do so its frequency must alternately rise and fall. But the frequency changes do not actually show up on the diagram so directly as the phase changes. In fact, when OM_2 has deviated farthest from OC there is no difference in frequency between them, and when the frequency deviates most the two vectors coincide. So is there any particular point in calling it f.m. rather than p.m.? Aren't they both the same, anyway?

In a sense they obviously are, and yet in another sense they aren't. Quite clearly it is impossible to alter the frequency of a carrier wave without altering its phase relative to what it would have been if the frequency had not been altered. And vice versa. If we were interested in only a single modulation frequency, then f.m. and p.m. would be practically the same thing. But now suppose we double f_m in Fig. 3. This means that each modulation cycle lasts only half as long. So if the frequency swing is kept the same as before, it has only half the time in which to build up a phase shift, and the phase shift will be halved. On the other hand if the phase swing is kept constant the frequency swing must be doubled to obtain it in half the time.

Calculus students will see at once that this relationship between frequency and phase is $f = d\phi/dt$ or $\phi = \int f dt$. The same relationship exists between speed and distance. You may care to think out the analogy of a piston in an engine, or constant-velocity and constant-amplitude gramophone recording.

The practical point is that if an f.m. receiver were used with a p.m. transmitter (or vice-versa) the results would be unsatisfactory. The p.m. transmitter would represent equal modulation at all frequencies by equal phase swings, which would mean that the frequency

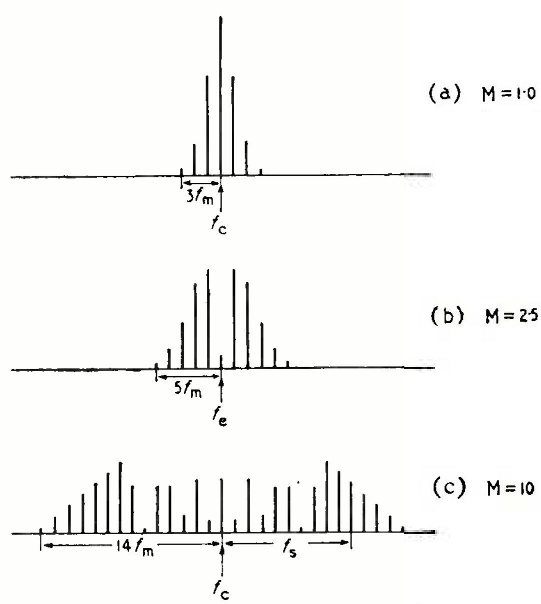


Fig. 7. The modulation index, M, which is equal to the angle of wag (in radians), is 0.1 in Fig. 4 and 0.5 in Fig. 6. Here are some more spectra, for M = 1, 2.5, and 10. Note how complicated f.m. sidebands become even when there is only one modulation frequency, if the frequency swing is relatively large.

swings would be proportional to modulation frequency, and reception would be decidedly lacking in bass and superabundant in "top." As a matter of fact, for a reason I shall explain presently, actual f.m. transmitters and receivers for broadcasting change-over to p.m. from about 3,000 c/s upwards.

And that is the cue to consider how f.m. (and p.m.) differ from a.m. as regards noise. Of the two radically different kinds described last month, let us take random or "fluctuation" noise first. It sounds like continuously escaping steam or rushing water in the background, and is inevitable whenever a large amount of amplification has to be used, as when receiving a very weak signal. I say "background" because if fluctuation noise voltages were anything like as strong as the signal they would (being continuous) reduce the entertainment value of the programme to about nil. So we must assume they are considerably smaller than the carrier amplitude.

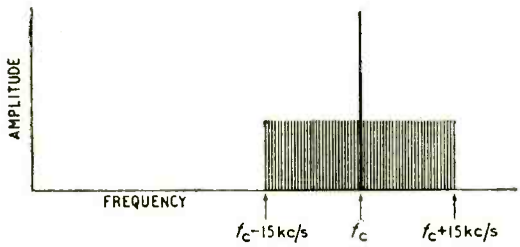
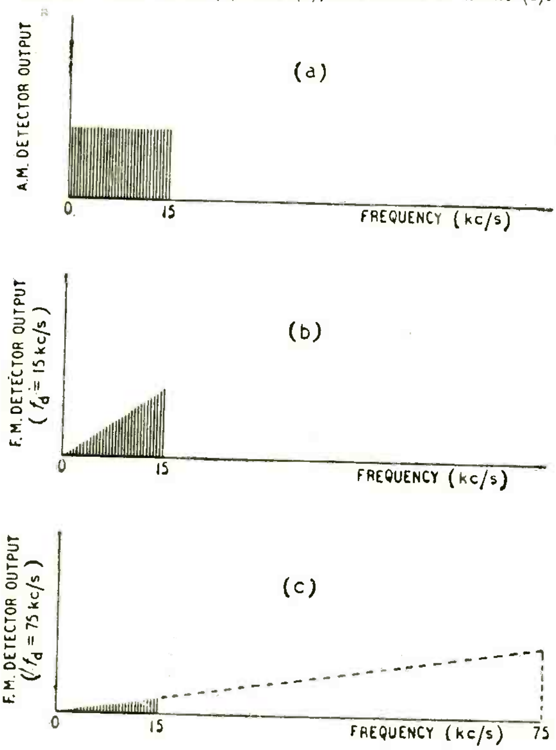


Fig. 8. Spectrum of carrier-wave and fluctuation noise after passing through a perfect band-pass r.f. tuner with 30 kc/s bandwidth.

Fig. 9. The detector in an a.m. receiver responds uniformly to Fig. 8, giving the a.f. noise output shown at (a). An equivalent f.m. receiver responds in proportion to the *difference* in frequency between carrier wave and noise (or sidebands), with the result shown at (b). If the f.m. deviation is increased from 15 kc/s to 75 kc/s, and the signal output adjusted to be the same as in (a) and (b), the result is as at (c).



Now the important feature of this type of noise is its uniform distribution over the entire frequency band. At first sight this would seem to put f.m. at a disadvantage, because the wider bandwidth of the radiated signal (compared with a.m.) necessitates accepting a wider band in the receiver and thereby bringing in more noise. It seems paradoxical—to put it mildly—to deliberately increase the bandwidth more than fivefold by standardizing a frequency deviation of 75 kc/s, in a system intended to reduce noise!

Since noise is reaching the receiver at all possible frequencies and (on the average) constant amplitude, we can picture it as an infinitely large number of vectors, all rotating at different speeds. We adopt our usual trick of stepping on to the carrier-wave vector so as to make it look stationary. Relative to it, equal numbers of noise vectors will be rotating in opposite directions. The first part of any receiver, up to the detector, is designed to select signals within a certain frequency band centred on the wanted f_c and reject all others. Suppose, for simplicity and for the sake of comparison, that we have two receivers, one a.m. and the other f.m., and that their selective circuits are identical and consist of perfect band-pass filters accepting all within 15 kc/s of f_c. Then all the noise voltages within this band are amplified equally and all the rest are cut out. The carrier wave and noise voltages applied to the detector can therefore be shown as in Fig. 8.

Because it is difficult to visualize all these noise voltages at once, let us focus attention on one of them, which (since they are all alike, except for frequency) can represent all. We can visualize the situation with the aid of Fig. 2(a), where CM is now the chosen noise vector. It produces a mixture of a.m. and p.m. The a.m., represented by the lengthening and shortening of OM as CM rotates, is the same at all frequencies (because we are assuming that the noise amplitude, represented by the length of CM, is the same), so the output of the a.m. detector (assumed perfect) is equal noise at all frequencies from 0 to 15 kc/s, as shown in Fig. 9(a). The p.m., represented by the angle of wag, ϕ, is also equal at all frequencies. But, as we have already seen, the frequency swing f_s is proportional to ϕ multiplied by the modulation frequency f_m. So it increases steadily as one moves away each side from the carrier frequency. Since the detector of an f.m. receiver is preceded by a limiter which shaves off the tops of the r.f. waves, so removing the a.m., and responds in proportion to f_s, its noise output must be as in Fig. 9(b).

The comparative merit of f.m. and a.m. is complicated by such matters as relative audibility of different frequencies; but assuming level a.f. response up to 15 kc/s (or whatever limit is assumed for both receivers) and 100 per cent depth of a.m. and ± 15 kc/s f_s, there is a 3 to 1 power ratio, or $\sqrt{3}$ to 1 voltage ratio, in favour of f.m.

Suppose now we increase the deviation ratio from 1 to 5, which necessitates widening the f.m. receiver bandwidth to ± 75 kc/s. Other things being equal, this means extending Fig. 9(b) right out to 75 kc/s, and the noise amplitude there will be five times as great as at 15 kc/s. But I have not troubled to draw this rather alarming picture, because we are only interested in signal output up to 15 kc/s, so we can

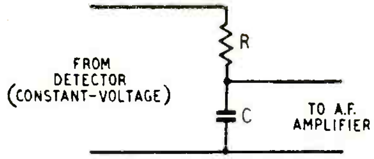


Fig. 10. Simple de-emphasis circuit, assuming a constant-voltage source. If for a constant current source (such as a pentode) C and R would be in parallel.

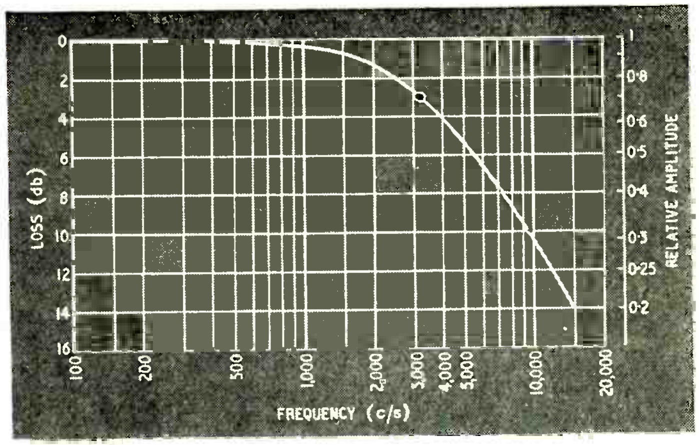


Fig. 11. Frequency characteristic due to the Fig. 10 circuit when CR = 50 microseconds.

put in a very efficient low-pass filter, cutting out everything above that, and we are no worse off than before. As a matter of fact, we are a good deal better off, because the five-fold greater signal deviation gives five times the signal output, and if we reduce everything to bring the comparison back to the original basis the noise is likewise reduced, and the result is Fig. 9(c), which clearly is a vast improvement on (a).

This is not all, however. We see that with f.m. most of the noise comes in with the top audio frequencies. It looks as if we are paying a heavy price for the extra fidelity of reproduction obtained by extending the a.f. range from about 4 kc/s (as is usual in medium-wave broadcasting) up to, say, 15 kc/s. Instead of the noise being about four times as great it is more like sixteen times. The relatively heavy noise in this extended part of the band competes with what is usually slight signal modulation, for at frequencies above about 4 kc/s there are usually only the harmonics that give characteristic tone to instruments and voices. So if they are systematically boosted in the transmitter there is little risk of their overmodulating it, and at the receiver they can be reduced to normal by a top-cutting circuit, which reduces the worst of the noise at the same time.

I explained this double process (pre-emphasis and de-emphasis) fully in the May 1947 issue, but as that is quite a long time ago perhaps I had better mention that the amount of boost and cut is rated (rather unexpectedly) in microseconds. This refers to the time-constant of the circuit used. For example, if the detector output voltage is applied to R and C in series (Fig. 10) and the a.f. is drawn from across C, at zero frequency the full detector output is passed on, but the upper frequencies are progressively cut. The turning frequency f_t (at which the loss is 3db) is when the reactance of C equals R ; i.e., $1/2\pi f_t C = R$, or $f_t = 1/2\pi CR$. CR is known as the time-constant, and the standard for British f.m. broadcasting is 50 microseconds (0.00005 sec.). Filling in this value for CR, f_t works out at about 3,200 c/s. The whole frequency characteristic given by this circuit is Fig. 11, from which one can see that if the top a.f. is 15 kc/s it is boosted 5 times at the transmitter, and cutting it down again to normal in the receiver achieves a 5-fold noise reduction at this frequency, and proportionately less at the lower frequencies.

I have already mentioned that f.m. allows a greater average signal output from a given transmitter, so that improves the signal/noise ratio from the other end, as it were. If all the other noise-reducing effects are also in operation, the net improvement over a.m. is very substantial. According to the ideal sort of theoretical comparison we have been making, it totals nearly 30 db, which is a signal/noise voltage ratio improvement of over 28 to 1, or a power ratio improvement of more than 800. In practice it means that an a.m. programme that would have an unpleasant amount of background noise would be quite quiet if changed over to wide-band f.m. In communication receivers, on the other hand, reception is intelligible when the signal strength is not much greater than noise, in which case the foregoing analysis does not hold, and the advantage of f.m. largely disappears.

The effect of motor ignition noise on receivers is quite different, so I shall have to hold it over until next month, when we shall also consider the f.m. receiver and especially the detector.

Wide-band Flexible Aerials

AERIALS which are mounted on vehicles for mobile radio-telephone transmission and reception are usually of the whip type in order to prevent damage by collision with trees or the top of a garage door frame. In addition, it is often necessary to have wide-band characteristics, since the transmitting and receiving frequencies may be as much as 13 Mc/s apart.

Wide-band characteristics may be obtained by increasing the diameter of the aerial, but this is incompatible with flexibility. These two differing requirements can, however, be met by the following method.

The aerial, which usually takes the form of a unipole, can in fact be made in the form of two or more unipoles set closely together and rising from a common base plate. The unipoles are fed from the centre of the base plate, from which they rise vertically. When more than two separate unipoles are employed, they may be mounted in a circular manner round the base plate, the unipoles lying parallel to one another. This arrangement is highly flexible, and the bandwidth can be increased enormously by increasing the number of unipoles.

In order to prevent the possible generation of noise signals when the ends of the unipoles are caused to collide either by vibration or by contact with, for example, an overhanging tree, the ends of the unipoles may be coated with rubber or other suitable compound.

(Contribution from E.M.I. Engineering Development, Ltd.)

Television at South Bank

AN important part is being played by television at the South Bank Exhibition; not only are demonstrations of large-screen projection television being given in the Telekinema but domestic receivers are operating in a number of the Pavilions. Programmes are derived in part from the normal B.B.C. programmes—the Alexandra Palace transmissions being received on a multi-element aerial attached to the Shot Tower—and local cameras are provided.

The distribution of television signals is by coaxial cable, the vision and sound carrier frequencies being those of the Sutton Coldfield transmitter, 61.75 Mc/s and 58.25 Mc/s. The vestigial-sideband system is used for vision and so the signals available from the cables are the same as those in the Birmingham area. Locally-produced signals are, of course, used to modulate what is, in effect, a miniature transmitter. The B.B.C. signals at the London frequencies are passed through a frequency changer to bring them to the Birmingham frequencies and then through a filter to change them to the vestigial-sideband form.

Projection box at the Telekinema seen from the theatre. In the centre is the television projector behind which can be seen one of the two film projection windows. On the left is the transportable television remote-control unit.

The general distribution is at radio-frequency for both sound and vision, except to the Telekinema, to which the sound is passed at audio-frequency. Coaxial cables of ¼in diameter with a solid aluminium sheath are used.

Arrangements are made for ten-minute transmissions for the domestic receivers with a five-minute interval signal derived from a monoscope, the switching being carried out automatically by a time-switch.

The cameras in the local studio use image orthicon tubes including a five-stage electron multiplier giving an output of 0.1 V. This form of tube was fully described in *Wireless World* for May 1950, p. 162.

The projection equipment used in the Telekinema has a 9-in c.r. tube operating at 50 kV and drawing 15 mA peak current. The normal mean current is about 1.5 mA, making the screen dissipation some 75 W. The screen is cooled by an airblast. A Schmidt optical system with an aperture of f/1.14 is used and has a spherical glass mirror of 27in diameter. The equipment is designed for operating with 405 or 625 lines, 50 frames, or 525 lines, 60 frames, but 405 lines is the standard adopted for the exhibition.

Spot wobble is used and the focus current is modulated at line and frame frequency to maintain proper focus over the whole picture area.

The results given by the whole installation are extremely good, both with local cameras and with B.B.C. programmes. The line structure is invisible and the picture detail over the whole area is exceptionally good, while the contrast range appears to be abnormally great. The brightness is quite adequate and, although rather less than that with film, one never felt during a lengthy demonstration any need of more. The demonstrations, for which a charge is made, include stereoscopic films and stereophonic sound, in addition to the large-screen television.

The distribution of the television signals throughout the Exhibition is carried out by Rediffusion, Ltd., the cameras in the Telekinema and their associated equipment have been provided by Marconi's W.T. Co., Ltd., and the projection apparatus by Cinema-Television, Ltd.

In addition to the demonstrations of both cinema and domestic equipment linked with the distribution system described above, a closed-circuit demonstration of 625-line television, with a vision bandwidth of 5.5 Mc/s, is staged on the second floor of the Transport Building. A new 6-lens C.P.S. Emitron camera with associated E.M.I. equipment is linked by a few feet of cable to two 12-in console receivers on which visitors can compare the received picture with the scenes below them.

Acoustics of the Royal Festival Hall

IT will be some time before the many acoustic measurements taken during the test and tuning period can be published and discussed, but it is now possible to give a subjective opinion on the main attributes of the new Royal Festival Hall on the South Bank Exhibition site.

The first test concert on February 14th, showed that railway noises and other sounds external to the hall were reduced by the double 12-inch cavity wall construction to levels well below the ambient noise inside the hall during pianissimo passages. Also that no major echoes occurred longitudinally and that the built-in absorptive ceiling resonators provided for echo suppression would not be needed and could remain blanked off.

To achieve clarity and definition in the musical sense, the hall was designed to give a high ratio of direct to reverberant sound, and in this respect the hopes of the designers were realized in rather more than full measure. Without the accustomed proportion of ameliorating reflected sound many people were critical of the bareness of tone, and, rather unreasonably, of the undeniable fact that an orchestra is a collection of individual instrumentalists. Certainly the new hall will be very revealing of the quality of musicianship in the performance of passages of fine texture, and should prove a wonderful incentive to better orchestral playing.

"Tuning" of the hall on the results of the earlier concerts has been directed mainly to increasing the reverberation, which now seems to be satisfactory, at least as far as the higher frequencies are concerned, but inside the hall one feels that there is still room for some further filling out at lower frequencies.

Reproduction via radio may be quite different for at least three reasons: 1. The microphone position is unique. 2. The transmission is through a single channel, whereas the concert-goer normally has the advantage of binaural hearing. 3. The B.B.C. can modify tonal balance or even add, if they think it desirable, a trace of extra reverberation.

Listening to the first broadcast it was apparent that the extreme low-frequencies sounded fuller than in the hall, but the violins and the higher wood wind still dominated the orchestra. Judging from the relative weakness of violas and cellos one might hazard a guess that maximum absorption is centred somewhere in the region of 100-200 c/s. Orchestras will have to work much harder to produce a sustained tone in *legato* playing—they will get little help from the hall. After *staccato* chords the body of sound evaporates with unexpected rapidity and this is the inevitable price which must be paid for the clarity, which is the hall's outstanding merit.

No further alterations to the acoustics are to be made at the moment of going to press, but the position will be reviewed after six months or so of normal use and a thorough sifting of further fact and opinion. Summarizing first impressions the Royal Festival Hall gives the freshness of an outdoor performance while effectively excluding the weather and the noise of London.

Throughout the test period records of reverberation time have been taken by the acoustics staff of the Building Research Station (D.S.I.R.) on instruments installed in a mobile unit parked outside the hall. Sources of sound used included single tones, revolver shots (producing wide-spectrum "white" noise) and the now famous test using the opening bars of Beethoven's "Coriolanus" in which long rests follow *fortissimo* chords by full orchestra. The recorders which have a range of 35 to 120db were fed through amplifiers from condenser-type microphones in various parts of the hall, and selective filters were inserted when any particular frequencies were under investigation. It is hoped at a later date to give some results of these measurements in support (or refutation) of first aural impressions.—F. L. D.

Aluminizing Cathode-Ray Tubes

By S. R. NEUBERGER, M.A. (Cantab) and J. H. JUPE, A.M.I.E.E.

Many people tend to regard aluminizing in cathode-ray tubes as a kind of magic property that somehow improves the picture, without really understanding what it is and how it works. The subject is made to seem even more vague and uncertain by various technical controversies which have taken place, and at times it has even been questioned whether aluminizing is really necessary. What, then, is aluminizing and what does it aim to do?

WHEN talking of the aluminizing in a television cathode-ray tube, we mean an extremely thin film of aluminium deposited over the inside surface of the fluorescent screen. This film achieves several distinct advantages, the first being to prevent the occurrence of "ion burn." Some viewers may have noticed a dark patch in the centre of the screen, produced by ion burn. This patch, which becomes progressively worse during life, is caused by the ions from any residual gas in the cathode-ray tube reaching the fluorescent powder on the screen. The presence of the aluminium film prevents this from occurring, since the ions cannot penetrate the film, although the electrons continue to pass through easily and reach the powder in the usual way. The other advantages obtained by aluminizing the screen are:—

(a) Light that would otherwise be emitted by the powder backwards into the tube is reflected by the aluminium film and so reaches the viewer through the front of the screen.

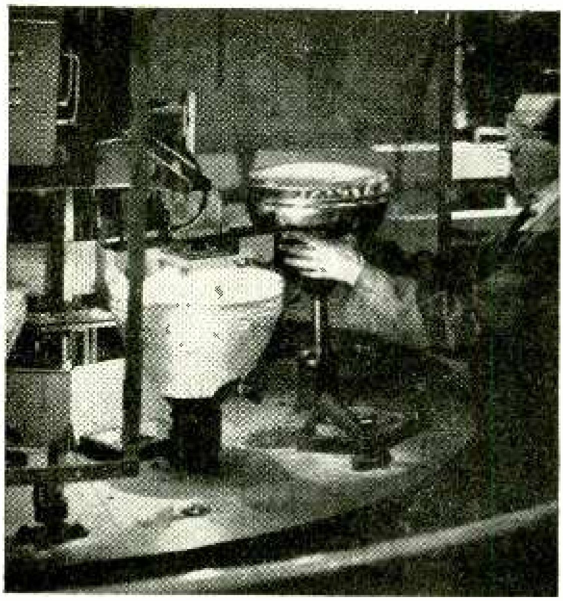
(b) Since no light from the screen reaches the inside of the tube, there is no possibility of its being so reflected by the walls of the bulb as to arrive on a dark part of the picture.

Together, therefore, the above two factors ensure that the aluminized screen shows a considerably improved contrast.

(c) The occurrence of "high voltage rash," the name given to the dark spots which sometimes appear on a television screen, is prevented. These spots tend to appear at places on the screen having a lower secondary emission than is found elsewhere. This difficulty can largely be overcome by making the phosphor powder as homogeneous and as pure as possible, but the presence of the aluminium is a further safeguard, since it holds the voltage of the whole screen area at the same level.

(d) The aluminium film raises the voltage of the screen to that of the final anode, which again means that the maximum possible efficiency, i.e., the maximum brightness, is obtained from the screen.

In order to fulfil these five important functions satisfactorily, the aluminium must be present as an extremely thin, strong, continuous film with a smooth



Part of a multi-head processing machine, showing a tube lit up by the vaporization of aluminium inside. Applied to its face is the measuring head of the automatic thickness-control apparatus.

and highly reflecting surface. The thickness of the film is particularly critical, for it must be thick enough to act as a barrier to the incident ions and yet so thin that it does not absorb too much of the beam energy. If this occurred, the brightness of the picture would be reduced by an amount that cannot be offset by the reflecting power of the film. It has been found that the required thickness of the film is about 0.1 micron (or 4×10^{-6} inches), and to produce a consistently good film with all the specified properties on the back of a powder screen is a difficult matter. The first step is the preparation of a smooth continuous surface, on which the aluminium vapour may condense. The techniques now generally in use for this are all based on forming a film of an organic lacquer that stretches tightly over the inside of the phosphor coating and is in intimate contact with it. Aluminium is then evaporated *in vacuo* and deposited on the lacquer film, which is itself subsequently removed during a baking process.

An apparatus has been developed at the Research Laboratories of The General Electric Company that will measure and control the thickness of the aluminium film while it is being deposited. This equipment consists essentially of a variable radio-frequency thermionic valve oscillator, the inductive coil in the tuned circuit of which is mounted in a measuring head. When the measuring head is brought close to the centre of the aluminium-backed screen, a change in the frequency of oscillation of this tuned circuit is produced.

The capacitance in the tuned circuit is varied so that the frequency of oscillation returns to its original value. The frequency-indicating device is a fixed r.f. oscillator, which is caused to beat with the output from the variable frequency oscillator, producing an audio frequency output that is applied to a loud-speaker or headphones. The change in capacitance required to produce zero beat frequency is a measure of the thickness of the aluminium film. A refinement in technique makes this device capable of automatically controlling the thickness of the aluminium film during deposition. The measuring head is held against the unaluminized screen and the measuring capacitance set to the required figure. Evaporation is commenced and the evaporating source is shut off automatically when the beat frequency falls to zero.

NEWS FROM THE CLUBS

Brighton.—Members of the Brighton and District Radio Club will hold an "inquest" on the National Field Day (June 2nd and 3rd) at their meeting on June 5th. Meetings are held every Tuesday at 7.30 at the Eagle Inn, Gloucester Road, Brighton, 1. Sec.: R. T. Parsons, 14, Carlyle Avenue, Brighton, 7.

Bromley.—Meetings of the North-West Kent Amateur Radio Society, the president of which is W. S. Scarr (R.S.G.B. president), are held on the first Friday of each month at 8.0 at Shortlands Tavern, Station Road, Shortlands, Bromley. Sec.: M. J. Frost (G3GNL), 15, Northbourne, Hayes, Bromley, Kent.

City of London.—"50 Years of Recorded Music" is the title given to a programme of cylinder and disc records (1900-1950) to be presented by R. H. Clarke to members of the City of London Phonograph and Radio Society on June 5th. Meetings are held at 6.30 at the "Cock and Magpie," 72, Wilson Street, London, E.C.2, on the first and third Tuesdays of each month. Sec.: R. H. Clarke, 12, Grove Road, North Finchley, London, N.12.

Gillingham.—The Gillingham Telecommunications Society's transmitter, G3GTS, is now fully licensed for telephony and 150 watts and QSL cards have been provided by the Borough Council. Meetings are held on alternate Tuesdays at 7.30 at the Medway Technical College, Gardiner Street, Gillingham. Sec.: C. E. Pellatt, 101, Boundary Road, Chatham, Kent.

Newbury.—The Newbury and District Amateur Radio Society will be manning a stand at the Arts and Handicrafts Exhibition to be held in the Newbury Corn Exchange from June 12th to 16th. A transmitter using the secretary's call sign, G3CJU/A, will be in operation as often as possible and on as many bands as possible. Sec.: A. W. Grimsdale, 164, London Road, Newbury, Berks.

Portsmouth.—The two clubs listed in our January issue under Portsmouth are no longer operating as separate entities. The title adopted is the Portsmouth and District Radio Society, meetings of which are held on Tuesdays at 7.30 at the Signal Club, Royal Marine Barracks, Eastney. Sec.: R. Short (G3AFF), 76, Roman Grove, Portchester, Hants.

Sidcup.—Meetings of the Cray Valley Radio Transmitting Club are held on the fourth Tuesday of each month at the Station Hotel, Sidcup, at 7.30. Sec.: A. Swindon (G3ANK), 135, Station Road, Sidcup, Kent.

Taunton.—At a recent meeting of the West Somerset Radio Society it was decided to change the title to Taunton and West Somerset Radio Society. Meetings are held on the first Tuesday of each month at 7.45 at the Castle Hotel, Taunton. Sec.: K. Farrell, 27, Victory Road, Taunton, Som.

Tyneside.—In addition to the three groups of the International Radio Controlled Models Society at Birmingham, London and Manchester given in our Directory of Clubs (January issue) there is also a section on Tyneside which meets regularly. Sec.: A. S. Wilson, "Cragside," Fatfield, Washington, Co. Durham.

Watford.—At the meeting of the Watford and District Radio and Television Society on June 5th at 7.30 at the Cookery Nook, The Parade, Watford, E. L. Gardiner (G6GR) will speak on "Test Gear." Sec.: R. W. Bailey, 32, Cassiobury Drive, Watford, Herts.

SHORT-WAVE CONDITIONS

April in Retrospect: Forecast for June

By T. W. BENNINGTON *

DURING April the average maximum usable frequencies for these latitudes decreased somewhat by day, and increased somewhat by night, which variations were in accordance with the seasonal trend.

Daytime working frequencies were, on the whole, decidedly low. In east/west directions the best received daytime frequencies were of the order of 17 Mc/s, and those around 22 Mc/s were usually weaker. Only very occasionally were frequencies higher than 22 Mc/s received. In north/south directions frequencies of the order of 24 Mc/s were frequently the best received during the daytime. At night 9 Mc/s was usually workable until well after midnight, and on north/south circuits frequencies considerably higher than this were usable at that time.

There was an increase in the amount of Sporadic E observed during April. Sunspot activity was, on the average, considerably higher than for several months past. On 18th a giant sunspot crossed the sun's central medirian, and following this there was a period of ionospheric storminess.

April was a very disturbed month, the stormy periods being 3rd-11th, 19th-22nd and 26th-27th. Seven Dellinger fadeouts were reported, two of them being of severe intensity. These were on 19th, 1505-1730 g.m.t. and on 25th, 0841-0945 g.m.t., the latter completely interrupting communications for a time.

Forecast:—During June the daytime m.u.f. for these latitudes will probably reach its lowest, and the night-time m.u.f. its highest, value for the coming summer season. Thereafter the daytime m.u.f. should begin to increase, and that for night-time to decrease again, towards the winter values.

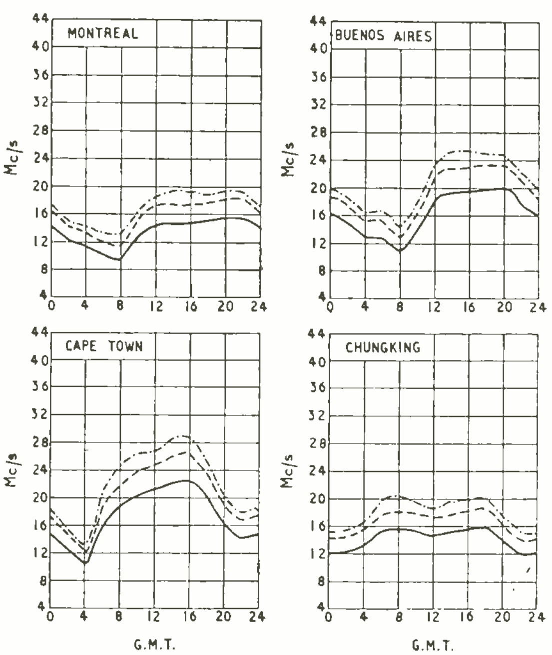
Working frequencies for long-distance communication are likely to be relatively low during the daytime over all circuits, and more particularly over those running in east/west directions from this country, where 15 Mc/s may be the highest regularly received frequency. Over north/south circuits 21 Mc/s should be the highest regularly usable frequency during the day.

At night 11 Mc/s should be usable till after midnight, and 9 Mc/s the night through.

Sporadic E is likely to be very prevalent, and 28 Mc/s and possibly much higher frequencies may be propagated to medium distances by way of this. Normal communication over medium distances will be controlled during the day by the E or F_1 layers, and usable frequencies for this purpose should be somewhat higher than during the previous month.

The accompanying curves indicate the highest frequencies likely to be usable over four long-distance circuits from this country during the month.

* Engineering Division, B.B.C



——— FREQUENCY BELOW WHICH COMMUNICATION SHOULD BE POSSIBLE ON ALL UNDISTURBED DAYS
- - - - - PREDICTED AVERAGE MAXIMUM USABLE FREQUENCY
-·-·-·- FREQUENCY BELOW WHICH COMMUNICATION SHOULD BE POSSIBLE FOR 25% OF THE TOTAL TIME

RANDOM RADIATIONS

By "DIALLIST"

Radio Shows To-day

ONE DOES NOT EXPECT any kind of radio exhibition to-day to provide the thrills and adventures that show-goers looked for in the days when wireless and electronics in general were still very young branches of physics and engineering. You remember, perhaps, the year when the first mains sets were shown? Or the screen-grid valve year? Or the pentode year? Or the c.r.t. television year? Wireless is grown up and settled in life now; and the younger brother, television, is no longer a child. Neither now makes progress by spectacular leaps and bounds. Both *do* continually make progress and no exhibition is without its highlights; but steady, regular development has now largely replaced the exciting forward jumps—sometimes jumps in the dark!—of the past. Hence, when I went to the Components Show I didn't expect to gape at some new wonder here or to gasp at another there. Come to think of it, whilst wireless and television have been doing their growing up I haven't been getting any younger myself. . . . Is it possible that the advances year by year are no whit less spectacular than they once were and that it is I, rendered less impressionable by the hand of time, who am no longer made to gape and gasp by stimuli that would have been adequate for the purpose in years gone by? Perish the thought!

Good Stuff

IF I FOUND nothing at the R.E.C.M.F. Show sufficiently startling to give rise to bated breath or a quickened pulse, I most thoroughly enjoyed my visit. In fact, I came away wishing that a few American technical writers had been with me so that I could have shown them what good stuff we produce. I met, though, quite a few friends and acquaintances from other countries abroad and found most of them loud in their praises of two outstanding qualities of our radio components: their good design and their good finish. I couldn't agree more! It's not for me to report in detail on the Show; but I must mention just one or two things that fascinated me. First, the tiny dry batteries for hearing-aids. One of these (15 volts) weighs under half an ounce and three of them placed side by side occupy rather less volume than an ordinary matchbox. There's a $22\frac{1}{2}$-volt battery, too, which weighs $\frac{5}{8}$ ounce; allowing for the insulation and the case, each of its 15 cells must weigh about one gram! It was good to see the first British-made metal-glass c.r.t. for television receivers. A very handy design, for it is literally nearly as broad as it's long—a 16-inch screen for an overall back-to-front length of $17\frac{1}{2}$ inches. I have room to mention only one more item, the new range of valves designed with an eye to improved mechanical reliability. The principles are sound and I think that the valves should make a name for themselves There is one thing, though, that we all want in valves besides mechanical reliability: can't manufacturers see their way to giving us a little more than the average 1,000 hours of service for our hard-earned money?

Médecin Malgré Lui

ONE OF THE VISITORS from abroad whom I met at the R.E.C.M.F. Show was my good friend Georges Friedrichs, who should be one of the happiest of men since he lives and runs his famous measuring instrument factory in the lovely High Savoy town of Annecy. A day or two after his return home I heard from him that he was sending me samples of a small 3-volt battery of French make, which was reputed to be of outstanding performance. The French, by the way, preserve the Voltaic tradition by calling a battery *une pile*. As he hadn't told me the trade name I amused myself by making a guess or two, for the French have a passion for English (or would-be English) trade names. When the small parcel eventually turned up it bore, to my surprise, a Customs label: "Inadmissible as samples. Medical appliances." The parcel proved to contain just two tiny batteries. The French had run true to form in their choice of a name. There it was printed large upon each: PILE WONDER.

Who Started It?

A WHILE AGO I thought I would like to know something of the history of soldering, which must be one of the oldest of the metal worker's arts. Silver soldering (or something very like it) was used by Egyptian jewellers 6,000 years ago, or more; brazing was known to them as well as to the Greeks and the craftsmen of the East. Soft soldering seems to have been the latest of all methods to come into use. When the Romans wanted to make water pipes they took a strip of sheet lead and hammered it on to a mandrel of circular section. Until about A.D. 200 they appear to have closed the seam by pouring in molten lead. One imagines that they used tallow as a flux and that they sealed off with the help of the blow pipe and the wiping cloth. The earliest genuine soft-soldered joint of which I can find any record is the seam of a Roman pipe found at Silchester. Curiously enough, the solder here is the very opposite of that used by a modern plumber for making a wiped joint; it is about 66/34, which is not far from tinman's solder to-day. Although W. R. Lewis most kindly gave me the run of the extensive (and magnificently catalogued) library of the Tin Research Institute, I can find very little about the materials or the methods of ancient solderers. I shall be most grateful to any reader who can send me any information.

Puzzling

THE ANSWER TO THE following problem is, very likely, quite simple. I confess, though, that it eludes me; nor have I so far obtained a satisfactory solution from any of the many people to whom I have put it verbally. Here it is. In one room I have a 4-valve battery set, whose 2-V filament accumulator is permanently connected to the output terminals of a Varley trickle-charger, the main components of which are a step-down transformer and a metal rectifier. The input terminals of the charger are connected via a 2-foot length of good flex to a wall-socket served by a 200-V a.c. mains lighting circuit and incorporating a switch on the phase lead. Wired across the output of the socket (and the input to the charger) is a 200-V miniature neon, used as a tell-tale. You see the idea? Mrs. Diallist, who prefers battery receivers for reasons which I do not pretend to understand, cannot (as otherwise she might) let the accumulator gas its head off; for there is the red eye of the little neon to remind her that she switched on the current at bed-time the night before and that it is about time to switch off. You can tell the state of the accumulator pretty well from the time that the neon takes to strike. If the cell is well up, the little lamp "fires" as soon as you close the switch, but if it is not, lighting-up is delayed for some seconds. Once when we had been away for a fortnight and no charging had been done, the interval by my watch between switching on and striking was 50 seconds. Can anybody, please, tell me why the state of a 2-V, 20-Ah cell, charging normally at 0.5 A, should affect the striking of a neon connected straight across the lighting mains supplying its charger?

UNBIASED

By FREE GRID

Seeking sanctuary.

The Fires of Smithfield

I SEEM to have raised a hornets' nest about my ears by my request in the April issue for verification of the date when de Forest evolved the amplifying valve which I said I had always thought to be 1912 but now doubted. So fierce were the execrations of the mob who demanded my head on a charger for writing 1912 when I ought (so they maintained) to have written 1907, that I went scurrying along to the sanctuary of that storehouse of scientific statistics, the Science Museum at South Kensington.

As the result of my visit there I now follow the example of Cranmer and withdraw my recantation and if, as the outcome of this, the fires of Smithfield and Oxford are to be rekindled, I take comfort in the fact that my stake will be shared by the pundits of the Science Museum.

Unfortunately I owe these base attacks on my veracity as a scientific historian to the fact that, led astray by Shakespeare and similar hack writers, I tried a bit of "elegant variation" instead of sticking to plain English when wording my original question. For this, and for this alone, I bow my head in shame and cry "*Peccavi*" which is, I suppose, best translated by the classic phrase "I dunnit."

What I ought to have asked is when did de Forest evolve the amplifying valve, instead of which, with misleading "elegant variation," I asked when he put the grid into Fleming's diode. Abundant evidence about this has been sent to me and to the Editor, but for clarity and conciseness I have found nothing to beat the potted histories attached to the exhibits in the Science Museum. The truth of the matter is that de Forest stuck the grid into Fleming's diode on January 29th, 1907, or, at any rate, that was the date of his patent. It is quite clear, however, that de Forest failed to appreciate the importance of his own invention and, to quote the words of B. S. T. Wallace in the *Telegraph and Telephone Journal* (March, 1932) "de Forest apparently did not fully understand the working of the grid at the time he took out a patent for it in 1907." The learned scribe at the Science Museum, after pointing out that de Forest actually allowed his British patent to lapse in January, 1911, makes it plain that it was not until 18 months later, in July, 1912, that he woke up to the fact that what he had invented was an electronically operated relay or, in other words, an amplifying valve.

A Date for Your Diary

DESPITE my efforts to secure St. Michael as the patron saint of radio (March issue), I see in *The Times* that the Archangel Gabriel has been appointed patron saint of telegraphists and telephonists. Naturally these words cover both wired and wireless telegraphy and telephony. I really don't see, however, why I should be compelled to share a patron saint with the peroxided blondes at the local telephone exchange, but I suppose I can do nothing about it. I have no mind to receive a severe rap over the knuckles such as was given to French wireless operators over twenty years ago when they chose St. Joan of Arc as their patron saint and were accused of usurping the functions and privileges of high ecclesiastical authority.

For those of you who are ignorant of these matters I would point out that March 18th is St. Gabriel's day.

Silent Sound

IN June, 1949, when administering a gentle rebuke to Mr. Punch for his unconscious plagiarism of something which had appeared in these columns ten years earlier, I remarked that there were few major inventions in the realm of radio and electronics which had not been anticipated in these columns. I ought to have added acoustics and a host of other "ics" which come within the scope of this journal. I gladly permit inventors to use, without let or hindrance, ideas which I put forward, and I certainly seek no sordid monetary gain, otherwise I should not publish them in these columns without obtaining the prior protection of the Patent Office. I do object, however, to these aforesaid "inventors" getting the ear of some gullible reporter on the staff of one of our great "dailies" and claiming as original an idea which has appeared in these columns many years previously.

The latest instance of this sort of thing appeared not so very long ago in one of the popular London daily newspapers. The news item was considered sufficiently important to warrant the use of valuable space for a photograph of the inventor and his brain-child which was something of a very trivial nature invented by me in a moment of exasperation no fewer than seventeen years ago and published complete with sketch in these columns on June 29th, 1934. I reproduced the sketch in the issue of June 23rd, 1938, on the occasion of the plagiaristic "re-invention" of the device by somebody else and I make no bones about reproducing it again.

As you will gather from the sketch, it is merely a device consisting of a microphone inside a soundproof piano and coupled to a pair of headphones whereby pianists in the embryonic stage are compelled to consume their own noise, so avoiding annoyance to other people. A simple switching arrangement brings an amplifier and loudspeaker into circuit when it is desired to use the piano normally. To extend this idea to other musical instruments as has now been done, is merely to do the obvious.

Consuming their own noise.