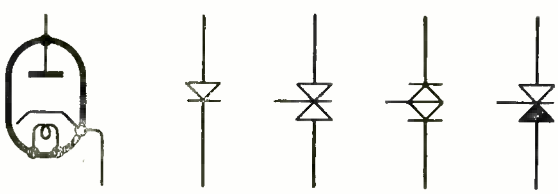
Wireless World

APRIL 1955 VOL. 61 No. 4

Transistor Symbols

JUDGING by our correspondence columns, there has been for some time a feeling that existing graphical symbols for transistors are unsatisfactory, and fail to convey a useful picture of the working of the device. We think this is probably because the base is almost invariably represented graphically by a heavy line, thus suggesting that it is analogous to the cathode of a thermionic valve. Colour is lent to this false idea because most transistor circuits show the base earthed. In fact, of course, it is the emitter which is analogous to the cathode and the earthed-base circuit is the transistor counterpart of the earthed-grid valve circuit.

To avoid this kind of confusion it seems imperative that any heavy line that looks like the graphical representation of a valve cathode should not be used in symbols for anything but the emitter. But to use such a line for the emitter would confuse those accustomed to the present symbol, in which it represents the base. Clearly, a radically different symbol is needed, and a possible solution would be to adopt the general idea suggested by P. M. Thompson in *Wireless World* for July, 1954 (p. 325). Mr. Thompson there described the system of symbols used by the Canadian Defence Research Establishment, in which transistor symbols are based on the conventional rectifier symbol.



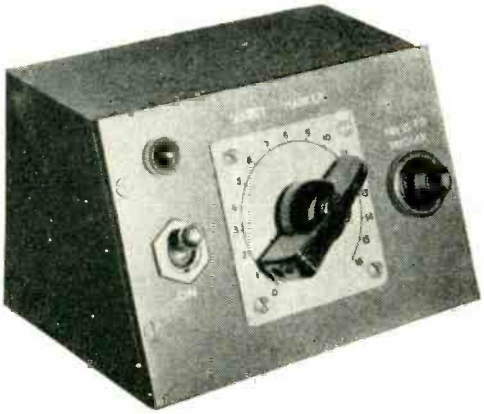
(a) (b) (c) (d) (e)

In the rectifier symbol, which is universally employed for any kind of two-electrode semi-conductor device having asymmetrical conductivity, the convention is that the bar represents the cathode of the equivalent thermionic diode and the triangle the anode (see (*a*) and (*b*) in the Figure). The junction transistor comprises two semi-conductor junctions back-to-back, and it seems logical to adopt a pair of rectifier symbols, also back-to-back, as at (*c*) and (*d*). As shown, the bottom element of these basic transistor symbols is intended to represent the emitter, the top the collector and the middle one the base. By analogy with (*b*) if conventional current flows out of the emitter when the base is positive to it, the symbol takes the form of (*d*) and represents an *n-p-n* transistor. Consequently (*c*) represents a *p-n-p* transistor, operating with negative base and collector and having current flowing into the emitter.

These symbols as shown have one serious defect, in that they do not distinguish between emitter and collector. It is essential to be able to identify the two easily in order to trace a circuit rapidly. In any complex valve circuit, for example, one generally starts by identifying the input and output circuits by their connection to grid and anode and one should be able to do the equivalent in a transistor circuit. Fortunately, the difficulty is easily overcome by thickening or blacking-in the emitter element of the symbol as at (*e*) and (*f*) and it is these symbols that *Wireless World* suggests might be adopted for junction transistors. The symbols can be extended on the same lines for multi-electrode transistors.

In support of this system of symbolism, it may be urged that it represents the "historical" approach towards a new device; the user is going from the known to the unknown. And, if anyone raises the objection that a transistor is not a rectifier, the answer seems to be that the basic symbol here advocated primarily represents a semi-conductor junction. One such symbol, then, stands for a junction acting as a rectifier; two in conjunction may fairly indicate an amplifying transistor.

A related question—that of the appropriate reference letter or letter symbol to denote a transistor in circuit diagrams or lists of parts—was raised by E. A. W. Spreadbury in our March issue. At this stage of development, however, there seems to be some doubt whether it is necessary or desirable to introduce a special symbol; the transistor might be allowed to share the letter V with the valve without risk of confusion or ambiguity.



Complete selector unit, housed in case with sloping panel.

TAPE SELECTOR MECHANISM

A Useful Accessory for Magnetic Tape Recorders

By J. E. PRICE and R. A. FREWER, B.Sc.(Eng.), Grad.I.E.E.

IT may seem a simple matter to those who are unaccustomed to the use of tape recorders to pick out a three-minute tune from several recorded on a half-hour reel of tape. However, people who own a tape recorder know from bitter experience how easy it is to overshoot by two or three yards. Paper markers solve this problem to a limited degree, but even so are far from satisfactory.

The device* to be described enables any given section to be selected with a high degree of precision. It consists of a specially designed switch, through which the tape passes, and a selecting mechanism. The tape may be divided into as many sections as is desired, the one required being chosen by means of the selecting mechanism, the number of sections being limited only by the number of positions on the selector.

At the beginning of each section a piece of adhesive tape about half an inch long is affixed to the back of the recording tape in order to thicken it by about four times. The modern plastic adhesive tapes are very suitable for this application. Since this type of tape is very thin, it has been found necessary to use four layers, the top layer being rather longer than the other three. The overlap thus formed gives a "streamlined" effect and aids the tape in passing the felt pressure pads. During a period of about six months no deterioration in either the pressure pads or the recording tape has been noticed.

* Provisional patent 33963/54.

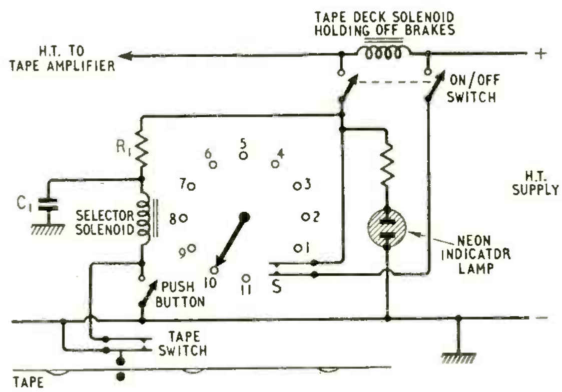
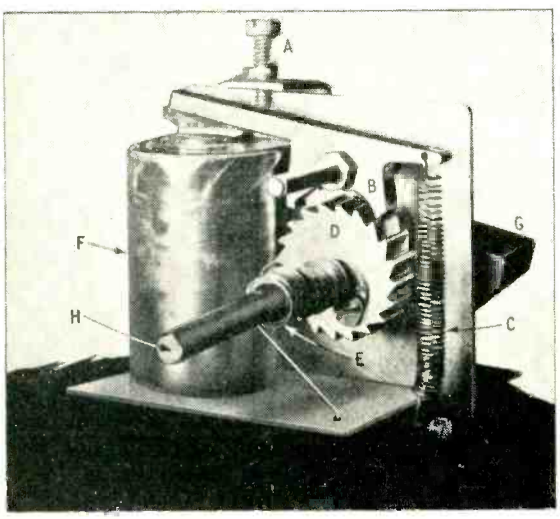
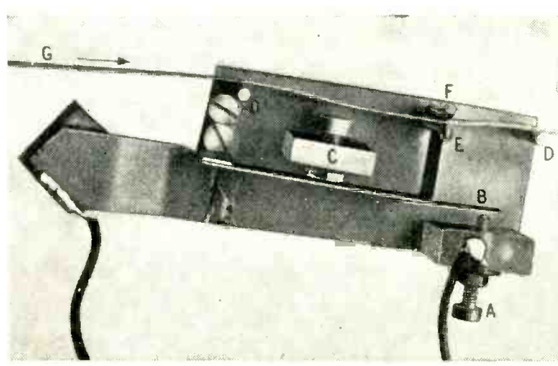


Fig. 1. Circuit diagram showing connections of tape switch and selector mechanism.

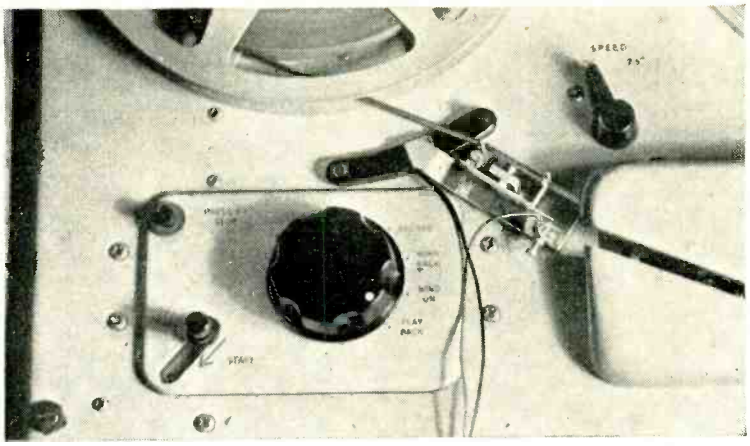
Selector with front removed. A, escapement adjusting screw (6BA); B, escapement; C, escapement return spring; D, ratchet wheel attached to H; E, actuating spring; F, solenoid which is mounted in slots to adjust height. G, arm attached to H which closes contacts S (Fig. 1); H, control knob spindle.





Tape switch. A, contact adjuster screw (6BA); B, contact spring; C, pillar spacing adjuster; D, tape guides; E, moving pillar attached to B; F, stationary pillar; G, tape, normal direction shown by arrow, coated side facing away from switch.

The recording tape is passed between two pillars which are forced apart by the thickened portion, thus causing a pair of contacts to be closed. The initial spacing of the pillars is at least twice the thickness of the tape in order to allow any joins to pass through. For use on half-track machines the switch could readily be modified so that only the lower half passes between the two pillars. For ease of loading the pillars are opened slightly at the top in the form of a Y. After consideration of many other types the present design of tape switch was chosen on account of its simplicity, freedom from contact bounce, high rate of response and in particular its complete freedom from any possibility of wear on the tape.



Tape switch as fitted to a "Wearite" tape deck.

The selector itself consists of a spring-loaded ratchet which is initially set to the number of the section required. Each pulse then allows the selector to fall back one position until it reaches zero, when a short-circuit is applied across the solenoid in the tape deck, thus causing the brakes to be applied. The selector may also be operated manually by a push-button switch. Since the selector solenoid simply releases the holding-back mechanism the power required is very small, and has been reduced still further by use of a capacitor C_1 which charges through R_1 and discharges through the selector solenoid when the tape switch is closed giving a current pulse of short duration.

The selector switch is capable of very rapid operation, due to the lack of inertia of the moving parts, and the mechanism is capable of responding at much higher speeds than are met with on any existing wind-on mechanism; thus the speed of response depends, to a large extent, on the efficiency of the tape recorder brakes.

This device is very useful when, for example, a number of three-minute tunes are recorded on one reel of tape. Contacts at either end of the recording tape can be arranged so that the brakes are applied when a few turns of tape are left on the reel, thus obviating the continual irritation of re-threading prior to playback after rewinding the complete tape. Also the mechanism can be used with equal ease in both directions so that if it is desired to hear again a particular section the mechanism is set to 1 and the tape is rewound.

It would be almost indispensable for recorded sound effects in the theatre. Anyone who has stage-managed a play will appreciate the almost limitless possibilities of tape recording in this field, but when sound effects become numerous, and have to be repeated, confusion can be caused only too easily. This device enables any particular sound effect to be selected at will, in a very short space of time, thus limiting extraneous noise due to unnecessary operation of the recorder controls, and enabling every effect to be reproduced dead on time and in exactly the right place. By reducing the spacing of the pillars on the contact switch, this device may be adapted for use as a detector of joins in a reel of tape. This may be a useful industrial application. Finally, dare we mention it, by the use of this device it would become possible to use tape recorders in that modern teenager's delight, the "Juke Box."

Tubeless Television?

SOME publicity has been given recently to various devices which, it is claimed, may replace the cathode ray tube for picture presentation in the television set of the future. The devices so far known depend for their operation on the phenomenon of electroluminescence. This was discovered in 1936 by Professor G. Destriau, of Paris, but his results were disregarded until about 1948, when various laboratories began to examine them further. Destriau found that the application of an alternating electric field across a thin layer of phosphor crystals resulted in the emission of light pulses at twice the frequency of the applied field. The light output of the layer increases as the frequency or the applied voltage is raised, over a considerable range, but the exact form of the relationship between these factors is rather complex. There is a threshold field below which no light is emitted. Special phosphors are used for electroluminescence but their base materials are usually zinc cadmium sulphides, as found in conventional cathode ray screens.

So far, the efficiencies of electroluminescent cells have proved to be very low. The higher figures quoted are about 5 lumens of green light per watt, which must be compared with 30 lumens per watt for a normal white phosphor under 10 kV electron bombardment.

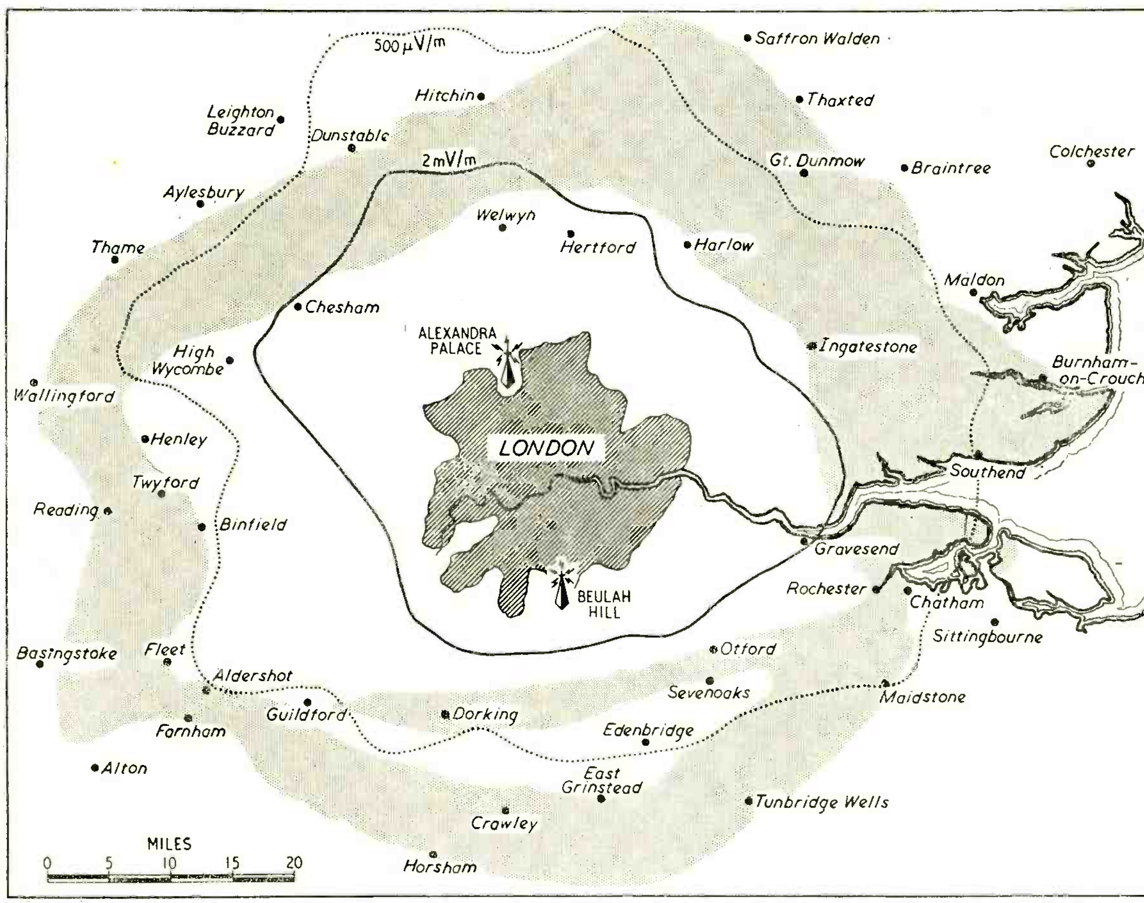
Recently a new phenomenon allied to electroluminescence has been discovered by Professor Destriau and by D. A. Cusano in America. A d.c. field has been found to enhance the luminescence of a phosphor excited by ultra-violet radiation or x-rays, and gains of 50 times in brightness have been claimed. The decay time after removal of the stimulating radiation is several seconds.

Two types of "light amplifier" depending on the effects mentioned above have already been demonstrated. In one, developed by R.C.A., a layer of electroluminescent phosphor is sandwiched between a transparent conducting electrode and a photo-conducting electrode. An alternating voltage of 1-5 kc/s is applied to the two electrodes. When the photo-conductor is illuminated its impedance falls sufficiently to allow the a.c. field to excite the phosphor. Gains of the order of 10 times are claimed, but no figures of the actual screen brightness are available. The second type, developed by General Electric, dispenses with the photo-conducting layer. A direct voltage of the order of 100 volts is applied to a layer of zinc sulphide 10 microns thick on a conducting glass support. Ultra-violet falling on the phosphor excites luminescence, which is enhanced by the applied field. Ten visible quanta are claimed to be emitted for one incident quantum of ultra-violet. Again no figure for the actual screen brightness is quoted.

Both these devices can be made to perform in a similar way to the well-known image convertor. As far as television is concerned, however, they do not appear to hold much promise. There is little to be said for their use in place of the normal viewing screen in projection systems, even allowing for a considerable reduction in the energy of the projected picture. The second type is ruled out on account of its excessive decay time, while the first would demand picture storage from frame to frame in the projection tube, since it would be unable to follow the instantaneous brightness of the normal scanning spot. This is because the upper limit of brightness of an electroluminescent layer (determined by the dielectric breakdown strength of the phosphor) is too low. Some measure of storage could perhaps be obtained by allowing feedback of the electroluminescent light to the photo-conductor but this would lead to other practical difficulties.

There is a third device, not yet known to have been demonstrated, which, on paper at least, comes nearer the goal of tubeless television. This uses an electroluminescent layer having electrodes in the form of closely spaced wires stretched vertically on one side and horizontally on the other. The volume of phosphor at the point of intersection of a vertical and a horizontal wire constitutes one picture element, and emits light when an a.c. voltage is applied to those wires. The formidable problems of producing such a screen and devising means for switching to each picture element do not yet appear to have been solved. Owing to the limitation on brightness mentioned above, this device will also require means of storing the signals from frame to frame.

In view of these facts one may conclude that the familiar cathode ray tube will remain with us for some time yet. It may, however, take new forms; for example, the development of a flat, wall-mounted cathode-ray tube approximately 3 inches deep has already been claimed by Willys Motors in America.



ALTERNATIVE LONDON TELEVISION. On this recently issued map showing the estimated coverage of the temporary I.T.A. transmitter being erected at Beulah Hill, Croydon, we have superimposed the 2 and 0.5 mV/m contours of the Alexandra Palace transmitter. For the Croydon transmitter the area between the same (estimated) field strength contours is shown shaded. The I.T.A. transmitter will have an e.r.p. of 60 kW whereas the Alexandra Palace transmitter has an e.r.p. of only 34 kW. The height of the aerials above sea level are: Alexandra Palace 600ft, Croydon 550ft. The permanent I.T.A. transmitter will have a much taller mast and an e.r.p. of three or four times that of the temporary station which will be in service for about eighteen months.

WORLD OF WIRELESS

Organizational, Personal and Industrial Notes and News

THE FAMILIAR Decca separate half-cheeses for transmission and reception have, in the new Decca 212, given place to a single parabolic cylinder scanner of about 4ft across. As it is intended primarily for small vessels, in which it is essential to reduce top weight, the r.f. unit has been separated from the scanner unit.

V.H.F. Sound Broadcasting

A REGULAR three-programme service of v.h.f. broadcasting will be introduced by the B.B.C. from Wrotham on May 2nd. The estimated coverage of the station is given on the map on page 161.

The frequencies to be used by Wrotham are 89.1 Mc/s (Light), 91.3 Mc/s (Third) and 93.5 Mc/s (Home). The e.r.p. of each transmitter will be 120 kW and the transmissions will be horizontally polarized.

Wrotham has been in operation experimentally since 1950; first with both a.m. and f.m. transmissions and latterly using f.m. only. It closed down on March 5th for nearly five weeks to permit the installation of a third transmitter, which will radiate the Home Service. This transmitter differs from the two already installed in that it is built as two separate units for parallel operation, and for the first few weeks of the new service only one of these units will be used.

The closing down of the Wrotham station for five weeks just prior to the inauguration of the f.m. service would have been an embarrassment to the industry and the retail trade in London. In response to a request, therefore, from the British Radio Equipment Manufacturers' Association, the B.B.C. is radiating a low-power (1 kW) test transmission from Alexandra Palace on 93.8 Mc/s daily from 9 a.m. to 11 p.m. until Wrotham restarts.

April Shows

DURING this month three exhibitions are to be held in London—R.E.C.M.F. (19th-21st), Physical Society (25th-28th) and A.P.A.E. (27th-28th). A list of exhibitors at the R.E.C.M.F. components show, which is to be held at Grosvenor House, Park Lane, W.1, is given on page 158.

The Physical Society exhibition of scientific instruments and apparatus is this year being held in the Royal Horticultural Society's New Hall, Westminster, S.W.1. There will be 136 exhibitors, including manufacturers and Government and industrial research organizations. On each of the first three evenings at 6.15 there will be a discourse, the subjects being: "The Free Electron as a Tool in Scientific Research," "Memory Systems in the Brain," and "Recent Developments in Luminescence and its Applications." The exhibition opens at 2.0 on the 25th and at 10.0 on subsequent days. It closes on the first three days at 8.0 and on the last day at 5.0. Admission is by ticket, obtainable on application to the Society, 1, Lowther Gardens, Prince Consort Road, London, S.W.7.

The annual exhibition organized by the Association of Public Address Engineers will be held at the Horseshoe Hotel, Tottenham Court Road, W.1, on April 27th (10.0-8.0) and 28th (10.0-6.0). There will be 18 exhibitors and there will again be half-hourly demonstrations of equipment throughout each day. Admission is by trade card or on production of this issue of *Wireless World*.

Interference Suppression

IN July, 1950, the Postmaster General appointed an 18-member committee to investigate interference caused by refrigerators, and twenty months later appointed another committee (of 21 members) to consider the question of interference from small electric motors.

Their recommendations are now embodied in two Statutory Instruments* laid before Parliament on March 1st by the P.M.G. They prescribe limits of noise voltages and fields which, from September 1st, must be complied with by *manufacturers* of electric refrigerators and by *users* of electric motors. The limits laid down are those given in British Standard 800: 1954. For both motors and refrigerators the noise voltage at the supply line terminals of the equipment must not exceed 1500 μV in the 200-1605 kc/s band and 750 μV in the 40-70-Mc/s band. The radiated field strength from motors, measured at not less than 33ft, must not exceed 100 μV/m and 50 μV/m, respectively, in these bands.

The question of making the regulations for small motors apply to manufacturers is to be reviewed during the next two years.

*"The Wireless Telegraphy (Control of Interference from Electric Motors) Regulations, 1955," No. 291, and "The Wireless Telegraphy (Control of Interference from Refrigerators) Regulations, 1955," No. 292. H.M.S.O.; 6d net each.

B.S.R.A. Convention and Show

THE ANNUAL convention and exhibition organized by the British Sound Recording Association opens at the Waldorf Hotel, Aldwych, London, W.C.2, on May 20th at 7.0 with a recital of magnetic recordings of film music. The exhibition of recording and reproducing equipment will be held from 10.30 to

7.0 on the 21st and from 10.0 to 6.0 on the 22nd. Admission is by catalogue (1s 6d), obtainable at the door.

PERSONALITIES

At the annual general meeting of the Parliamentary and Scientific Committee in February, **Dr. S. Whitehead,** M.A., D.Sc., M.I.E.E., F.Inst.P. (director of E.R.A.), was re-elected joint honorary secretary. The committee comprises members of both Houses of Parliament (at present 44 Peers and 119 Members) together with representatives from 94 scientific and technological institutions. It holds lectures and discussions on subjects of national interest with a scientific content, particularly those subjects which may come before the Lords or Commons. Dr. Whitehead is a past-chairman of the international committee on radio interference (C.I.S.P.R.) and has acted as deputy chairman of the P.M.G.'s committees on radio interference from ignition systems and from small motors.

D. C. Birkinshaw, M.B.E., M.A., superintendent engineer of B.B.C. television, is going to the United States in company with one of the television drama producers to study television techniques and organization. They leave on March 26th and will be away three weeks.

W. R. Fletcher, B.Sc.(Eng.), A.M.I.E.E., who joined the B.B.C. in 1936 as an assistant maintenance engineer at the Lisnagarvey, Northern Ireland, station, has been appointed engineer-in-charge at Brookmans Park. He succeeds **D. Hamilton-Schaschke,** who has become resident engineer, British Far Eastern Broadcasting Service, Singapore. After serving at a number of the Corporation's stations, including the short-wave transmitter at Rampisham, Dorset, where he was senior maintenance engineer, Mr. Fletcher was seconded for two years to the Ceylon Broadcasting Service. In 1951 he was appointed resident engineer of the B.F.E.B.S., Singapore.

D. H. Ray, B.Sc., M.I.E.E., the new head of the Engineering Department of the Mid-Essex Technical College, Chelmsford, has been assistant head of the Electrical Engineering Department of the College of Technology, Birmingham, for some years. During the war he was released from the Army to assist in the training of radio mechanics at the College of Technology, where he took a permanent appointment after the war. He is a member of the C. & G. advisory committee on radio and television servicing.

On the death of a cousin the family honours have devolved upon **R. F. Payne-Gallwey,** who becomes the fifth baronet. Sir Reginald is chairman of the Radio Industries Club.

This year's president of the Radio Society of Great Britain is **H. A. Bartlett** (G5QA) who has been a member of the council for the past three or four years. His special interest is long-distance working.

OUR AUTHORS

Francis Oakes, who is with the Ferguson Radio Corporation where he is in charge of transistor applications research, writes on the d.c. stability of transistor circuits in this issue. Educated in Vienna, he came to this country in 1939 and became a naturalized British subject in 1947. Before joining Ferguson's he was assistant chief of the electronics laboratory of the Morgan Crucible Company where he led a team of graduates working on a number of projects, including research into properties of materials, and on the development of carbon resistors.

M. P. Johnson, author of the article in this issue describing a method of testing precision oscillators, received the B.A.Sc. degree from the University of Toronto in 1936. He then came to this country and joined the General Electric Company at Coventry as a graduate apprentice. He later went into the transmission laboratory, where he is now in charge of a section dealing primarily with precision master oscillator development and negative feedback amplifiers.

OBITUARY

Donald Macadie, M.B.E., the inventor of the original d.c. multi-range amps-volts-ohms meter, which later became known as the Avometer, has died at the age of 83. After his retirement from the Post Office in 1933 he devoted a considerable part of his time to the activities of the Automatic Coil Winder and Electrical Equipment Company which he helped to form in 1923 to manufacture the Macadie coil winder and the Avometer.

Cyril H. Ford, chief engineer of E.M.I. Sales and Service, Ltd., has died at the age of 58. He was originally with Marconi's at Chelmsford and transferred to the Marconiphone Company in 1922. In 1931 he became chief engineer of the Service Department at Hayes on the formation of Electric and Musical Industries, Ltd. He was a member of the exhibition technical committee of the R.I.C.

IN BRIEF

Broadcast Receiving Licences current in the United Kingdom at the end of January totalled 13,903,950, including 4,307,772 for television and 263,741 for car radio. The number of television licences increased during the month by 151,783.

The tenth **Annual Electronics Exhibition** organized by the Northern Division of the Institution of Electronics, will be held at the College of Technology, Sackville Street, Manchester, from July 14th to 20th. On the first day the show will open at 2.0 p.m., but on subsequent days at 10.0 a.m. It will close daily at 10.0 p.m., except on Saturday when it closes at 6.0 p.m. There will be two main sections, one covering scientific and industrial research and the other manufacturers' products. Tickets are obtainable free from the organizing secretary, W. Birtwistle, 78, Shaw Road, Rochdale, Lancs.

In order to meet the increasing demands for **Mobile Radio** in the United States the Federal Communications Commission proposes reducing the channel spacing and making more stringent standards for equipment. According to a report in *Wire and Radio Communications* the spacing in the 25 to 50-Mc/s band is to be reduced from 40 kc/s to 20 kc/s, and in the 152 to 162-Mc/s band from 60 kc/s to 15 kc/s. In this country the spacing is 50 kc/s and 100 kc/s respectively in the 72 to 88 and 156 to 184 Mc/s bands.

Colour Television Lectures.—A course of eight lectures on "The Science of Colour Applied to Colour Television" by Professor W. D. Wright will be given on Tuesdays and Thursdays at 4.30 p.m. (from April 26th) in the Physics Department of Imperial College, Imperial Institute Road, London, S.W.7. Application for admission to the course, for which the fee is two guineas, should be made to the Registrar, Imperial College, Prince Consort Road, London, S.W.7.

New Zealand Television.—Our New Zealand contemporary, *Radio and Electrical Review*, reports that an Australian company (Rola Company Pty., Ltd.) and its New Zealand associate (Loudspeakers, Ltd.) are applying for permission to introduce into Australasia the Zenith system of subscription television—Phonevision.

The twenty-sixth edition of the **Trader Yearbook** (1955) is a veritable mine of information on the radio industry. In its 304 pages it includes directories of trade organizations, manufacturers and trade names, a buyers' guide and a considerable amount of technical information including some 300 valve base diagrams, abridged specifications for current television and sound receivers and a list of i.f.s used in post-war sound receivers. The Yearbook is obtainable by post from the Trader Publishing Company, Dorset House, Stamford Street, London, S.E.1, price 13s.

Sargrove Electronics ask us to point out that the **Direct-Reading Capacitance Meter** illustrated on p. 141 of our March issue was a development version; the final model is unlikely to be in full production for some months.

The Post Office has allocated the call-sign G9AED to the temporary experimental **Band III Television** transmitter which Belling & Lee are erecting on Beulah Hill, South London. The 250-watt transmitter, with its 16-dipole aerial giving an e.r.p. of 1 kW, is planned to be brought into service on April 1st. It will radiate a series of static patterns on 194.75 Mc/s, the vision frequency allocated to the London I.T.A. station.

Further changes in the licensing regulations governing the **Radio Control of Models** have been announced by the Post Office. Licensees will now only be required to check the transmitter frequency as often as may be necessary to ensure that it is operating within the authorized band and, in addition, the equipment may be operated by anyone under the personal supervision of the licensee.

An eight-page programme, giving explanatory notes and full details of the records to be played at the lecture-demonstration on **Sound Reproduction** by G. A. Briggs at the Royal Festival Hall on May 21st, is being produced. Copies, price 1s post free, will be available from Wharfedale Wireless Works, Ltd., Bradford Road, Idle, Bradford, after the middle of April.

The lectures given by Sir Edward Appleton, Professor G. W. O. Howe and Dr. J. Thomson at last year's I.E.E. meeting to celebrate the **Jubilee of the Thermionic Valve** are being published as a book by the Institution. It will also include an appreciation of Sir Ambrose Fleming and Lee de Forest by C. F. Booth (G.P.O. assistant engineer-in-chief). The book, entitled "Thermionic Valves 1904-1954," is available to non-members, price 9s.

The chairman of the new council of the **Technical Publications Association** is C. E. Cunliffe, manager of the Publicity and Publications Department of A. C. Cossor, Ltd.

INDUSTRIAL NEWS

Associated-Rediffusion, Ltd., the programme contractors who will provide the material for the weekday transmissions from the I.T.A.'s London transmitter, have ordered most of their studio and O.B. equipment from **Marconi's.** The equipment includes complete installations for three 3-camera studios, one 2-camera studio, two 3-camera O.B. vehicles and master control gear. The company has recently acquired Adastral House, Kingsway, London (to be renamed Television House) and have studios at Wembley and a theatre at Walham Green.

What is believed to be the first post-war exhibition of **Imported Electronic Equipment** and components is being organized jointly by Rocke International, Ltd., and B. & K. Laboratories, Ltd. The exhibition, which will be held from April 25th to May 6th at 59, Union Street, London, S.E.1 (near London Bridge station), will include instruments from America and the Continent. Tickets for the display, which is open from 9.0 until 7.30 (Monday to Saturday), are obtainable from Rocke International at the above address.

Industrial Television Equipment is to be provided by Marconi's for the Windscale plutonium factory of the U.K. Atomic Energy Authority at Sellafield, Cumberland. It will be used for observing at a safe distance conditions which are dangerous to examine at close quarters.

To extend the radio-telephone service for the county's ambulances the Essex County Council has ordered from **Pye Telecommunications** a fixed station and 45 mobile transmitter-receivers. The fixed transmitter will be installed at Hainault and be remotely controlled by line from the Ilford ambulance depot.

An electro-optical camera, specially designed by **Winston Electronics,** of Hampton Hill, Middlesex, for the United States Government, was amongst the cargo on the first flight of the new transatlantic freight service inaugurated by Airwork, Ltd. The sequential image convertor has been designed to enable photographs of 0.1μsec exposure to be taken at 0.5μsec intervals. It will be used at the Aberdeen proving ground—a weapon-testing centre.

The contract for planning the whole of the temporary I.T.A. station at Croydon has been awarded to **Marconi's,** who are supplying the vision and sound transmitters, aerial and 200ft mast. Work has begun on the temporary buildings for the station, which is scheduled to open in September.

Intercommunications Equipment Company, of 286-288, Leigh Road, Leigh-on-Sea, Essex, inform us that their marine R/T equipment (HA/66/RTA) has received the G.P.O. Certificate of Type Approval. The 50-watt transmitter operates on eight crystal-controlled frequencies within the band 1.4-8 Mc/s and, in addition to covering the same band, the receiver also covers medium and long waves.

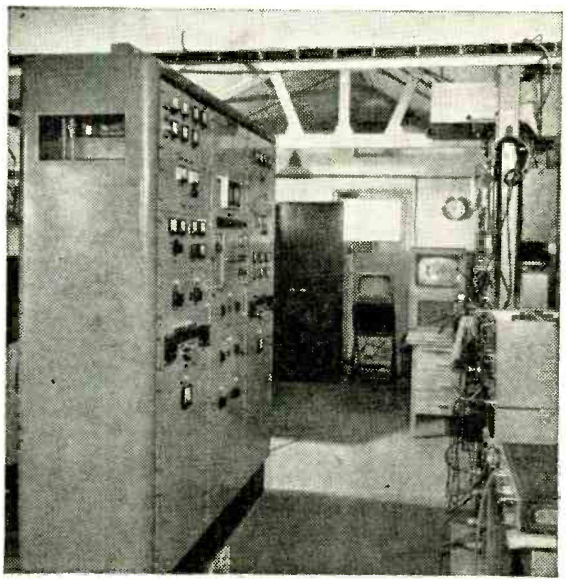
New Marconi House?—A new office building is to be erected by the English Electric Company on the site of the old Gaiety Theatre adjacent to Marconi House, Strand, the London office of the Marconi Company, which is in the English Electric group.

Pye-Polygon Agreement.—Pye, Ltd., have formed an association with the Polygon Record Company and announce that the business of the Polygon Record Co. (1954), Ltd., will be conducted from 66, Haymarket, London, S.W.1, the address of the Nixa Record Co., Ltd.

The multiplicity of television aerials on the living quarters at the Tower of London have been removed by order of the Ministry of Works and a communal aerial system has been provided. This has been installed by **E.M.I. Sales and Service** and feeds into a four-stage distribution amplifier. The output of 2V r.f. is fed into two "ring mains" of coaxial cable which encircles the whole of the Tower, providing a signal for individual members of the residential staff.

A feature of the **Marconi Marine** equipment installed in the new Grimsby steam trawler *Joseph Knibb* is the recently introduced "Gannet" R/T gear. The receiver has a rotating-loop aerial enabling the set to be used for direction finding as well as for communications.

On behalf of the United States Navy Department the Hazeltine Electronics Corporation has awarded three



THE FIRST of 20 low-power television transmitters ordered from Standard Telephones & Cables by the B.B.C. is being used at the temporary station at Tacolneston, Norwich. The combined sound and vision transmitter is shown on the left in this photograph. The vision transmitter produces a peak-white power of 0.5 kW. All the 20 transmitters are for operation in Band I, some being used at temporary sites and others as standby equipment at permanent stations.

British companies contracts valued at over $26M for the development and production of **Military Electronic Equipment** for N.A.T.O. countries. The contracts received by B.T-H., G.E.C. and Ferranti are valued at $11.5M, $10.5M and $4.25M, respectively.

Thorn Electrical Industries, Ltd., manufacturers of **Ferguson** sound and television receivers, have purchased ground at Enfield, Middlesex, on which they are erecting another factory. The new site is within a few hundred yards of their present factory.

Clare Instrument Company, which was formed twelve months ago by J. de Gruchy, a contributor to *Wireless World* on instrument technology, has moved from Rickmansworth, Herts, to 8, South Street, West Worthing (Tel.: Worthing 3407). The London office remains at 39, Victoria Street, S.W.1 (Tel.: Abbey 1816).

John Ould, Ltd., of 389, Fifth Avenue, New York, 16, U.S.A., has been formed to operate as a sales organization for British electronic and allied equipment. Their appointment as sole concessionaires for the United States was recently announced by W. Bryan Savage, Ltd., and Pamphonic Reproducers, Ltd.

A **Tape-to-Disc** recording service is provided by "Deroy" Sound Services, of Little Place, Moss Delph Lane, Aughton, Ormskirk, Lancs. Masters and pressings of both 78 r.p.m. and microgroove discs are supplied.

The title of Hadley Sound Equipments, Ltd., of Cape Hill, Smethwick, Staffs, has been changed to **Hadley Telephone and Sound Systems, Ltd.**

The telephone number of **Superior Radio Supplies** in the advertisement pages of this issue, which went to press in advance of this section, should be Elgar 3644.

COMPONENTS SHOW

THE RECORD number of 142 exhibitors will be participating in the twelfth annual exhibition of components, valves and test gear which opens at Grosvenor House, Park Lane, London, W.1, on April 19th for three days. The show opens at 10.0 each day and closes at 6.0 on the first, and at 9.0 and 5.0 respectively, on the two following days. Admission is restricted to wearers of an official badge obtainable, by engineers and technicians in the "user" industries and the Services, on application to the organizers, the Radio and Electronic Component Manufacturers' Federation, 22, Surrey Street, London, W.C.2. This year's exhibitors are listed below.

	Stand No.
A.B. Metal Products	41
A.K. Fans	123
Advance Components	30
Aerialite	85
Aero Research	99
Allan Radio, Richard	8
Antiference	56
Associated Electronic Engineers	92
Automatic Coil Winder Co.	72
B.I. Callender's Cables	57
Bakelite	127
Belling & Lee	16
Bird, Sydney S., & Sons	53
Bray, Geo., & Co.	109
British Electric Resistance Co.	35
British Mechanical Productions	76
British Moulded Plastics	2
British Physical Laboratories	78
Bulgin & Co.	21
Bullers	1
Carr Fastener Co.	75
Clark, H., & Co.	116
Collaro	10
Colvern	55
Communications & Electronics	93
Connollys (Blackley)	9
Cosmocord	79
Creators	105
Daly	100
Dawe Instruments	73
De La Rue & Co. (Plastics)	83
"Diamond H" Switches	6
Dubilier Condenser Co.	45
Duratube & Wire	52
Edison Swan Electric Co.	42
Egen Electric	37
Electro Acoustic Industries	40
Electronic Components	108
Electronic Engineering	98
Electrothermal Engineering	120
English Electric Co.	106
Enthoven, H. J., & Sons	58
Erg Industrial Corporation	119
Erie Resistor	29
Ever Ready Co.	125
Ferranti	44
Fine Wires	114
Garrard Engineering Co.	64
General Electric Co.	135
Goldring Manufacturing Co.	17
Goodmans Industries	47
Gresham Transformers	70
Guest, Keen & Nettlefolds	115
Hallam, Sleigh & Cheston	117
Hassett & Harper	141
Hellermann	89
Henley's Telegraph Works Co.	136
Hunt (Capacitors)	23
Igranic Electric Co.	12
Imhof	25
Insulating Components & Materials	122
Jackson Bros.	74
J-Beam Aerials	80
Langley London	130
London Electrical Co.	36
London Electric Wire Co.	61
Long & Hambly	31
Magnetic & Electrical Alloys	110
Mallory Batteries	97
Marconi Instruments	103
Marrison & Catherall	132
McMurdo Instrument Co.	39
Measuring Instruments	102
Micanite & Insulators Co.	101
Minnesota Mining & Mftg. Co.	126
Morganite Resistors	15
Mullard	65, 94, 95
Multicore Solders	69
Murex	137
Mycalex Co.	3
N.S.F.	49
Neill, James, & Co.	90
Oliver Pell Control	134
Painton & Co.	46
Parmeko	27
Partridge Transformers	24
Permanoid	88
Plessey	67, 68
Pye	96
Radio Instruments	84
Reliance Electrical Wire Co.	26
Reproducers & Amplifiers	32
Reslosound	50
Rola Celestion	77
Ross, Courtney & Co.	104
Salford Electrical Instruments	34
Sankey, Joseph, & Sons	128
Scott, Geo. L., & Co.	118
Simmonds Aerocessories	140
Sims, F. D.	133
Spear Engineering	121
Stability Radio Components	51
Standard Insulator Co.	142
Standard Telephones & Cables	5, 62
Static Condenser Co.	112
Steatite & Porcelain Products	38
Stocko (Metal Works)	131
Stratton & Co.	60
Suflex	48
Supply, Ministry of	91
Swift, Levick & Sons	139
Symons, H. D., & Co.	113
Taylor Electrical Instruments	19
Telcon-Magnetic Cores	111
Telegraph Condenser Co.	54
Telegraph Construction & Maintenance Co.	66
Telephone Manufacturing Co.	33
Thermo-Plastics	11
Transradio	124
Truvox	28
Tucker Eyelet Co.	81
Tufnol	129
Vactite Wire Co.	7
Vitavox	43
Walter Instruments	86
Wego Condenser Co.	18
Welwyn Electrical Laboratories	63
Weymouth Radio Mftg. Co.	13
Whiteley Electrical Radio Co.	14
Wiggin, Henry & Co.	138
Wimbledon Engineering Co.	87
Wingrove & Rogers	59
Wireless Telephone Co.	71
Wireless World and *Wireless Engineer*	107
Woden Transformer Co.	20
Wright & Weaire	82
Zenith Electric Co.	4

Design for an F.M. Tuner

1—*Underlying Principles of Receivers for the New B.B.C. Service*

By S. W. AMOS,* B.Sc. (Hons.), A.M.I.E.E., and G. C. JOHNSTONE,* B.Sc. (Hons.)

IN anticipation of the B.B.C. frequency-modulated service, due to start in May with regular programmes initially from Wrotham, the authors have constructed a suitable tuner for feeding high-quality audio amplifiers. The tuner, for which constructional details will be given in next month's issue, includes a built-in mains unit and is designed to use readily available components. Underlying principles and general design features are discussed in the present article.

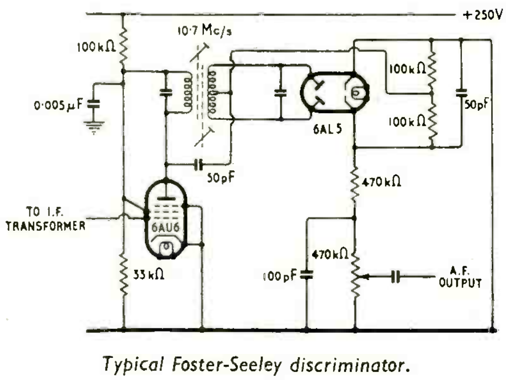
The B.B.C. proposes initially to employ carrier frequencies spaced at 200 kc/s intervals in the frequency range 88.1-94.5 Mc/s. This range is, however, only part of the range (Band II) allocated by international agreement to v.h.f. sound broadcasting. The full extent of the band is from 87.5 Mc/s to 100 Mc/s, and whilst at present the frequencies in the range 95 Mc/s to 100 Mc/s are used by police and other services, it is quite conceivable that in time frequencies in the upper part of the band will be employed for broadcasting purposes; thus the desirable receiver covereage is 87.5 Mc/s to 100 Mc/s.

The tuner's sensitivity should be such that at any point within the service areas the three local B.B.C. transmissions can be received. As the three transmitters will be of approximately equal power the field strengths at the receiving aerial will be approximately equal. For the purposes of classification the service area of each transmitter is divided by the B.B.C. into two regions; these are the first-class service region (field strength greater than 1 millivolt per metre) and the second-class service region (field strength between 250 microvolts per metre and 1 millivolt per metre). The significant difference between these two regions is that within the latter area some trouble from ignition interference may be experienced.

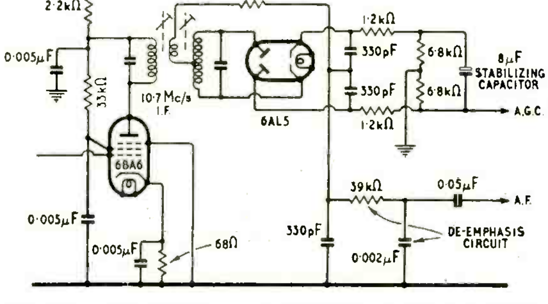
The receiver input voltage V is related to the field strength E at the aerial by the expression $V = \frac{E\lambda}{2\pi}$, where λ is the wavelength. In deducing the expression it was assumed that the aerial is a half-wave dipole, that matching is perfect throughout, and that feeder losses are negligible. For Band II λ is approximately π metres and the above expression may be simplified to E/2. Thus at the edge of the second-class service area the signal at the receiver terminals will be of the order of 125 microvolts.

However, this figure cannot be used as a basis for receiver design without some further qualification. The maps published by the B.B.C. give the average field strength at an aerial height of 30 feet. For lower aerials the field strength is less, being approximately proportional to height. Moreover, the field strength within a building is likely to be appreciably below the outdoor value, and tests indicate that this drop under unfavourable conditions may be of the order of 30 db. Thus at the edge of the second-class service area, with a picture-rail aerial, in a ground-floor room, at the side of a building remote from the transmitter, the signal at the receiver terminals may be as low as 4 μV. With such a small input the signal-to-noise ratio is likely to be barely acceptable, but this figure indicates the order of sensitivity required for a tuner destined for universal use.

Before the general form of the tuner can be considered, it is necessary to decide the type of discriminator to be used. The most popular ones are the Foster-Seeley and the ratio detector. The choice is governed by considerations of linearity and amplitude modulation rejection. The Foster-Seeley discriminator is capable of better linearity than the ratio detector but requires careful design and adjustment to obtain it, whereas the linearity of the ratio detector is not greatly affected by small variations of circuit parameters. As an indication of the distortion of the two, the Foster-Seeley can give less than 1% harmonic distortion at 75-kc/s deviation, whilst the ratio detector for the same deviation may give approximately 3%.



Typical Foster-Seeley discriminator.



The f.m. ratio detector; a de-emphasis circuit is included also in the Foster-Seeley discriminator.

* B.B.C. Engineering Training Department.

The chief difference between the two detectors is in their amplitude modulation rejection properties. The Foster-Seeley circuit is balanced, and thus gives good amplitude modulation rejection at its centre frequency; elsewhere its response to a.m. is proportional to the difference between the signal and centre frequencies. The ratio detector is also balanced at the centre frequency, but by virtue of the action of the stabilizing capacitor, its response at other frequencies is very much less than that of the Foster-Seeley circuit. For this reason it is usual to precede a Foster-Seeley discriminator by an amplitude limiter. Whilst such a limiter is not essential before a ratio detector, it can be employed to give additional rejection at high signal levels. The limiter used with a Foster-Seeley discriminator requires approximately 1 volt of signal at its *input* for limiting, whereas the ratio detector requires a signal of approximately 1 volt at the diode for limiting. Since the stage preceding a ratio detector may operate at full gain one i.f. stage can sometimes be saved by adopting this detector; in a particular design this may well be the deciding factor. On balance it was decided that the ratio detector was better suited for use in the tuner to be described.

Receiver Amplification

With a ratio detector the gain required from the aerial terminals to the detector is of the order of 10^5; with a Foster-Seeley discriminator this is the order of gain required prior to the limiter grid. The major portion of this gain must be obtained from the i.f. amplifier, but there will be a useful contribution from the frequency changer and r.f. amplifier. The necessity for an r.f. amplifier is not immediately obvious, because its gain will be considerably less than that of the same valve used as an i.f. amplifier. In spite of its low gain, the stage is necessary for the following reasons. The noise factor of a mixer stage is almost always considerably larger than that of an r.f. amplifier; since the signal-to-noise ratio of the tuner is determined almost entirely by that of its first stage, it is clear that this stage should be an r.f. amplifier for best signal-to-noise ratio.

Moreover the stage reduces feedback from the local oscillator to the aerial. Such feedback can cause interference to other receivers, and must be held to a low level. It has been suggested that in order to minimise such interference the maximum oscillator voltage appearing at the aerial terminals (loaded by an aerial or dummy load) should be less than 200 microvolts within Band II, and less than 500 microvolts at other frequencies. With the additive type of mixer usually employed at v.h.f. the local oscillator may provide up to 3 or 4 volts output at the grid of the mixer and the reduction of this voltage to the specified limits at the aerial terminals calls for careful design. With the multiplicative type of mixer, this problem is less acute because the input grid is screened from the oscillator grid. Finally, the increased selectivity conferred by the r.f. stage provides increased protection against image channel interference and i.f. break-through.

In order to calculate in detail the gains of the various stages of the tuner we must consider the circuit of each stage in greater detail. Three types of r.f. stage are commonly employed. These are the single pentode, the earthed-grid triode and the cascode (a combination of earthed-cathode and earthed-grid triodes in cascade). The behaviour of the cascode is generally similar to that of a pentode, having an overall mutual conductance equal to that of its constituent triodes. Due to the absence of partition noise, it has, however, a lower noise factor than the corresponding pentode. Except under conditions of extremely low field strength it is doubtful if the better signal-to-noise ratio justifies the employment of a cascode circuit in preference to an r.f. pentode.

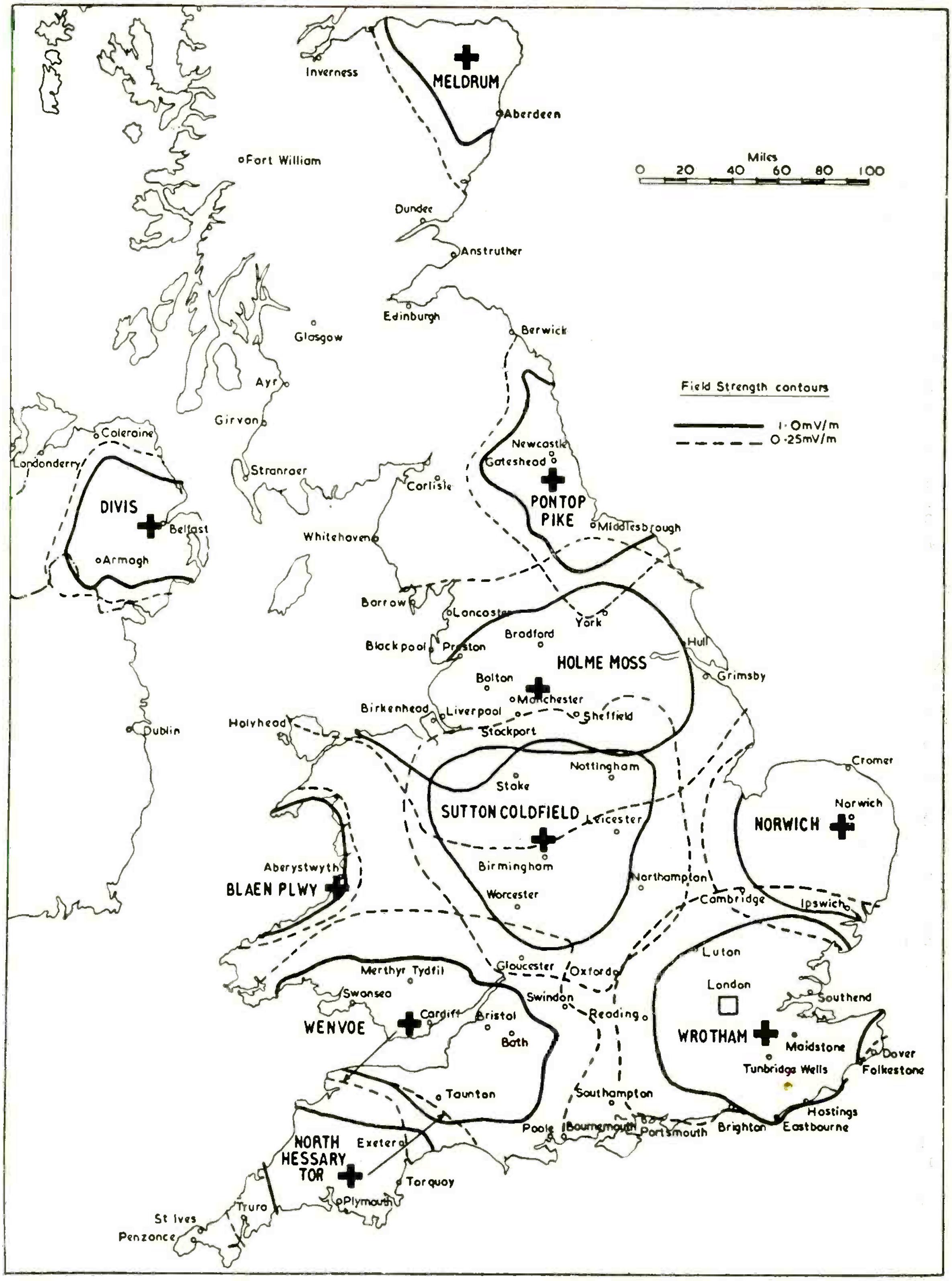
The earthed-grid triode r.f. stage is not generally favoured at frequencies as low as 100 Mc/s because it suffers from a number of disadvantages. First, the gain available from the aerial input circuit is low, due to the low input impedance ($1/g_m$); secondly, the noise factor is higher than that of a cascode and comparable with that of the r.f. pentode; thirdly, it offers insufficient protection against oscillator feedback to the aerial, the output and input circuits being linked by the anode a.c. resistance of the valve.

There thus seems little advantage in departing from a simple pentode r.f. stage. In general, because of the damping of the first tuned circuit by the aerial resistance and the input resistance of the r.f. stage, there is no point in having variable tuning in this circuit; it is normally sufficient for the circuit to be resonant at the mid-band frequency. The damping resistance due to the valve will be of the order of 2 to 6 kΩ and is in parallel with the dynamic resistance of the tuned circuit. If we assume a total tuning capacitance of 15 pF (i.e., the sum of the valve input capacitance, strays and a small amount of lumped capacitance) and a Q value of 50, the natural dynamic resistance of the tuned circuit is approximately 5 kΩ. This is reduced by valve damping to 1.5 to 2 kΩ and the aerial feeder impedance must be matched to this resistance to secure maximum voltage transfer and correct feeder impedance termination. With a 75-ohm feeder, the impedance ratio is about 1 : 25 and the voltage step-up ratio consequently about 5. Thus the total damping resistance from all sources is approximately 1,000 Ω, which, for a tuning capacitance of 15 pF, gives a working Q value of approximately 10. The response is then 3 db down at each end of the band, relative to the response at the mid-band frequency.

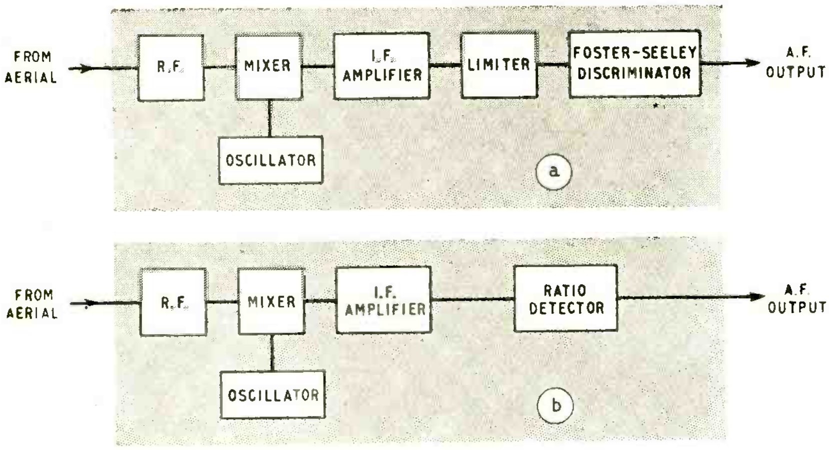
R.F. Stage

The gain from grid to anode of the r.f. stage, is intimately linked with the input resistance of the mixer stage, which is usually low, of the order of 2 to 3 kΩ. With this value there is some advantage to be gained by having variable tuning for the anode circuit, and with an additive type of mixer, variable tuning is essential to present a relatively constant impedance to the oscillator. The size of the tuning elements is determined largely by the requirements of the oscillator circuit, with which the anode circuit must be ganged. In general, this necessitates a tuning capacitance of the order of 20 to 30 pF, and hence gives a natural dynamic resistance in the region of 2.5 to 5 kΩ. The total load presented to the r.f. stage is thus 1 to 2 kΩ, giving a stage gain of approximately 10 with a valve having a mutual conductance of 6 mA/V. The gain from aerial input to mixer grid is thus about 50, and the gain required from the mixer and i.f. stages is 2×10^3. With a triode mixer, the input resistance is rather difficult to predict, because Miller effect plays a large part in determining it; under certain circumstances it may even be negative.

The combination of oscillator and separate mixer is



Estimated coverage of the first ten f.m. stations to be brought into service is shown on this map reproduced by courtesy of the B.B.C. The frequencies of the three transmitters at each station were given on page 56 of our February issue.



Block diagrams showing the main differences between (a) f.m. receiver with Foster-Seeley discriminator and (b) with a ratio detector.

usually preferred to the multplicative mixer, because the former gives an appreciably higher conversion conductance (about 2 to 3 mA/V compared with 0.5 to 1.0 mA/V). The oscillator may be a Hartley, Colpitts or Reinartz type but there are two factors which restrict the choice. First, it is desirable that one "pole" of the tuning capacitor should be earthed; this eases ganging problems. Secondly, the cathode of the oscillator should preferably be earthed; with the cathode divorced from earth, the cathode-heater capacitance forms a significant part of the total tuning capacitance, and there is a risk of microphony and hum induction due to movement of the heater with respect to the cathode.

Receiver Bandwidth

The component values in the oscillator circuit are a compromise between the extremes of a large tuning capacitance, to "swamp" valve capacitance variations, and a small value, to give a high dynamic resistance and hence maximum assistance to the maintenance of oscillation. A reasonable compromise value of tuning capacitance is 30 pF.

The mixer and i.f. amplifier are required to give a voltage gain of approximately 2×10^3 and have to satisfy certain selectivity requirements. The channel spacing of 200 kc/s would appear to impose fairly stringent requirements on receiver selectivity to minimize adjacent-channel interference. However, for any given locality the transmitters employing adjacent channels will be remote greographically and it is doubtful if any appreciable adjacent-channel interference will result. The bandwidth of the i.f. amplifier is thus determined largely by the harmonic distortion tolerable, the local-oscillator frequency drift and threshold effect.

The phenomenon of threshold effect is peculiar to all forms of angular modulation and there is no comparable effect in amplitude modulation. In brief, when the amplitude of an interfering signal exceeds that of the wanted signal, there is an abrupt deterioration of the signal-noise ratio. For ignition interference and random noise, the peak value of the noise signal is proportional to the square root of the receiver bandwidth and to preserve the signal-to-noise ratio at the highest possible value, the receiver bandwidth should be the minimum consistent with adequate bandwidth for the wanted signal. For a signal with a deviation of 75 kc/s, the sidebands extend well beyond the apparent swept limits of ±75 kc/s and thus it is usual to assume a minimum bandwidth, between the 3-db loss points, of 180 kc/s. To allow for oscillator frequency drift this is usually increased to between 200 and 250 kc/s.

The r.f. circuits of v.h.f. receivers have bandwidths measured in Mc/s rather than kc/s and the receiver selectivity is almost entirely determined by the bandwidth of the i.f. amplifier. As an indication of the performance likely to be achieved by a practical i.f. transformer we will assume each winding to have a Q-value of 50 and the coupling factor to be unity (kQ = 1). At an operating frequency of approximately 10 Mc/s the response is 0.6 db down at 75 kc/s from resonance and 7 db down at 200 kc/s from resonance. With a coupling factor of unity the response in the passband for Q-values exceeding 50 tends to be unsatisfactory and it is usual to employ coupling factors between 1 and 1.5 which give small "rabbit's ears" and maintain reasonably flat response in the passband.

The overall bandwidth depends on the number of i.f. transformers employed and this, in turn, is determined by the total number and the stage gains. The gain per stage is given by $g_m R_d n/(1+n^2)$ where n is the coupling factor (=kQ), R_d is the dynamic resistance of either tuned circuit alone (assuming both the same) and g_m is the mutual conductance of the i.f. valve. With n between 1 and 1.5, $n/(1+n^2)$ varies between 0.5 and 0.446. This is a very small variation and thus the stage gain depends almost entirely on R_d and g_m. R_d is given by ωQL and, for maximum gain, Q and L should be large. An upper limit to the value of L is set by the minimum value of tuning capacitance which can be employed; whilst it is possible to tune by valve and stray capacitance alone, this is undesirable because valve capacitances vary, particularly when an a.g.c. voltage is applied, causing appreciable change in the shape of the i.f. response curve. In general the lowest minimum value of lumped capacitance is of the order of 15 to 20 pF; even with these values appreciable detuning may occur. Where the highest stage gain is not of prime importance, 50 pF may be taken as a suitable value of lumped tuning capacitance.

The Q-value of the inductor depends upon many factors, amongst which are wire size, coil-former dimensions, and screening-can dimensions. By careful design, Q-values of the order of 100 at 10 Mc/s can be realized; if the lumped tuning capacitance is 20 pF, and valve and stray capacitance total 10 pF, a stage gain of about 200 can be obtained from a valve with a mutual conductance of 8 mA/V. This may be taken as representative of the upper limit of gain per i.f. stage and with such component values instability would probably occur. In practice, Q-values in the region of 70 to 80 are more likely to be obtained and with a tuning capacitance of 50 pF the stage gain is in the region of 70.

With an i.f. transformer of this kind having 50-pF tuning capacitors the gain of an additive-pentode mixer is about 20; the i.f. amplifier is thus required to contribute a gain of about 100 to give the required overall gain. This gain could be obtained from a single i.f. stage but it is preferable to use two stages. Where a ratio detector is employed the last i.f. stage can then be operated as a high-level limiter. This improves a.m. rejection for large inputs whilst giving useful gain for small input signals.

Oscillator Frequency

The general form of the receiver is determined as described above but there are a number of additional features of an f.m. receiver to which attention must be paid. For example, should the oscillator frequency be above or below that of the signal? The lower value permits better oscillator stability because a larger tuning capacitor can be used; the higher value gives less likelihood of second-channel interference. In order to discuss the choice further, it is necessary now to consider the precise value of the intermediate frequency.

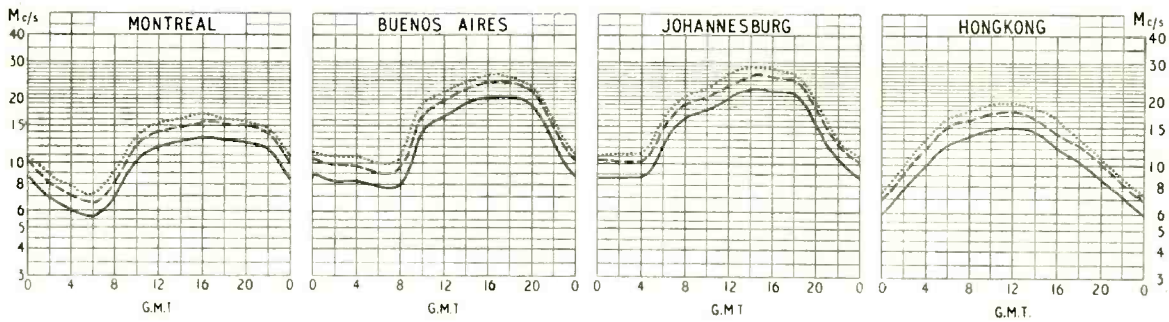
One of the unfortunate features of an f.m. receiver is that harmonics of the intermediate frequency are generated in late i.f. stages and the discriminator; this is due to the pulsating nature of the current in such stages. These harmonics can reach early stages of the receiver and may cause whistles and/or the appearances of "dead" carriers. To minimize this, the i.f. should be so chosen that its harmonics do not lie in the band to be received. Where the band is 88 to 108 Mc/s (as in the U.S.A.) the i.f. must be above 21.6 and below 22 Mc/s to satisfy this requirement. At such frequencies, it is difficult to achieve adequate selectivity. A lower limit to the value of the i.f. is set by the requirement that the frequency shall be greater than half that of the band to be received, to ensure that there are no image signals within the band itself. This minimum value for 88 to 108 Mc/s is 10 Mc/s and a frequency which seems to be favoured as the best compromise is 10.7 Mc/s. This i.f. has the disadvantage that the oscillator frequency can fall within the received band; for example, when the receiver is tuned to 88 Mc/s, if the oscillator frequency is 98.7 Mc/s, any oscillator radiation can cause interference to local receivers tuned to 98.7 Mc/s. Alternatively if the oscillator frequency is 10.7 Mc/s below the signal frequency and the receiver is tuned to say 98.7 Mc/s interference may be caused to receivers tuned to 88 Mc/s. Interference can thus occur over a range of frequencies at either end of the band, and for the British Band II, this range is 1.7 Mc/s. This difficulty could be overcome by adopting an i.f. of say 12.5 Mc/s, but there remains the problem of image interference and oscillator harmonics falling in this band.

With an intermediate frequency of 10.7 Mc/s, the two image channel bands are 66.1 to 78.6 Mc/s and 108.9 to 121.4 Mc/s. The former band includes the vision carrier of television channel 5 and a number of relatively high-power police and public service transmissions in the band 70 to 80 Mc/s. The band 108.9 to 121.4 Mc/s includes aircraft communication channels, which are less likely to cause interference.

With the oscillator above the signal frequency there is a possibility of the oscillator second harmonic causing interference in Band III; with the oscillator below, the harmonics fall clear of Band III. Summarizing, there is a possibility of interference with Band III television receivers when the oscillator frequency is high, and the possibility of image channel interference when the oscillator frequency is low. Provided these effects are minimized, receivers can be satisfactorily operated with high or low oscillator frequencies. But possibly on balance the choice would be for a higher oscillator frequency.

Oscillator radiation can be a serious problem and can occur in three distinct ways: (a) from the wiring or chassis due to circulating currents (b) from the aerial (c) from the mains lead. For all three classes of interference, limits have been laid down by the B.S.I. for television receivers and doubtless similar limits will be laid down for v.h.f. frequency modulated sound receivers. Clearly the design of any v.h.f. tuner should be such as to conform at least with these limits.

SHORT-WAVE CONDITIONS *Predictions for April*



THE full-line curves given here indicate the highest frequencies likely to be usable at any time of the day or night for reliable communications over four long-distance paths from this country during April.

Broken-lines curves give the highest frequencies that will sustain a partial service throughout the same period.

.... FREQUENCY BELOW WHICH COMMUNICATION SHOULD BE POSSIBLE FOR 25% OF THE TOTAL TIME

— — — PREDICTED AVERAGE MAXIMUM USABLE FREQUENCY

——— FREQUENCY BELOW WHICH COMMUNICATION SHOULD BE POSSIBLE ON ALL UNDISTURBED DAYS

D.C. Stability of Transistor Circuits

By FRANCIS OAKES*, M.Inst.E., A.M.Brit.I.R.E., Assoc. I.E.E.

Basic Formulæ and Design Data for Junction Types

A TRANSISTOR can be regarded as a combination of two diodes, one of them, biased in the forward direction, representing the emitter-base junction, the other, biased in the reverse direction, representing the base-collector junction. Transistor action, due to minority carrier injection, allows the reverse current of the base-collector junction to be controlled by the forward current through the emitter-base diode. Apart from this conduction by minority carriers, a leakage current flows across the base-collector junction due to impurities in the collector. This current, referred to as I_{co}, is not controlled by the emitter current, and unfortunately, increases rapidly with rising temperature.

Direct-current Relationships.—At any transistor operating point for which the emitter potential is positive, and for which the collector potential is negative with respect to the base, the current I_e (conventional) flowing into the emitter is equal to the sum of the currents I_c and I_b flowing out of the collector and base respectively. This can be expressed in the following forms:

$$I_e = I_c + I_b \quad \ldots \quad (1)$$

The collector current, on the other hand, is made up of the flow of minority charge carriers transferring a current αI_e from the emitter and by the impurity current I_{co}. The factor α which is referred to as the emitter direct-current amplification factor is a positive number, somewhat smaller than unity for junction transistors. The impurity current I_{co} is the current which will flow from the base to the collector when there is zero current flowing into the emitter. These circumstances may be represented in the equation

$$I_c = \alpha I_e + I_{co} \quad \ldots \quad (2)$$

Substituting this expression for I_c into equation (1), the base current can be obtained in terms of I_e and I_{co}:

$$I_b = I_e(1 - \alpha) - I_{co} \quad \ldots \quad (3)$$

Influence of I_{co} upon I_b, I_c and I_e.—When interpreting these expressions for application to practical design or to circuit analysis, it is important to realize that I_{co} is a fixed quantity which is determined by the particular transistor and by the temperature of the collector junction. Furthermore, that of the remaining three currents I_b, I_c and I_e, only one can be chosen at will, for a given current amplification factor α. In other words, if an operating point is chosen in a region of the static characteristic plane where α is of a certain desired value, the circuit must be so designed that suitable current conditions are fulfilled for all three transistor currents. For instance, if the emitter current has been suitably chosen and is supplied by a constant current generator and, because of bad design, the base current cannot adjust itself to a sufficiently small value as indicated by equation (3), the operating point will be forced into a region of low current amplification. This can be seen in Fig. 1. Operating points for comparatively high base currents are found only in the shaded area. Thus, it is of interest to express each of the direct currents in terms of each of the remaining two, the emitter-to-collector current amplification factor α and the base-to-collector current amplification factor α'. The latter is given by:

$$\alpha' = \frac{\alpha}{1 - \alpha} \quad \ldots \quad (4)$$

A graph for easy conversion is shown in Fig. 2.

Equation (2) immediately yields:

$$I_e = \frac{I_c - I_{co}}{\alpha} \quad \ldots \quad (5)$$

From equation (3) it follows that:

$$I_e = \frac{I_b + I_{co}}{1 - \alpha} = (1 + \alpha')(I_b + I_{co}) \quad \ldots \quad (6)$$

Substituting I_e from equation (5) into equation (3), yields:

$$I_b = \frac{I_c(1 - \alpha)}{\alpha} - \frac{I_{co}(1 - \alpha)}{\alpha} - I_{co} \quad \ldots \quad (7)$$

Therefore

$$I_b = \frac{I_c}{\alpha'} - \frac{I_{co}}{\alpha} \quad \ldots \quad (8)$$

Thus,

$$I_c = \alpha' I_b + \frac{\alpha'}{\alpha} I_{co}$$

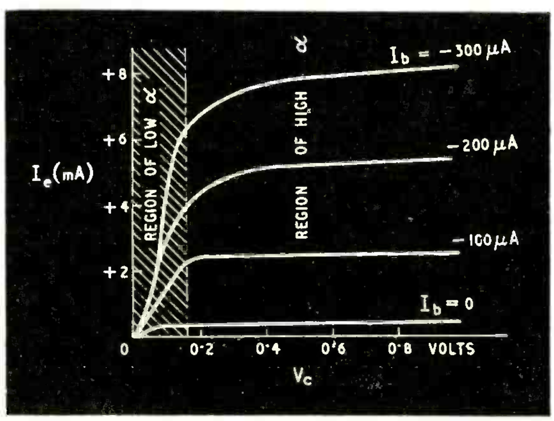


Fig. 1. Emitter currents for constant base currents in a junction transistor.

*Ferguson Radio Corporation.

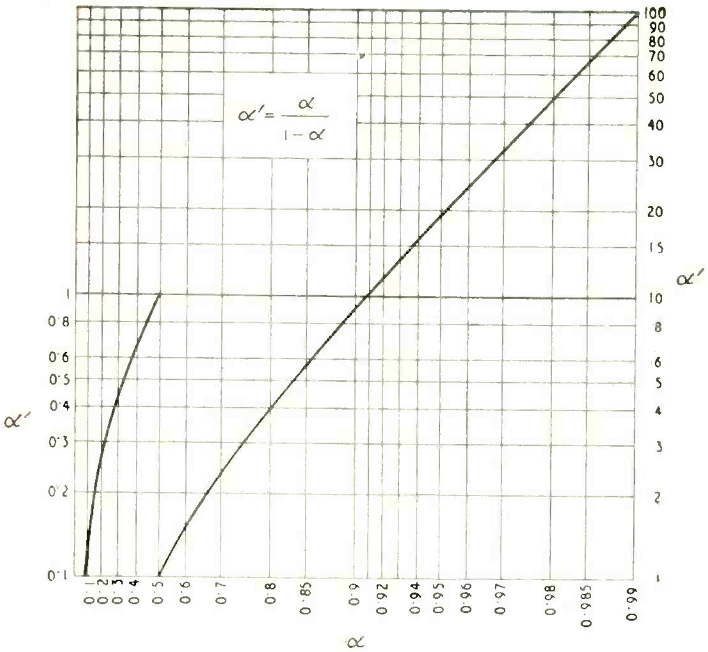


Fig. 2. Correlation curve for transistor current amplification factors

very considerably. The same holds good for the grounded collector connection provided that the base current is controlling the other two currents.

An interesting case is that of a transistor connected across a voltage source, emitter positive, collector negative and with the base terminal left disconnected. The base current is thus zero and the emitter and collector currents are identical and equal to:

$$I_c = I_e = \frac{I_{co}}{1 - \alpha} = (1 + \alpha')I_{co} \quad .. \ (12)$$

as follows from equations (6) and (10).

This shows that a transistor which will pass a leakage current I_{co} when connected across a voltage source via its base and collector terminals will take a current $(1 + \alpha')I_{co}$ when connected via its emitter and collector terminals. Since $(1 + \alpha')$ can easily be of the order (or in excess) of 30, it can be seen that an I_{co} of only a small fraction of a milliampere can be responsible for an augmented leakage current capable of destroying the transistor. In amplifier and oscillator circuits, the transistor is often connected in grounded-collector or grounded-emitter configuration, and the base direct current is usually held substantially constant. Under normal operating conditions, the leakage current I_{co} is initially quite small, but increases as a result of warming up through normal collector dissipation. The increased I_{co} in turn raises the collector current by an amount $(1 + \alpha')\ I_{co}$ which can now become quite appreciable, and in turn contributes to raise the collector temperature. The process is cumulative and the collector current "runs away" exceeding the safe limit and destroying the transistor.

But since:

$$\frac{\alpha'}{\alpha} = \frac{1}{1 - \alpha} = 1 + \alpha' \quad .. \quad .. \quad .. \ (9)$$

$$I_c = \alpha' I_b + (1 + \alpha')I_{co} \quad .. \quad .. \quad .. \ (10)$$

or:

$$I_c = \frac{\alpha I_b + I_{co}}{1 - \alpha} \quad .. \quad .. \quad .. \quad .. \ (11)$$

These relationships are set out in the table given below.

Amplified Leakage Current and Collector Current "Run-Away."—Some important implications follow from these equations. When a transistor is operated in grounded-base connection, the *emitter current controlling the collector current*, the leakage current is simply flowing across the base-collector diode reverse resistance. It therefore appears as a leakage current of magnitude I_{co}, being a part of the current flowing through the collector. If, however, the transistor is operated with a grounded emitter, *the base current controlling the collector current*, the portion of the emitter and collector current due to the flow of impurity current is $(1 + \alpha')I_{co}$. This means, that with a good transistor giving a large current amplification α' the leakage current flowing in the emitter and collector paths will be increased

CURRENT CONVERSION TABLE

→	I_b	I_c	I_e
I_b	I_b	$\frac{I_c}{\alpha'} - \frac{I_{co}}{\alpha}$	$(1-\alpha)\ I_e - I_{co}$
I_c	$\alpha' I_b + (1+\alpha')I_{co}$	I_c	$\alpha\ I_e + I_{co}$
I_e	$(1+\alpha')\ (I_b + I_{co})$	$\frac{1}{\alpha}\ (I_c - I_{co})$	I_e

Transistor Circuit Stability.—Since the influence of the impurity current upon the collector current cannot be neglected, it is important to ensure that this influence will not exceed the safe or permissible limits. The intrinsic current can rise to many times its original value for a temperature rise of 20° or 30°C, and for instance, if a transistor is operated near its maximum permissible collector dissipation, any increase in collector current due to the increase in leakage current at raised temperature will have to be held within close limits.

A stability factor can be defined as:

$$S = \frac{\partial I_c}{\partial I_{co}} \quad .. \quad .. \quad .. \quad .. \quad .. \ (13)$$

which is the rate of change of collector current produced by a change of impurity current. For stable operation, S should be as low as possible, and good stability can usually be obtained by suitable circuit design at the expense of power economy.

As can be seen immediately from the current relationships set out in the table, the stability factor for the grounded-base amplifier where the emitter current controls the other currents,

$$S = 1 \quad .. \quad .. \quad .. \quad .. \quad .. \ (14)$$

and for the grounded-emitter amplifier,

$$S = (1 + \alpha') = \frac{1}{1 - \alpha} \quad .. \quad .. \quad .. \ (15)$$

This indicates that the grounded-emitter amplifier will be more seriously affected by variations in I_{co}

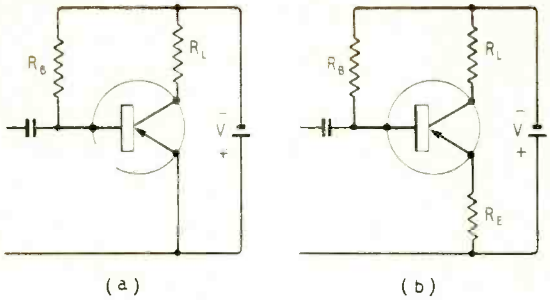


Fig. 3. Simple transistor amplifier (a) without stabilization, (b) with stabilizing resistor

due to temperature changes or other reasons. It is possible however to stabilize the collector current against such effects by the application of negative feedback. In applications where the loss in a.c. gain produced by such feedback would be detrimental, bypass condensers have to be used to reduce the feedback action to a permissible level at the operating frequencies.

A simple practical amplifier circuit is shown in Fig. 3, by way of illustrating the principle of stabilization. Fig. 3(a) does not contain a stabilizing resistor; R_B represents the base bias resistor, R_L the load. Under normal operating conditions, the emitter-to-base voltage is so small that it can be neglected, therefore the voltage across the bias resistance R_B is practically equal to the battery voltage. Hence

$$I_b = \frac{V}{R_B} \quad \ldots \quad (16)$$

$$I_c = \alpha' \frac{V}{R_B} + (1 + \alpha')I_{co} \quad \ldots \quad (17)$$

and

$$S = \frac{\partial I_c}{\partial I_{co}} = (1 + \alpha') = \frac{1}{(1 - \alpha)} \quad \ldots \quad (18)$$

Equation (18) is of course identical with equation (15).

If the stabilizing resistance R_E is included as shown in Fig. 3(b), the voltage across R_B is no longer equal to the battery voltage, but equals the difference between this and the voltage drop across R_E. Thus, an increase in I_{co} will produce an amplified leakage current through the emitter. This in turn will drop additional voltage across the stabilizing feedback resistor R_E. This additional voltage reduces the voltage available across the bias resistor R_B thereby cutting down bias current and reducing the collector current. In this way, the increase of collector current on account of I_{co} is reduced.

$$I_b R_B = V - I_e R_E \quad \ldots \quad (19)$$

Using the conversion table, I_b and I_e can be expressed in terms of I_c.

$$\left(\frac{I_c}{\alpha'} - \frac{I_{co}}{\alpha}\right) R_B = V - \frac{R_E}{\alpha}(I_c - I_{co})$$

$$I_c\left(\frac{R_B}{\alpha'} + \frac{R_E}{\alpha}\right) = V + I_{co}\left(\frac{R_B}{\alpha} + \frac{R_E}{\alpha}\right)$$

$$I_c\left(\frac{1-\alpha}{\alpha} + \frac{R_E}{\alpha R_B}\right) = \frac{V}{R_B} + I_{co}\left(\frac{1}{\alpha} + \frac{R_E}{\alpha R_B}\right)$$

$$I_c = \frac{\frac{\alpha V}{R_B} + I_{co}\left(1 + \frac{R_E}{R_B}\right)}{1 - \alpha + \frac{R_E}{R_B}} \quad \ldots \quad (20)$$

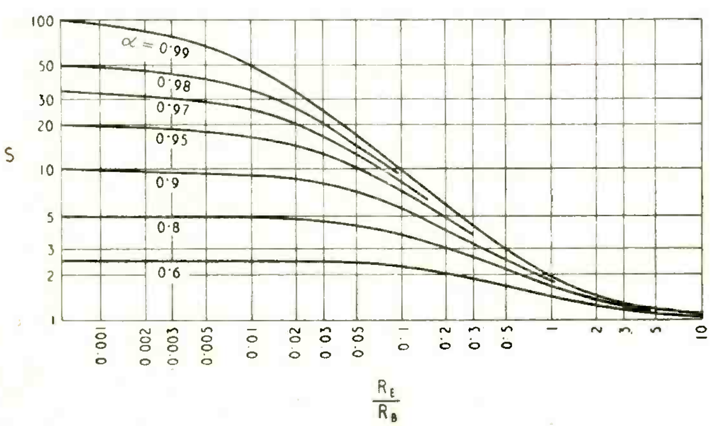
$$S = \frac{\partial I_c}{\partial I_{co}} = \frac{1 + \frac{R_E}{R_B}}{1 - \alpha + \frac{R_E}{R_B}} \quad \ldots \quad (21)$$

Equations (20) and (21) show that the collector current is reduced by negative feedback, which depends on the ratio of stabilizing feedback resistance to base bias resistance.

Curves correlating the stability factor with this ratio are shown in Fig. 4. As the ratio R_E/R_B approaches zero, the stability factor rises towards the value without stabilization expressed in equations (15) and (18). These curves give a good picture of the stabilizing action of the circuit in Fig. 3.

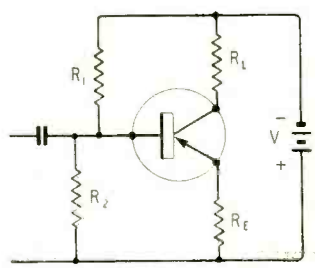
Supposing this amplifier has to operate at a current of 4mA with a collector voltage of 1 volt, and with a load d.c. resistance of 125 ohms, then the circuit could be powered by a 1.5-volt cell without stabilization, i.e. as shown in Fig. 3(a). If the current amplification under these conditions is equal to $\alpha' = 32$ corresponding to $\alpha = 0.97$, a stability factor $S = 33$ would result. Assuming I_{co} at room temperature to equal 5μA, than a 20°C temperature rise at the junction could raise I_{co} by about 50μA. This would increase the collector current by 1.65mA. If the maximum permissible collector dissipation is 5mW, the margin of safety would then be reduced to half. The load drops 0.7 volts, leaving 0.8 volts at 5.65mA, i.e.

(*Continued on page 167*).



Left: Fig. 4. Stability factor S as a function of $\frac{R_E}{R_B}$ for different values of current amplification factor α.

Below: Fig. 5. Potentiometer-stabilized amplifier.



4.5mW to be dissipated by the collector, as compared with 4mW at room temperature.

If a second cell is used, raising the battery voltage to 3 volts, a stabilizing feedback resistor R_E dropping 1.5 volts at room temperature can be inserted. Since the current to be carried is 4 mA, the value of this resistance will be 375 ohms. It will dissipate approximately the same amount of power as the transistor. The feed resistance R_B has to supply a base current of:—

$$I_b = \frac{I_c}{\alpha'} - \frac{I_{co}}{\alpha} = 0.12\text{mA}.$$

Allowing for the voltage drop of 1.5 volts, R_B has to be 12,500 ohms. The resistance ratio R_E/R_B therefore equals 0.03. From the curves, the stability factor is found as $S = 17$.

Thus, the collector current will change by 850μA for a 50μA change in impurity current. The collector voltage will be reduced by 0.425v., due to the voltage drop across R_L and R_E (totalling 500 ohms). The collector will thus operate at 4.85mA with only 0.575 volts—rather a serious reduction—from collector to emitter. The collector dissipation is thus reduced to 2.79mW, i.e. to less than for the cold condition when I_{co} was negligible. This will be accompanied by a loss in signal-handling capability due to the reduced collector-to-emitter voltage. A better compromise would be possible by a reduction in R_E, but this would necessitate a value of battery voltage which might prove inconvenient, lying between the steps available by connecting cells in series.

An alternative method of stabilization is therefore illustrated in Fig. 5. Here, improved stabilization is obtained by use of the potentiometer arrangement consisting of the resistors R_1 and R_2. If the internal resistance of the battery can be neglected, the resistances are effectively in parallel, and the stability factor for this circuit is therefore again given by equation (21), provided that

$$\frac{1}{R_B} = \frac{1}{R_1} + \frac{1}{R_2} \qquad (22)$$

Thus, also

$$S = \frac{1 + R_E\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}{1 - \alpha + R_E\left(\frac{1}{R_1} + \frac{1}{R_2}\right)} \qquad (23)$$

Allowing an additional current drain across the potentiometer $R_1 - R_2$ to dissipate about the same amount of power as the transistor, i.e. 4mW, this would imply a current drain of 1.33mA. R_2 drops 1.5 volts, and therefore equals 1130 ohms. R_2 also drops 1.5 volts, but carries the base current in addition to the 1.33mA, totalling 1.45mA, and therefore equals 1010 ohms. Their parallel value therefore is $R_B = 540$ ohms, $R_E/R_B = 0.7$ and therefore, the stability factor $S = 2.3$. This is a considerable improvement with an additional 50% power consumption compared with the improvement by the use of R_E alone, without the potentiometer bias supply.

The temperature change under consideration will raise the impurity current by 50μA as before. This, however, will result in a rise of collector current of only 115μA with additional drop in voltage of 0.0575 volts produced jointly by R_E and R_L. The collector dissipation is thus $(4 + 0.115)(1 - 0.0575) = 3.87$mW i.e. less than cold, and with the signal-handling capacity virtually unchanged.

Conclusions.—The basic principles outlined above can be applied to the design of more complex circuits. Where transistors are used in tandem, arrangements can be made for a transistor operating at a lower power level to stabilize a transistor operating at a higher power level, and at the same time to provide useful amplification.

WORLD'S JOURNALS

OVER 160 journals from more than 20 countries are scanned regularly by the compilers of the Abstracts and References section of our sister journal *Wireless Engineer*. Each month abstracts from, and references to, some 300 articles are included in the section, which is compiled by the Radio Research Organization of the Department of Scientific and Industrial Research.

The 60-page annual index to the Abstracts and References, including both subject and author sections, is included with the March issue of *Wireless Engineer*, which is obtainable from our publishers, price 6s.

New Music

Designed to generate any tone produced by the human voice or any musical instrument this electronic synthesizer, built under the direction of Dr. Harry F. Olson in the Princeton Research Laboratories of the Radio Corporation of America, also places at the disposal of musicians a medium of expression in which new tones and rhythms can be composed and performed without the intermediary of traditional methods of music making. The photograph, left, shows Dr. Olson at the keyboard.

Waveguides as Microwave Links

POSSIBLE ALTERNATIVE TO RADIO AND LINE COMMUNICATION

THE demand for channels of communication expands so rapidly that the organizations whose duty it is to provide them must continually be ready with new supplies. Hitherto these have always been available by drawing on higher and higher frequencies. Each doubling of the upper frequency limit brings in about as many new channels as all those already in use. But we are now reaching the stage at which such resources will no longer be acceptable. Radio waves of the millimetre order (i.e., above 30,000 Mc/s, or 30 kMc/s) are seriously obstructed by rain, clouds and other kinds of weather. This may be all very well for storm-detecting radar, but not for communication. Even at frequencies several times lower, propagation of radio waves in the open is appreciably affected by such influences. Meanwhile, the alternative of a coaxial line also fails because its attenuation increases fairly steeply with frequency. The same applies to waveguides—with one exception. The Bell Telephone Laboratories have recently published an account of theoretical and experimental exploration of this exception,* and they conclude that it has interesting possibilities.

A most important characteristic of waveguides is that propagation along them can take place in a number of different modes. These modes are divided into two main classes, according to whether there is a lengthwise component of electric field, in which case they are called E modes (in America, TM), or of magnetic field, when they are called H or TE modes. The two classes are subdivided according to the numbers of half-cycles of field pattern in two cross-sectional dimensions. Below a certain critical frequency, corresponding to a wavelength of the order of twice one of these dimensions (or a sub-multiple thereof), propagation ceases. The critical frequency for a given cross-section depends to some extent on the mode, and by taking advantage of this fact and by choosing a suitable shape for the guide, it is possible to eliminate all modes but one. This is the usual practice with waveguides as now used for such purposes as connecting a transmitter to its aerial—at most, perhaps, 100ft away. Hitherto, the idea of using waveguides for long-distance transmission has not been favourably considered, because at frequencies low enough for the attenuation not to be excessive the guide has to be so large as to be uneconomic. At 4 kMc/s, for example, the loss in even a theoretically perfect guide is 40db per mile, which is quite useless. At 1 kMc/s the figure is 2db per mile, which would be satisfactory were it not that the guide would have to be more than 6in wide and would be usable only for a narrow band of frequency.

Past theory had indicated that for one exceptional mode (and its multiples of the same type) the attenuation would *decrease* with rising frequency, which, of course, is just what is wanted. At first this seemed too good to be true, and even when the theory was checked it was still reckoned that it would not be so in practice, owing to the necessity for perfect uniformity of cross-section. This particular mode is the H_{01} (or TE_{01}) in a cylindrical guide. The reason for its peculiarity is that the electric lines of force are concentric circles, as shown in Fig. 1(a) and (b), and

* S. E. Miller. "Waveguide as a Communication Medium," *Bell System Technical Journal*, Nov. 1954, pp. 1209-1265.

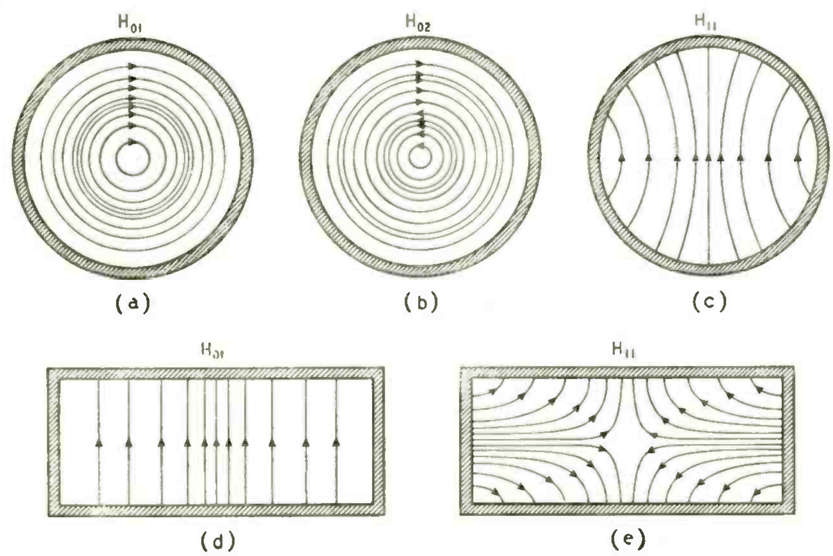


Fig. 1. The H_{01} mode in a cylindrical waveguide (a), together with its multiples such as H_{02} (b), H_{03}, etc., has the unique feature that the lines of electric force (shown in these diagrams) take the form of closed concentric loops, not touching the guide walls as in other modes such as (c), (d) and (e), and consequently loss decreases with increase of frequency. In E modes, the magnetic field patterns are similar to the electric patterns shown here.

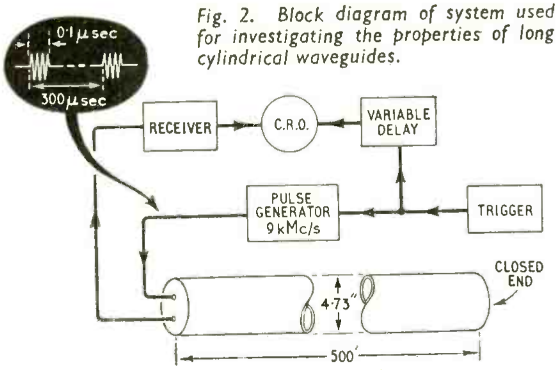


Fig. 2. Block diagram of system used for investigating the properties of long cylindrical waveguides.

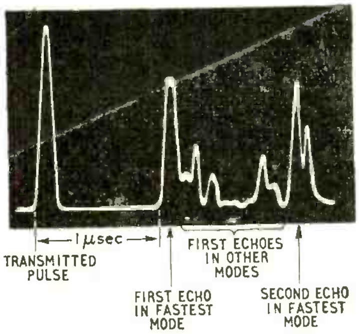


Fig. 3. The first two or three microseconds of the oscilloscope display, showing the transmitted pulse and reflections.

consequently no longitudinal currents are induced in the guide walls as with other modes. The only wall currents are those needed to confine the wave to the interior of the guide, and the loss from that cause decreases with frequency. Taking 2db per mile as a reasonable figure for attenuation and 2in diameter as a reasonable size of pipe, the frequency for these conditions is 50 kMc/s, at which the wavelength is 6 millimetres, and the maximum usable bandwidth about 500 Mc/s.

As already hinted, this attractive prospect is somewhat clouded by practical difficulties. One, the need for generating and dealing with 6-mm waves, can safely be left to development. A less obvious snag is that owing to the wavelength being so much smaller than the diameter of the guide (as is necessary in order to achieve the low loss) propagation is not restricted to this one mode. Energy at 50 kMc/s can in fact travel along a 2-in guide in many different modes. At first sight this might seem to be an advantage, because each mode can be regarded as a separate channel, like a wire in a multi-core cable. But unfortunately even slight curvature or non-uniformity of the guide causes part of the energy in one mode to change to another, which would cause mutual interference between channels working on the same frequency. Seeing, however, that owing to the greater attenuation of the other modes only the H_{01} would be likely to be employed, it might not appear to matter very much if a small proportion of the H_{01} energy were lost to other modes, provided it was not enough to add seriously to the 2db per mile. Moreover, the signal energy converted into another mode is always liable to be converted back again farther along. If all modes had the same velocity, this would partly offset the loss. But as it happens they have not, so by the time energy is converted back into the H_{01} mode it is out of step with the parent signal and so distorts or confuses that signal.

In order to study the practical possibilities the Bell Telephone Laboratories set up a 500-ft straight cylindrical waveguide. The highest frequency for which suitable measuring equipment was then available was 9 kMc/s ($3\frac{1}{3}$cm), for which the inside diameter of guide corresponding to a theoretical 2db loss per mile is 4.73in. The guide of this diameter was aligned to within $\frac{1}{8}$in of a straight line throughout its length, and its cross-section was cylindrical within about 0.008in.

The experimental procedure, indicated in Fig. 2, was to inject short pulses at one end of the guide, and receive echoes from the other end (closed by a metal plate) for oscillographic display on a time base. A variable delay was provided in order to extend the observation to pulses received after a large number of journeys to and fro along the guide. Each pulse, lasting 0.1 microsecond, occupied 100ft of guide while in transit, and the first echo was received 1μsec after the initial blip corresponding to the send-off from the generator. Fig. 3 shows this first stage of events as seen on the screen. The clear space between the pulse received direct from the transmitter and the first echo from the far end shows that the pipe was sufficiently free from imperfections to cause no appreciable reflections from anywhere along its length. The clutter of echoes following on the heels of the first home is made up of modes having lower velocities. There are about 40 possible modes for this guide and frequency, but the resolution of the 0.1 μsec pulse is not good enough to allow them all to be picked out.

A continuation of the display, in Fig. 4 (a), shows that most of these modes die out after a few reflections, whereas the mode giving the prominent first echo in Fig. 3 was still going strong enough to be well above noise level after 200 return trips, amounting to 40 miles. The attenuation can easily be measured by comparing amplitudes of blips, and was found to be about 3db per mile. This could only be the H_{01} mode, for which the theoretical figure in this

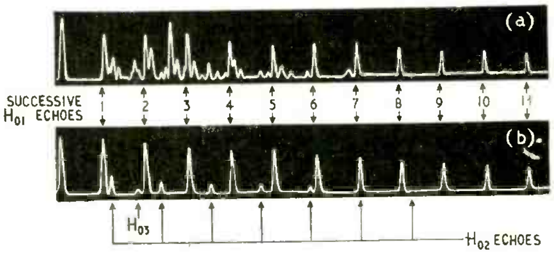


Fig. 4. A more extended view of pulse echoes, (a) without, and (b) with, a mode filter in the experimental waveguide.

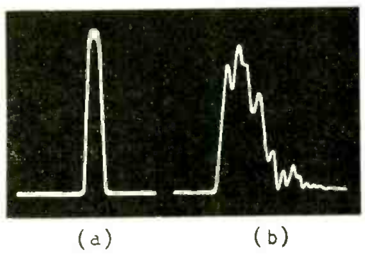


Fig. 5. (a) Shape of pulse as received without distortion, and (b) with distortion due to energy that has been travelling for part of the distance in different modes having lower velocities.

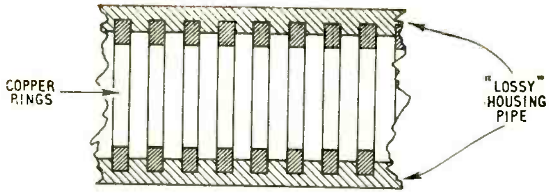


Fig. 6. Spaced-ring waveguide construction, forming a continuous mode filter, especially helpful for reducing curvature losses.

size and material of guide is 1.9db, all the other modes having much greater rates of attenuation. The possibility of transmitting signals over long distances by waveguide was thus demonstrated.

The next experiment was to introduce a mode filter, with the result shown in Fig. 4 (b). The only responses now to be seen, other than the first circular electric of H_{01} series, are a series of seven identifiable by their velocity as the second circular electric or H_{02} (Fig. 1 (b)) and one little specimen of the third circular electric or H_{03}.

So far, matters look very well (except for the practical difficulty of installing a pipe say 40 miles long, dead straight and perfectly cylindrical throughout, within close tolerances). But the results just described, in which even long-distance responses differ little from Fig. 5 (a), are the best of a very mixed bag. Some of the others were more like (b). It was found that varying the length of the guide no more than about a foot, by means of a piston at the far end, could make differences as drastic as these. Further investigation showed that the distortion evident in Fig. 5 (b) was caused by mode conversion, as already described, and that what the piston did was to vary the distance between conversion and reconversion points, causing either reinforcement or cancellation.

A large proportion of the Bell Telephone report is devoted to a study of this mode conversion problem and what it might be expected to amount to in a 50-kMc/s 2-in guide. An important part of the problem is the effect of bends, which cause energy to be converted from H_{01} to E_{11}. One method of preventing this is to use an elliptical pipe for the bend. Another is to devise a guide that attenuates the E_{11} mode without unduly increasing the loss of H_{01}. One type of such a guide consists of copper rings held in an insulating pipe, as shown in Fig. 6. In a more easily manufactured variation of this, the conductor is a continuous helix. It must not be imagined that even with these aids the bends can be sharp. The sort of curvature envisaged for the spaced-ring or helical guide is a bending radius of 2,000 feet! This is calculated for a 2-in guide at 48kMc/s, and would double the normal dissipation loss. It appears, however, that there are other methods for negotiating sharp bends, and the author of the report concludes that waveguides have a future as multi-channel links. It is suggested that a 2-in pipe could provide 500-Mc/s channels from 35kMc/s to 75kMc/s, at which the theoretical attenuation per mile is 3db and 1db respectively. The 500-Mc/s bandwidth seems to be somewhere near the maximum: if so, it would presumably exclude present systems of television, especially as even that limitation of bandwidth assumes such an amount of distortion as would make it desirable to use a distortion-tolerant type of modulation, such as pulse-code and regenerative repeaters at 25-mile intervals.

Commercial Literature

Low-frequency Transformers (operating down to 2c/s); hermetically sealed input types with balanced windings, internal screens and Mumetal cases. Note from Avis & Baggs, 11-13, Gosbrook Road, Caversham, Reading, Berks.

Audio Amplifier (8-10 watts), with frequency response of ±0.25db between 20c/s and 30kc/s, and associated pre-amplifier and control unit with volume and tone controls, recording compensation, etc. Booklet on the RD Junior from Rogers Development Co., 116, Blackheath Road, Greenwich, London, S.E.10.

Permanent-bit Soldering Iron, claimed to last indefinitely and to require no filing. Available with ⅛-in, $\frac{3}{16}$-in, ¼-in and ⅜-in bits. Also permanent tips for fitting as caps to ordinary bits. Leaflets from Light Soldering Developments, 106, George Street, Croydon, Surrey.

Stabilized H.T. Supply; dual channel design for giving positive and negative potentials with respect to earth and other facilities. Voltages are variable while current is 0-250 mA per channel. Leaflet from Joyce, Loebl & Co., Vine Lane, Newcastle-upon-Tyne 1.

Non-corrosive Flux having a chemical structure with resistance to water and low electrical conductivity. Historical review of development in this field and description of testing methods by Dr. W. Rubin on a leaflet from Multicore Solders, Maylands Avenue, Hemel Hempstead, Herts.

R.F. Induction Heater (12kW) with output coupling arrangements enabling it to be used with either fixed or remote work stations. A process timer is included, while the cooling equipment is self-contained. Leaflet from E.M.I. Factories, Hayes, Middlesex.

Unit Cabinet System intended for high-quality sound reproduction equipments. Also amplifiers, tuners, loudspeakers, gramophone motors, pickups, tape recording equipment and other accessories. Catalogue from the Classic Electrical Company, 352-364, Lower Addiscombe Road, Croydon, Surrey.

Information-storage Magnetic Recorder (Ampex model 306) for industrial and scientific applications. Uses frequency modulated carrier system and has frequency response of 0 to 5 kc/s with tape speed of 30 inches per sec. Equipments with anything from one to 14 tracks. Leaflet from Rocke International, 59, Union Street, London, S.E.1.

Power Amplifier with 50 watts output and frequency response at this power of 15c/s to 20kc/s ±1db. Harmonic distortion at 1,000 c/s claimed to be 0.002%. This and four other new instruments made by Krohn-Hite (Cambridge, Mass., U.S.A.) described in a leaflet from Rocke International, 13 East 40th Street, New York 16, N.Y., U.S.A.

Insulated Resistance Wires with a new epoxy-based enamel coating called Diamel which is claimed to have durability, high breakdown voltage and resistance to solvents and heat with freedom from pinholes. Details in a booklet "Electrical Resistance Materials" from Johnson Matthey & Company, 78-83, Hatton Garden, London, E.C.1. Also another booklet on precision-drawn seamless tubes.

Television Frame Output Windings, complete with laminations ready to clamp into existing shroud; available at present for a certain number of receivers Note from Direct TV Replacements, 134-136, Lewisham Way, New Cross, London, S.E.14, with a new catalogue containing technical servicing information, price 1s including postage.

Oscillograph C.R. Tube (type 4EP1) incorporating post deflection acceleration, giving high deflection sensitivity (about 1mm per volt) with good brightness. The final acceleration voltage of 2kV can be increased to 8kV for high writing speeds. Note from Electronic Tubes, Kingsmead Works, High Wycombe, Bucks.

Transistor Hearing Aid operating from a 1.5-volt carbon pen-cell battery (or others) and measuring 2½in × 2in × ¾in. Is claimed to run for a year at 8 hours a day on six pen cells. Leaflet from Bonochord, 48, Welbeck Street, London, W.1.

Propagation on Bands I and III

Direct Practical Comparison

By F. W. R. STRAFFORD, M.I.E.E., and I. A. DAVIDSON, B.A.

WITH the advent of Band III television transmissions in this country, a large number of problems arise connected with the propagation of television signals at frequencies of the order of 200 Mc/s. If co-siting of the transmitters is adopted, then the strength and variations of the Band III signal must be considered in relation to that of Band I, as in most areas that will have a Band III signal, a Band I signal will also be present.

A preliminary investigation has been made of the relative behaviour of the signals on the two bands, using a transmission of 180.4 Mc/s radiated by the B.B.C. from the Sutton Coldfield mast. The signal was horizontally polarized, and therefore the experiment will not necessarily give an exact picture of propagation with a vertically-polarized signal, which has been chosen for the Band III service. However, useful information was obtained up to a range of about 30 miles from the transmitters. The 180.4-Mc/s transmission was beamed in a south-easterly direction, and all the observations were made within a few degrees of the centre of the beam.

Details of the two transmissions are given in Table 1.

Two receivers were used for the purpose of making the measurements and were installed in a mobile research laboratory. The outputs from the receivers were fed to a pen-recorder, enabling a continuous record to be made on both 61.75 Mc/s and 180.4 Mc/s. The receiver sensitivities were checked throughout by suitable signal generators. Initially the levels were adjusted so that on an open site, free from reflections and within visual range of the mast of the transmitters, the outputs of the two receivers were equal, thus compensating for the differences in the radiated power; i.e., 100/1. The mobile unit then toured through a number of differing types of sites, such as built-up and rural areas, at various distances from the transmitters, and at each site a record was taken with the mobile unit moving slowly. The receiving aerials were at a mean height of 25 feet from the ground. It was therefore possible both to estimate the relative strengths of the signals at each site, and also to investigate the importance of local variations of the field strength at the two frequencies.

Table 1

	Band I	Band III
Modulation	Television waveform	Square wave
Frequency	Vision 61.75 Mc/s Sound 58.25 Mc/s	180.4 Mc/s
E.R.P.	100 kW	1 kW
Polarization	Vertical	Horizontal
Aerial height (above ground)	750 feet	600 feet

A vertical dipole was used on Band I, and either a horizontal dipole or a horizontal "Yagi" array on Band III. The records show that two distinct types of fluctuations in signal strength are present—rapid and slow.

Rapid Variations

Fluctuations in the signal received by a dipole aerial when moved over short distances occurred on all the records. These are of a periodic nature, the rate of fluctuation being about three times greater on the Band-III transmission, as would be expected since the fundamental frequencies are similarly related. An example of this type of variation is shown in Fig. 1 and is a tracing of a typical pen-recording.

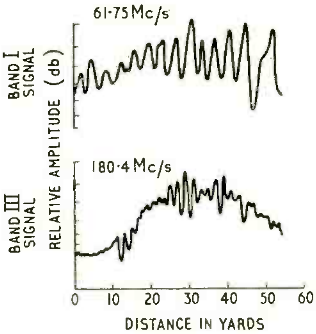


Fig. 1. The rapid fluctuations with distance due to local reflections are shown here. The marks on the decibel scale are 1 db apart, but are unevenly spaced because of the characteristics of the recorder.

In all cases a local reflecting object could be identified as the cause. The periodicity of the variation depended on the relative direction of the transmitting station with respect to the reflecting object, but generally posssessed a wavelength of between $\lambda/2$ and λ; i.e., 7 ft. 6 in. to 15 ft. on Band I and 2 ft. 6 in. to 5 ft. on Band III. It was further established that these fluctuations were originating from a local reflector. By substituting a directional array in place of the dipole aerial, the fluctuations were completely removed. The distance of the reflecting object was in most cases sufficiently near to the receiver not to cause any noticeable ghost images. This was determined on Band I by viewing the picture, and on Band III by examining the trailing edge of the square modulation pulses.

Slow Variations

In addition to the rapid variations in the presence of reflecting objects, the signal level on both frequencies showed slow variations, even under open site conditions. These variations were non-periodic, the distances between successive maxima ranging between 15 and 60 yards on both bands. The amplitude was also similar on both bands, but there was no definite correlation between them. Examples of this type of fluctuation are given in Fig. 2 (a) and (b), showing that they are quite random with distance on both bands.

The variations were present both in built-up areas and in open country, and no definite objects, such as trees or buildings, could be found to explain them. Furthermore, the variations were independent of the type of receiving aerial that was used. The most probable explanation is absorption and diffraction of the signal by ground irregularities, quite small changes in ground height or variations in its conductivity, or dielectric constant, being sufficient to explain them.

The effect of these variations is twofold. When considering the service area for a given type of receiving aerial, it is possible to calculate the minimum field strength required, assuming such factors as the forward gain of the aerial and the sensitivity of the receiver. For 90 per cent coverage of a given area, however, because of the slow variations in the signal level, the mean field strength must be greater than the calculated minimum level. From the records it has been calculated that this difference is approximately 6 db for satisfactory reception in 90 per cent of receiver locations. Secondly, in fringe areas, the variations cause large differences in the signal/noise ratio over distances of about 30 feet, and hence between adjacent houses.

Mean Level

At each site the mean levels of the two signals were determined from the records, the amplitude of the signal being averaged over distances up to ¼ mile. No absolute measurement of the signal was made, since comparison only was required. In each case the level was determined relative to the signals obtained on a reflection-free site within visual distance of the transmitting aerial as previously explained. These results are given in Table 2.

Table 2

	Distance from Transmitter (miles)	Site	Field strength relative to that of site "A"	
			Band I (db)	Band III (db)
A	12	Open country	0	0
B	19	Built up area	−9 / −16 *	−14 / −21 *
C	19	Open country	−10 / −5 *	−16 / −15 *
D	34	Open country	−12	−34

* Taken at two nearby sites in the same area.

It can be seen from this table that, compared with Band I, the Band III signal drops more rapidly as the distance from the transmitter is increased. The measurements at 34 miles correspond to the horizon distance and, at this range, a small hill reduced the Band III signal to the noise level of the receiver.

From the foregoing practical, but admittedly inextensive tests, the theoretical prediction of increased propagational losses with increasing frequency has been verified. Workers in various countries have also verified this prediction*, but their results have invariably been plotted in terms of median field strengths, whereas the television aerial installer is far more interested in the house-to-house problem.

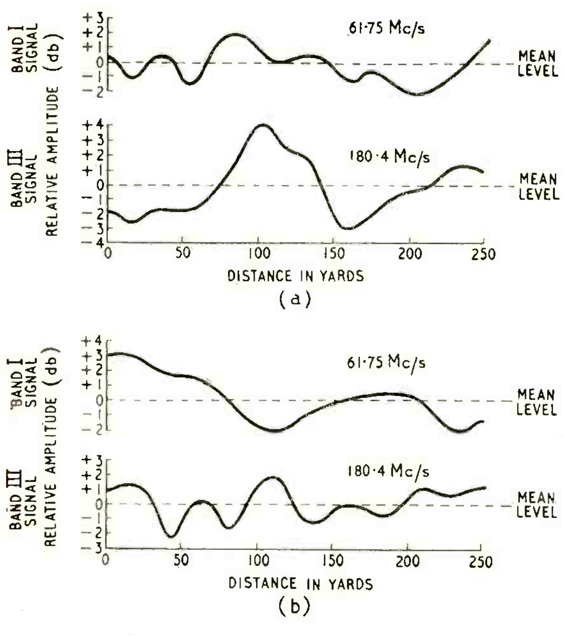


Fig. 2. Two examples (a) and (b) of slow fluctuations are shown here

In Conclusion

Probably the most interesting conclusion which may be drawn is that when one is in a region of weak signal strength in a built-up area, the compulsory requirement of a multi-element directional aerial automatically makes it unnecessary for the site to be "probed" to find the best location for its installation. This is explained under "Rapid Variations." On the other hand, in regions of high average signal strength where a simple non-directional dipole may suffice to provide adequate input to the receiver, it does not matter much whether the aerial is located in a trough of signal field strength due to reflections, since adequate signal is still likely to exist at that point. Of course, it is assumed that no long-distance reflections are present likely to cause a displaced image or ghost, in which case a directional aerial would obviously be required.

The results also show that, in terms of square miles of service area, independent of population considerations, a single Band-III transmission can never be so effective as a similarly located Band-I transmission unless the former is either (a) delivering far more power from its aerial or (b) possesses a much higher mast or, preferably, both.

* See for example: J. A. Saxton. "Basic ground-wave propagation characteristics in the frequency band 50-800 Mc/s." *Proc. I.E.E.*, Pt. III, July 1954.

Interference Suppression

Techniques for Dealing with Small Commutator Motors

By R. DAVIDSON,* B.Sc., A.Inst.P.

As reported elsewhere in this issue, regulations have now been made for the control of interference from domestic and industrial apparatus driven by small electric motors. This article reviews the general principles of suppression and describes some of the latest methods that are being used on such apparatus.

MANY readers will be familiar with the basic principles of interference suppression, but for those who are new to the subject these principles will be briefly re-stated. The supply current to a commutator motor is discontinuous and the discontinuities cause radio-frequency currents to flow in the motor and its associated wiring. These r.f. currents have a wide frequency spectrum and may cause interference to both sound and television reception. The currents and their associated energy may be propagated in several ways, but the majority of interference results either from direct radiation from the motor to the aerial of the receiver or by propagation along the mains wiring and subsequent radiation to the receiver aerial. Interference by direct radiation is usually comparatively local, but interference resulting from propagation along the mains wiring, and subsequent radiation, may occur at considerable distances from the source. Since interference resulting from both these modes of propagation is received via the receiver aerial little can be done to abate interference at the receiver, and suppression measures must be taken at the source. If these measures are concentrated on preventing the flow of radio frequency currents into the mains wiring it is usually found that the direct radiation from the appliance is also reduced to tolerable limits. Interference is suppressed at the source by taking one or more of the following steps.

(i) Fitting capacitors between supply lines and the frame of the appliance to reduce the impedance between these points and thus by-pass the asymmetric component of the radio frequency currents, i.e. the component flowing from the appliance along the lines and back to the appliance via earth. This component is the cause of interference in the majority of cases.

(ii) Connecting capacitors between supply lines to reduce the impedance between lines and thus by-pass the symmetrical component of the radio frequency currents, i.e. the component flowing from the source along one supply line and back to the source via the other supply line.

(iii) Fitting inductors in series with the supply lines to increase the impedance of the lines at radio-frequencies and reduce both asymmetric and symmetrical components.

The types of capacitors or inductors to be used and their positioning relative to the source of interference will depend on the frequency bands over which suppression is required. Here it must be stressed that, except in special cases, components employed for suppression over the low frequency sound broadcast bands will not be effective at television frequencies, and separate components will be required here. Furthermore, different techniques are used for suppression over the two frequency ranges.

A very wide range of suppressor components is now available both for incorporation into appliances by manufacturers and for fitting to existing appliances by retailers and the general public. Suppression over the sound broadcast frequencies (150 kc/s—1.6 Mc/s) can be achieved by fitting suppressors either within the appliance in the supply lead at the plug, or permanently at the supply point, but due regard must be taken of the safety regulations governing the maximum values of capacitance which may be fitted in the various positions. (These values are fully detailed in the revised British Standard Specification No. 613 which will be published shortly.) Within the appliance it is usual to fit capacitors of 0.01μF-0.1μF across the lines and up to 0.005μF between lines and frame for sound-broadcast suppression. These capacitors are available in paper dielectric as combined units in tubular form or potted in moulded boxes. Separate capacitors are available in paper dielectric or with high permittivity (high "K") ceramic dielectric, the last-mentioned usually in the form of discs. High "K" ceramic capacitors are very compact and have low self inductance, but are subject to considerable changes of capacitance with temperature. Users should, therefore, ascertain that the capacitance value will not rise above the maximum permitted

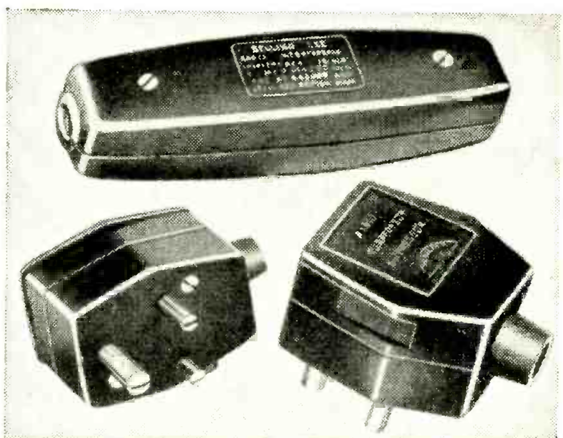


Fig. 1. Cord grip suppressor (top) and (below) plug suppressors. These can be fitted by the user.

* Dubilier Condenser Company.

value within the temperature range likely to be experienced inside the appliance, nor fall below the minimum capacitance necessary for effective suppression. Radio frequency chokes are available for incorporation inside appliances in wavewound form on iron dust or ferrite cores, as toroids on ferrite cores, or in rectangular form on flaked iron cores. The last-mentioned two types, using closed cores, require few turns on the windings and are especially suited for the heavier current applications.

Two types of radio suppressor which may be conveniently fitted by the user of an appliance are the cord-grip suppressor and the plug suppressor (see Fig. 1). In the cord-grip type capacitance values similar to those which may be fitted within the appliance are used. In the plug suppressor the maximum capacitance values permissible are 0.005μF between line and earth, 0.1μF between line and neutral and 0.05μF between neutral and earth, but it is usual to supply plugs with capacitors only in the last two positions.

For suppression at Band I television frequencies components must be fitted either within the appliance (preferably close to the brushes) or in the supply lead within about 9in of the appliance. Radiation of interference from the lead becomes excessive if suppression is attempted at greater distances from the appliance. Fortunately the components required are very small and can usually be housed within the appliance. Very

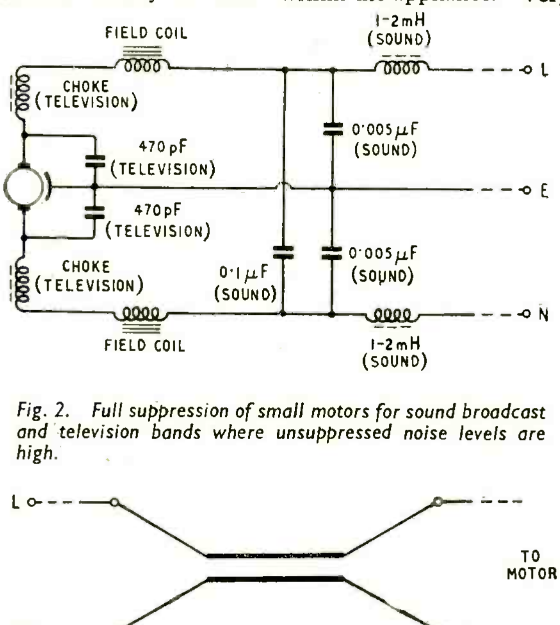


Fig. 2. Full suppression of small motors for sound broadcast and television bands where unsuppressed noise levels are high.

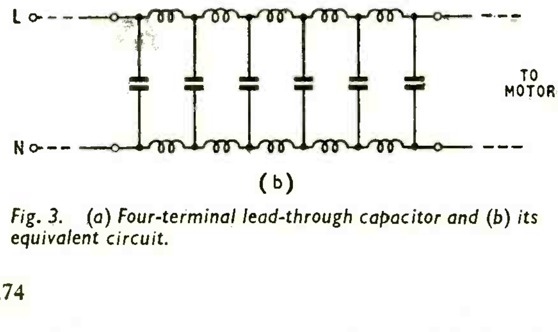


Fig. 3. (a) Four-terminal lead-through capacitor and (b) its equivalent circuit.

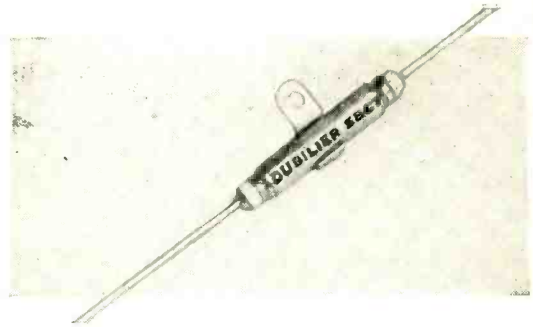


Fig. 4. Lead-through capacitor (0.005μF) for suppressing interference on Band I from electric drills, etc.

effective suppression is achieved on many commutator motors by fitting 470-pF capacitors from brushes to frame and small self-resonant dust-core inductors in the brush leads or incoming mains leads. For those who wish to fit television suppressors outside the appliance, small cord-grip suppressors incorporating inductors are available for wiring into the mains lead close to the appliance.

The new regulations which have been made call for suppression to within the limits laid down in British Standard Specification No. 800, "Limits of Radio Interference," which covers the frequency bands 200 kc/s—1605 kc/s and 40 Mc/s—70 Mc/s. For motors generating high levels of interference on both sound radio and television bands it may be necessary to fit all the suppressors shown in Fig. 2, which gives typical component values.

Recent developments in the suppressor field, some using novel techniques, have fortunately simplified the suppression problems for certain types of appliances. For wide-band suppression of interference from appliances which have a strong symmetrical component of interference, and this includes at least one type of sewing-machine motor, the four-terminal lead-through capacitor has been introduced.* In this suppressor the supply leads are connected to the two plates of a rolled paper capacitor at one end of the winding and the appliance leads to the plates at the other end of the winding. It is arranged that the supply current has to traverse the whole of the winding so that good capacitive coupling between lines is achieved over a wide frequency range, and the inductance of the winding is placed in series with the supply leads to aid asymmetric suppression (see Fig. 3). With this construction a comparatively large capacitance can be used to provide suppression at sound frequencies, whilst still being effective at television frequencies, provided the capacitor is fitted close to the source of interference.

Two developments in single-pole lead-through capacitors should be mentioned as they have rendered possible simple high-frequency suppression of two classes of appliance which hitherto were most difficult to suppress—electric drills and similar appliances and low voltage d.c. motors. Most readers will know by now that lead-through capacitors properly fitted are effective up to frequencies well beyond the television Band III and do not suffer from the disadvantages of conventional capacitors† which have appreciable self

*British Patent No. 727496.

†"R.F. Characteristics of Capacitors." *Wireless World*, August, 1952.

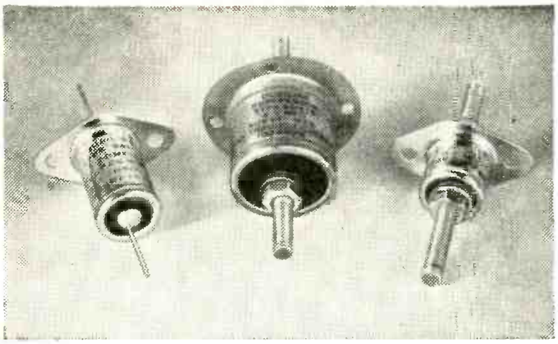


Fig. 5. Group of metallized paper lead-through capacitors suitable for low-voltage d.c. motors (left 2μF, middle 4μF, right 0.5μF).

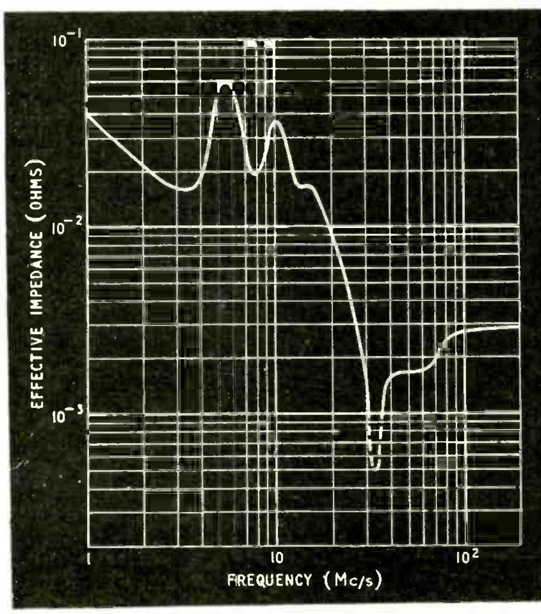
inductance. A small 0.005-μF lead-through capacitor has been introduced which is designed to be particularly effective for suppression of Band I interference from electric drills and similar metal-cased appliances, and measurements show that it will also be effective on Band III. This capacitor is illustrated in Fig. 4.

Low voltage d.c. motors usually have low impedance field and armature windings and require high capacitance values to achieve suppression. For suppression at both sound broadcast and television frequencies a lead-through construction is essential, and to meet these two requirements a range of metallized paper capacitors is now available with capacitances up to 4μF at 150 V d.c. working. Some examples of this range are illustrated in Fig. 5. Lead-through capacitors behave as high-attenuation transmission lines and the peaks and troughs in their impedance-frequency characteristic are predictable from the dimensions of the capacitor winding. By using metallized paper the attenuation of the plates is very much increased, and at a certain critical frequency at which, it is believed, all radio-frequency reflections from the equivalent transmission line back on the supply line are completely attenuated, an extremely low effective by-pass impedance is achieved. This effect is illustrated in Fig. 6 which also shows the very low overall impedance obtainable with this type of capacitor. Over the dotted portion of the graph between 30 and 36 Mc/s no signal whatever was detectable on the suppressed line from the capacitor when a signal of 0.25 volt was injected on the line to the capacitor. A receiver capable of measuring 2.5μV input voltage was used for this test.

The use of 470-pF capacitors for television suppression of small motors was mentioned earlier. A single unit is now available comprising, in effect, three 470-pF capacitors in delta connection which measures only $\frac{3}{4}$in × $\frac{3}{16}$in and has three connecting leads. The two outer leads are connected one to each brush of the motor with the central lead to the frame of the motor. It is simpler to fit than separate capacitors and has been found to give, in many cases, several decibels more suppression than that obtained with separate components. The circuit diagram of this unit, used in conjunction with television inductors on a small motor, is shown in Fig. 7.

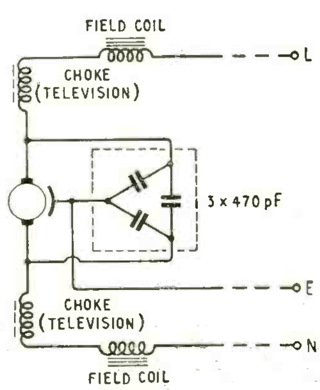
Mention should be made of combined filter units for both sound broadcast and television suppression which, although not novel, have been improved in efficiency and compactness in the last few years. These units are particularly suitable for the larger appliances such as cine-projectors and accounting machines and are usually fitted in the supply leads immediately inside the housing of the appliance.

No review would be complete without strong emphasis being placed on the safety precautions which must be observed when fitting suppressors either within appliances or in the supply lead or the supply plug. The requirements of B.S.613 are such as to ensure that suppressor components used in the various positions are of a sufficiently high grade and have sufficiently high margin of safety at the operating conditions that failure is most unlikely. These requirements must be rigorously observed, especially in positions where component failures may lead to risk of shock to the user of the appliance. For similar reasons the recommended maximum values of capacitance for various circuit positions must equally be observed. For instance the maximum capacitance which may be connected between lines and frame inside a portable appliance not doubly or fully insulated is 0.005μF. Larger capacitances will pass sufficient current at the supply frequency to cause unpleasant shock if the frame of the appliance is unearthed. Many people complain of a sensation of shock from the frame of a correctly suppressed appliance using 0.005-μF capacitors and operated with the appliance unearthed. Such people should not blame the suppressor or the manu-



Left:—Fig. 6. Impedance/frequency characteristic of 4μF metallized paper lead-through capacitor (Dubilier type SBN13).

Below:—Fig. 7. Use of three 470-pF capacitances in a single unit for suppression at television frequencies.



facturer who fitted it but should, in their own interests, use the earth lead with which such appliances are provided and connect it to the supply through a properly installed 3-pin plug and socket rather than through a 2-pin one. Space does not permit details of all the safety recommendations for the fitting of suppressors but readers are urged to make sure that suitable components are employed whenever they are installing suppressors and that the wiring is most carefully checked.

There are various sources of expert guidance on suppression problems. The Code of Practice on the general aspects of radio interference abatement (to be published shortly by the British Standards Institution), and the relevant British Standards listed therein, give very great assistance. Manufacturers of suppressor components provide technical data on their suppressors and advice on their use and in many cases are able to carry out interference suppression tests. The Post Office, of course, have a vast fund of experience on interference suppression and are also able to help with advice.

In conclusion some reference must be made to future prospects. This year full-time f.m. broadcasts on Band II and low power television broadcasts on Band III are due to commence. Existing Band-I suppressors will be adequate in most cases for Band II. Until full-power transmissions are available on Band III it is impossible to be dogmatic about interference conditions on this band and it is generally agreed that further work on suppression techniques is required at these frequencies. It can be said, however, that measurements to date on a number of types of domestic appliances fitted with efficient Band-I suppression have shown that radiated and mains-borne noise levels on Band III are sufficiently low that such suppression is also expected to be adequate on this band in many cases.

LETTERS TO THE EDITOR

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

Frequency Allocation

I HAVE been reading with great interest your recent editorial comments on the present unsatisfactory state of frequency allocation in this country.

For the past twelve months I have been engaged in negotiations with the G.P.O. on the subject of re-accommodating in the spectrum users of mobile radio who are to be displaced from their present positions by the advent of Band III television. It would, of course, be wrong for me to comment on this work while it is still under discussion, but I have seen enough of the general problem of frequency allocation to enable me heartily to endorse your view that better machinery must be found for the administration of radio frequencies if their immense benefits are to be fully enjoyed by the community in peace, and if we are to have a sound basis of frequency allocation for defence.

I have sought many people's advice on this subject and it seems to me that the best proposal I have so far come across is that the task of allocation should be allotted specifically to one Minister, and to one without departmental responsibilities, such as the Lord Privy Seal. There is a precedent for such an arrangement in that atomic development and radio research are being administered in this way, presumably because the Minister in charge is not departmentally concerned with conflicting interests.

I do not think it would be difficult to conceive of a permanent impartial body working under the Minister which would undertake as its first task an impartial investigation of the present frequency position and the merits of the various conflicting claims being made for space in the spectrum.

It would clearly be essential that the first part of such an examination should be devoted to the relative merits of civil and military claims. I do not see why we should accept the suggestion that military claims for frequencies should be regarded as sacrosanct and not subject to justification. Frequencies, after all, are only a raw material in peace or in war and Service departments should be required, just as much as civil users, to give specific assurances of economic utilization. I cannot accept the proposition that security considerations are any serious bar to satisfying this condition.

A further conclusion I have formed as a layman is that the subject of frequency allocation is not nearly such a difficult one as we have been led to believe. The problem appears to me to be simply that of dividing a cake and not of cooking it. There have been too many technicians engaged in the task and too few persons skilled in the established arts of arbitration. For this reason I feel that the chairman of the suggested investigating body should be one of Her Majesty's judges.

House of Commons. L. P. S. ORR.

Quality on V.H.F.

A MOMENT'S thought on the chances of better quality from existing receivers via f.m. shows how masterly was the condensation of facts by Mr. Bishop in his letter in the December, 1954, issue.

The radio industry produces receivers capable of giving the most intelligible listening from the general reception conditions prevailing. These conditions have normally demanded the suppression of more than half of the B.B.C.'s transmitted frequency range on long and medium wavelengths. It is the fault neither of the B.B.C. nor of the set designers that the reproduction of the higher frequencies is inadequately provided for in the majority of radio sets in use today.

Only the complete redesign of the audio amplifiers, speaker units, etc., used in these sets will allow the frequency range available via the f.m. service to be reproduced, and enable us to appreciate to the full the general high standard of transmission by the B.B.C.

F.M. attachments to existing receivers can only provide a silent background, which may expose some frequencies previously masked by interference.

High Cross, nr. Uckfield, Sussex. C. E. WATTS.

Diplexers for Reception

THE use of a filter network for combining the output from two television transmitters operating on sound and vision frequency respectively and conveying it to a radiating system via a single feeder is well known and, of course, is an established practice of the B.B.C.

With the advent of Band III television it will often be necessary to use this selective process in the reverse sense and I see no reason why the term diplexer, which has been used to describe the transmitter combining network, should not equally apply to the receiving counterpart.

For this reason I would like to make an attempt to define a diplexer as follows:—

"A diplexer is a combined low-pass/high-pass filter for the purpose of conveying energy from two sources of differing frequencies to a common sink impedance such that there is minimum interaction between the individual sources of energy. The linearity of such a system permits that it may be used in the reverse sense."

Putting this in a simplified manner and applying it in the practical sense to Band I/Band III television reception, we may substitute the following definition:—

"A diplexer is a combination of tuned filters designed in such a manner that the output from two aerials operating on differing frequencies (e.g., Band I/Band III) can be connected to a single input (a television receiver) without interaction.

"A diplexer can also be used in reverse; i.e., a single aerial responsive to Band I and Band III can, by a single feeder be connected to a receiver having individual Band I and Band III input connections."

It is interesting to observe that the use of this term appears to be quite common in the United States where such arrangements are already in use for connecting Band IV receiving aerials to existing BandI/III combined aerials.

Perhaps some of your readers may have some better suggestions.

Belling & Lee, Ltd., F. R. W. STRAFFORD
Enfield.

As She is Spoke

MR. PAWLEY, in your March issue, asks for a suitable abbreviation for "television recording," and I would like to suggest that what they make is a "replica" or a "reproduction." The programme would then be "transmitted from a reproduction."

Mr. Scroggie, in his letter, finds no justification for the use of a word describing a process, to represent the result; the term "recording" as used above. Tape recorder language is also burdened with this term, for an understandable reason. The public is accustomed to the use of a "record" in relation to gramophones and seems to accept the term as describing a disc carrying a reproducible message; one goes "to buy a record of so-ond-so." Were you to describe a tape recorder as capable of making a record, the public may assume it makes discs; by saying it makes a "recording" that possible confusion is ameliorated. But a happier term would be welcome; could one suggests a "magneprint"?

Editorial approval appears to be extended to the proposed E.M.I. use of the term "tape records" for ready-recorded magnetic tapes and with some amusement one recalls that mother used to safeguard the laundry with tape records—strictly embroidered autograph tape.

To avoid confusion is not simple. One need but wonder what youngsters whose school musical instruction was given on the "recorder" think when offered a "recorder" at, say, 100 guineas, and how they may wonder what tape has to do with the English flute.

The growth of language is quite illogical. A magnetic tape recorder makes a "record" by close analogy with, but more directly than, a typewriter; yet we type a "letter," never a "record" and we keep a "duplicate," a "carbon copy" or a "stencil," which last serves a "duplicator" though, in fact, it is a "multiplicator."

W. D. ARNOT

Bristol Magnetic Recorder Company,
Bristol, 3.

I AM afraid I cannot agree with Mr. Scroggie that the use of the word "recording" as a noun constitutes a misuse of the English language.

It is very convenient to refer to the quality of a recording, meaning ambience, frequency response, absence of distortion, etc., and to the quality of a record which would cover surface noise, swinging, and all other mechanical aspects.

Surely a recording is made on tape and is then transferred to disc, and must be referred to as a recording, whereas a record is something you can pick up and throw into the waste-paper basket if you don't like it.

Wharfedale Wireless Works, Ltd., G. A. BRIGGS.
Idle, Bradford.

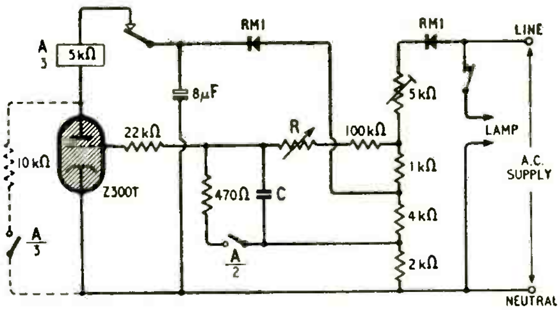
Neon Timers

I HAVE followed with interest the correspondence on this subject and would like to comment on the observations of N. J. Wadsworth, in the January issue, regarding the design of photographic exposure timers. The actinic intensity of a tungsten filament lamp has been found to vary as the fifth power of the supply voltage and timers have been designed already* in which the exposure interval is made inversely proportional to the fifth power of the supply voltage.

Cold cathode trigger tubes are considered preferable to neon stabilizers for this application. The trigger tube is cheaper and its striking voltage is likely to be more stable than that of the neon tube.

When compensation is obtained solely by using an unstabilized condenser-charging voltage, this must be made only a few per cent greater than the striking voltage of the neon or trigger tube. Any variation in the striking voltage then becomes serious. Also, with supply voltages falling below the nominal value by more than about 7 per cent, the timer becomes seriously over-compensated. The cure is then worse than the disease.

These difficulties are overcome by using two forms of voltage-sensitive correction simultaneously. The circuit shown here is based on this principle and is scarcely more



complex than those you have published already. The timing resistor, R, may have any value between 1 and 10 megohms and the timing condenser, C, is conveniently 4 to 20μF. The 5-kΩ preset control must be set to give time intervals equal to 0.6CR at the nominal supply voltage. With supply voltage variations from $+15$ to -20 per cent of the nominal value, the intensity-time product then changes by no more than $\pm$ 5 per cent. Compensated timers of this kind are useful for repetition work, particularly where high-contrast materials are used.

Methods of producing a substantially constant intensity-time product by judicious proportioning of the circuit and valve parameters have been investigated in the laboratories of Ilford, Limited and are the subject of British Patents 656,275 of 1948 and 667,296 of 1949.

Physics Research Laboratory, D. M. NEALE.
Ilford, Limited, Brentwood, Essex.

* "Photographic Exposure Timers providing compensation for Supply-Voltage Variations." R. J. Hercock and D. M. Neale. *Proc. I.E.E.*, Vol. 99, Part II, No. 71, Oct., 1952, pp. 507-515.

Recovering Hidden Signals

YOUR contributor James Franklin (March issue) speaks of the correlation function as "one of the latest methods of analysing electrical signals—or indeed variations in time of almost any kind." Moreover, "Actually it was invented by G. I. Taylor in 1920, but only recently has it come into prominence and been used in a practical sort of way."

Possibly your contributor does not regard mathematical use as "practical," so the fact that this function has been studied and developed by mathematicians since the days of Fourier at latest may leave him cold. The integral involved, the "product by composition" is fundamental to functional analysis, integral equations, transforms and the like and its importance has been recognized for well over a century.

In the more "practical" fields of finance, commerce, meteorology, economics and optics it has been used and taught as a standard instrument for investigating time series, certainly for most of this century.

Perhaps Young (1813) just can be claimed as a candidate for priority in the field of optics and also, much later, Rayleigh. However, Sir Arthur Schuster applied the correlation function to the same problems as your contributor in various papers at the turn of the century. These are well known, in the sense that they are cited in many modern textbooks, including those for communications engineers. One in 1899 dealt with hidden periodicities in meteorological data, others with the coherency of white light. The method was that described by your contributor, using functions of real variable only and therefore confined to the past of the data. The real "latest developments" came after 1930, when Wiener and others extended the method to complex variables.

Your contributor, however, is by the nature of his apparatus concerned only with the real-variable correlation function. If he finds it "the latest method," this is because he, not the function, is the later arrival.

Farnborough, Hants. R. A. FAIRTHORNE.

Voltage Multipliers

I READ with interest "Cathode Ray's" article on voltage multipliers (March 1955) and should like to make two comments.

1. The circuit of Fig. 10 can be used as a trebler. All that is necessary is to earth the *top* end of G, not the bottom end. The rule that can be derived from this is:—If you add any stages of multiplication to a circuit of this type do this always on the supply side (this will obviate the need for reversal). This can also be seen quite clearly in "C.R.'s" Fig. 12. You can, for instance, remove C_1 and D_1, still taking your output from the right-hand side, and the multiplication factor will be 5 instead of 6. Similarly, you can add a stage between the bottom end of the ladder and G in Fig. 12.

2. Sometimes voltage multipliers are used with a supply of unidirectional pulses of short duration (such as line flyback pulses). In this case D_2 and C_2 in Fig. 10 would preduce no step-up of voltage, and D_2 may be replaced with a resistance, a typical value (in a line flyback circuit) being 1MΩ. The only disadvantage is an increase in source impedance, but the deterioration is generally considered insufficient to warrant the use of a rectifier in place of R.

London, N.W.2. G. N. E. PASCH.

Special Quality Valves

THE article in your December issue refers to the use of a wiring jig to hold the contacts of miniature valveholders in their correct positions during chassis wiring. Such a jig is very desirable to ensure mechanical alignment of the contacts but it has been found that this procedure can lead to poor electrical contact between the holder and the valve pin. In certain miniature valveholders which use brass contacts, the heating-cooling cycle caused by soldering (with the jig or valve pin in position) usually results in an appreciable loss of contact pressure. In a limited number of cases this is sufficient to produce a very "noisy" contact. No such difficulties have been found when using beryllium-copper contacts.

Nottingham. A. T. DENNISON.

Electronics on the Farm

I CAN assure Mr. Taylor that "the hoary old stager" can be substituted by a unit operating from a wireless battery, but I assume from his letter than he has not tried one of these units. If he will do so I think that he will find that the contact trouble to which he refers will disappear.

Units using neon tubes as a switch and also units using electronic circuits are manufactured, but I believe they are all mains operated and they are also of necessity more expensive.

Line test units are marketed and may be bought independently of the unit, and they are of such design that they can be left permanently connected to the fence line. One particular testing device is so arranged that the actual value of the output from the pulse unit can be measured.

May I suggest to Mr. Taylor that when choosing a pulse unit he should consider output characteristics since some of the types of unit on the market give a large voltage and consequent large spark on open circuit, but when connected to a fence of average insulation resistance they may give a relatively poor shock to an animal having a contact resistance of the order of 10,000 ohms, due to the inherent regulation of the unit.

Orpington. C. W. ROBSON.

MOST of the electric fences on the market work off a standard 120-volt h.t. battery, and these are fairly big and bulky items to store away, even in so-called "portable units," and are, as far I can find, the highest voltage type on the market.

I have made and operated quite a few fences on the resistance-capacitance principle, and found them very satisfactory and reliable. With neon types, one is up against snags at once. The major one is that the striking voltage is far too high for the standard battery to give any length of service; with the RC type I have still had the fence working with the battery reading 45 volts on load. The ideal is, of course, the cold-cathode trigger type, but I have only used these on mains-operated units, extensive searchings having failed to find a manufacturer who makes one that can strike or be triggered as low as 60 volts.

Incidentally, Mr. Taylor will find that a piece of grass about six inches long (if wearing boots, and shorter if in Wellingtons) will only give a slight tingle in the fingers if held to the fence. Much cheaper than neons or having to walk the full length of a twenty-acre field to see if the unit is on or off.

Truro, Cornwall. D. A. BOND.

Viewers' Strike?

I COULD hardly agree more with Mr. Niall (February issue), and wish him every success if he wants to organize a viewers' strike. I assume it is his intention that viewers will cease to view when their licences expire.

I shall then achieve the Four Freedoms. Freedom from timebase harmonics which ruin all B.B.C. reception in TV hours. Freedom from re-transmission of the TV sound programme in the 3.5 Mc/s amateur band. Freedom from various r.f. oscillators on various short-wave broadcast bands. And freedom from rough notes sliding up and down the 14 Mc/s amateur band.

I am in favour of TV suppression—the total suppression of those ill-designed or ill-adjusted models which cause such widespread interference to almost anything except TV.

The possession of a TV set ought not to give one the right—as it seems to do—to moan about interference from others, yet cause interference oneself. Why not try it on the other foot for a change?

"First cast out the beam from thine own eye."

Worksop. H. S. CHADWICK (G8ON).

TESTING PRECISION OSCILLATORS

Automatic Recording of Frequency Stability

By M. P. JOHNSON,* E.E.(Toronto), A.M.I.E.E.

CARRIER frequencies used in multi-circuit carrier telephone systems must be kept stable if no undue frequency translation of the received audio is to occur. On modern British coaxial cable carrier systems it is usual to derive all carrier frequencies from a master oscillator operating at 124 kc/s. Such an oscillator normally has a frequency drift of less than 2 in 10^7 per month and a frequency temperature deviation of less than 2 in 10^8 per 30°C. An extremely precise source of frequency is needed for the development and testing of oscillators of this stability and it is very desirable that the source should be continuously available. An attractive possibility adopted by the author's firm was to measure automatically and record against the National Physical Laboratory transmission on 2.5 Mc/s from station MSF at Rugby. It was ascertained that over the 10 miles from Coventry, where the development was carried out, to the Rugby station MSF ground wave reception was dominant and Doppler effect was negligible.

There are several methods available for displaying the frequency difference between the standard and test sources. For example, needle-like pulses can be produced from the difference frequency and the mean value of these is then proportional to the difference frequency. Alternatively the difference frequency can be passed as a constant current through an inductance and the voltage across the inductance is then proportional to the difference frequency. Another method is to charge a capacitor at a rate corresponding to the cycles of the difference frequency and use suitable linearizing circuitry to produce a voltage proportional to the frequency difference. Circuits dependent upon waveform can, in general, be difficult, especially at low difference frequencies. Those dependent upon pulses developed by differentiating circuits are subject to false operation when noise is present, as is the case with radio signals. Moreover, with some of these methods long time constants are necessary to obtain a reasonably steady d.c. output to the recording instrument, and this results in a poor response to short-term variations.

The method we actually chose is free from these difficulties and from linearity problems. A count of the difference frequency is made over regularly recurring gating periods and an output current is obtained that is proportional to the count and hence to the difference frequency. Thus the recorded reading is the average of its own gating period only. This independence of previous readings is not easily obtained with the other methods.

Actually the difference frequency is counted for 116 seconds. The recording meter connected to the counter is arranged to respond linearly to the count and so a linear scale of difference frequency is obtained. A count of 58 causes a full-scale meter deflection. This corresponds to a difference frequency of one cycle per two seconds or 0.5 c/s in 2.5 million c/s, which is a frequency difference of 20 parts in a hundred million, or 20 in 10^8. The meter records the frequency difference at the end of the first count and continues this reading until a different count causes it to change. Four seconds after the first count, the counter commences a second 116-second count without altering the pen recorder reading. At the end of this 116-second count the pen recorder changes, if necessary, to suit the new frequency difference and this process is repeated throughout the normal operation of the equipment. As 58 counts give a full-scale reading, the meter can record any of 58 discrete readings across the paper chart.

The equipment may be set to operate at counting times of 116, 232, or 464 seconds. In each case a count of 58 yields a full-scale reading on the meter.

* G.E.C. Telephone Works.

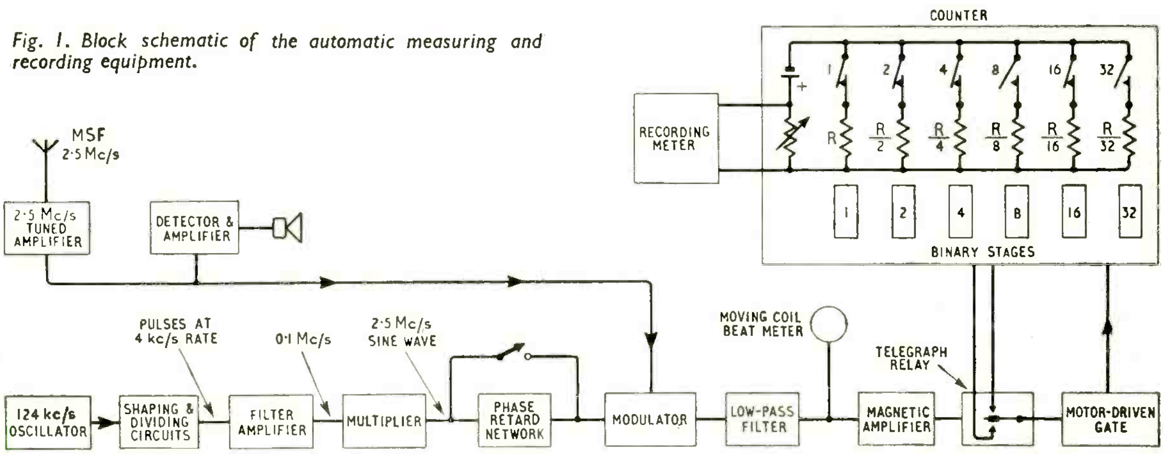
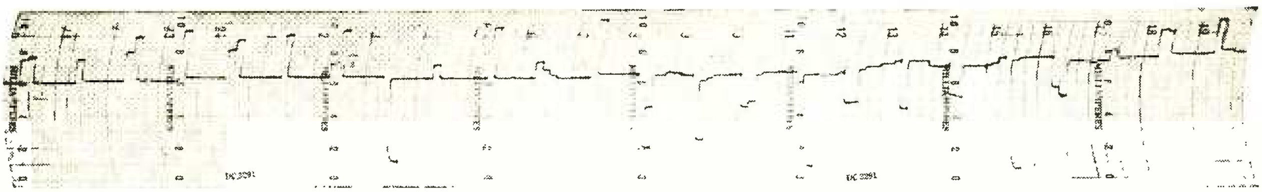


Fig. 1. Block schematic of the automatic measuring and recording equipment.



At 116 seconds the full-scale reading corresponds to a frequency difference of 20 parts in 10^8. At 232 seconds it corresponds to 10 in 10^8 and at 464 seconds to 5 in 10^8.

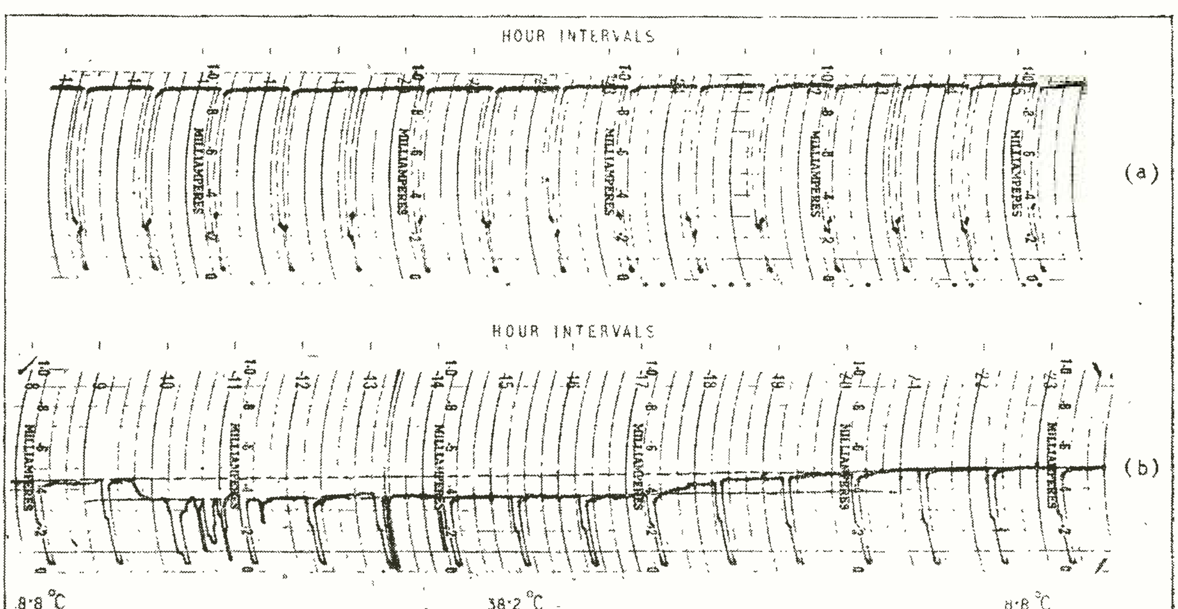
The general arrangement of the measuring equipment is shown in Fig. 1. The 124 kc/s master oscillator frequency is translated by division and multiplication to 2.5 Mc/s for comparison with the 2.5 Mc/s radio signal. The two are then combined in a modulator which gives the difference frequency without a d.c. component. This difference frequency is amplified and applied to a telegraph relay, which operates the counter during the counting period, which is controlled by the gate operated from a 50-c/s synchronous motor. This gate actually consists of a telephone relay spring-set mounted on a slotted cam which is driven at 1 revolution per two minutes through a gear train by the motor. The counter (a binary type) contains relays which switch parallel resistors into a circuit supplied with a constant voltage so that a current is obtained in the circuit proportional to the total count in each period. A moving pen recorder then displays this output current. Frequency differences of 5, 10 and 20 parts in 10^8 can be displayed with full-scale deflection on the meter by using time intervals of approximately 8, 4 and 2 minutes respectively for the gating period, as already mentioned.

The 2.5-Mc/s receiver comprises five stages, each tuned to 2.5 Mc/s. Audio monitoring for announcements and noise checks is obtained from a detector and amplifier in parallel with the output to the modulator. In the chain associated with the local 124-kc/s oscillator a two-valve tuned multivibrator is used in the first place to perform a division of 124 kc/s to 4 kc/s. It is preceded by a two-stage shaping circuit and also followed by a pulse shaping circuit which gives 4-μsec pulses at a repetition rate of 4 kc/s. (This output is, of course, rich in harmonics of 4 kc/s). These pulses are fed into a three-stage filter amplifier which selects the 25th harmonic, namely 100 kc/s. The resulting sinusoidal output is applied to a frequency multiplier, in which an input Class-A stage drives hard a Class-C stage tuned to 2.5 Mc/s. The frequency multiplier is then followed by a two-valve filter amplifier tuned to 2.5 Mc/s to supply the modulator.

The low-pass filter which follows the modulator reduces any signal leakage back to the aerial and thus helps to prevent loop singing. A magnetic amplifier is used to amplify the resulting difference frequency. It has a reasonable zero stability and thus enables a positive drive to be applied to the telegraph relay. The actual difference frequencies for full scale deflection of the recording meter on each of the three ranges are 0.125 c/s, 0.250 c/s and 0.500 c/s. At such frequencies it is not easy to achieve a perfect sine wave free from noise, and for this reason the telegraph relay was chosen, in preference to valve trigger circuits, because it is probably easier to adjust against false operation.

The counter uses cold cathode valves (Osram type CCT5) in six binary stages to give a total count of 63. Of this, 58 counts are used to give full-scale deflection on the recording meter. Each binary stage

Fig. 2. Typical records from the equipment with full-scale reading of 20 parts in 10^8; (a) drift rate of one oscillator, (b) frequency/temperature performance of another oscillator. Troughs in the traced line are due to 5-minute breaks in the MSF transmission.



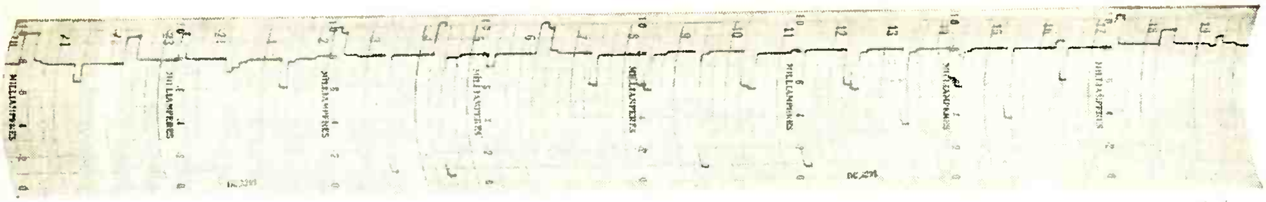


Fig. 3. Record obtained from the equipment over a period of 48 hours. The full-scale reading is 5 parts in 10^8. The five-minute breaks in the MSF signal are again clearly defined while the "pulses" rising above the normal trace are due to interference from a local transmitter during these breaks.

has associated with it a telephone relay and at the end of the first count the appropriate binary stages operate their relays and so give rise to a current which is proportional to the count. For example, in Fig. 1, the relay contacts are shown operated for a count of 23. The relays do not release unless a subsequent count demands it. A switch and two more binary stages enable the normal gating time of 116 seconds to be extended to 232 or 464 seconds. A four-second interval is allowed between readings at the 116-second gating rate.

It is necessary at times to establish whether the oscillator under test is higher or lower in frequency than the standard source. A simple method of doing this is to use a centre-zero moving coil meter to indicate the beat frequency and a phase retarding network connected as shown in Fig. 1. An inductive or phase retard network connected in series with a circuit introduces a phase lag which has at the moment of connection the effect of slowing down the wave applied to it. It appears as if the frequency were momentarily decreased. Thus an oscillator whose frequency is higher than MSF with a difference frequency of a 10-second cycle will appear to have its frequency decreased, and the 10-second swing on the beat meter of Fig. 1 will momentarily, but quite clearly, slow down. If the frequency were below MSF, the difference frequency would be increased and the 10-second cycle would be shortened to give a momentary acceleration of the beat meter.

Of course, there are bound to be certain small inaccuracies in the measurement system, but if a stabilized mains voltage is used and a radio path free from interference is assumed, these are not too serious. The gating or counting period is controlled by the motor which is synchronized with the 50-c/s mains frequency. Variations of the mains frequency will consequently affect the counting time of 116 seconds and multiples of it. This will directly affect the count and, of course, the pen recorder reading. The error due to this cause should not normally exceed 1%, i.e. the count itself would have an error of 1%. Care has been taken with the cutting of the cam and arrangement of the spring-set operation so that the counting-time variations due to these are less than 0.1%. In counting systems such as this where a fixed gating period is used an error of 1 is always possible in the count. At full scale this would be 1/58 or 1.7% and at 10% of full scale it would be 17%. Errors in the recording meter circuit might be 2% resulting from drift in the voltage source and 1% due to resistor tolerances. Excluding inaccuracies in the recording meter, a total error of 6% could occur at full scale and 21% at 10% of full-scale reading. On the range 0-20 in 10^8 the 21% error would give an incremental error of 4 in 10^9, which is acceptable.

Fig. 2 shows some typical records obtained from the equipment. The sudden troughs in the line at hourly intervals are caused by the 5-minute cessation in the MSF transmission at 15 minutes past the hour. Fig. 2(a) shows the drift rate of a particular oscillator under stability investigation. The frequency/temperature performance of another oscillator is displayed in (b). Table I shows the worst errors

Table I

Manual Reading parts in 10^8	Percentage error in pen reading	Actual error parts in 10^9
0.86	30	2.6
5.36	3	1.6
15.7	1	1.6
20.1	0.5	1.0

observed on a chart run for about ten minutes at each of the listed readings. A full-scale sensitivity of 20 parts in 10^8 was used. Checks were made by timing with a stopwatch a sufficient number of beats on the beat meter to enable the frequency difference to be determined to an accuracy of better than 0.5%.

The equipment described has now been in operation for about six months. For routine maintenance it is returned at two-weekly intervals. If this is done little trouble is experienced from spurious readings due to faulty adjustment or electrical interference. For example, the chart of Fig. 2(b) was taken at an early stage in the development when spurious reading were more common. In spite of this the performance is reasonably defined. A run of 72 hours with no spurious reading is not unusual. Fig. 3 is representative of the equipment in its present state.

Observations to date have indicated that no deviations that have been observed could be attributed to Doppler effect.

From the charts, the short-term stability and the long-term frequency stability of an oscillator over the preceding 24 hours or longer may be calculated in several minutes. To obtain these results to the same accuracy by manual methods would have required human effort for 24 hours or longer.

It is often necessary to check the frequency/temperature performance of an oscillator before the quartz is fully aged. The frequency deviation due to temperature must be separated from that due to ageing. To do this, a continuous chart run is taken for a sufficient length of time at the initial temperature, then continued while the oscillator is held for a sufficient time at the second temperature, and continued further while the oscillator is returned to, and held again at, the initial temperature. The initial temperature drift lines may be quickly extended on the chart, and their mean distance from the line at the second temperature is the required frequency/temperature deviation. Apart from this simple calculation, it is only necessary to set the automatic temperature controller to the required temperature after the appropriate time has elapsed. This, too, could of course be made automatic. In contrast, it is a long and tedious process to obtain the frequency/temperature performance by manual methods.

Oscillators of the performance mentioned in the first paragraph of this article may have supply-voltage coefficients of frequency of less than 1 part in 10^8. These coefficients are measured during initial adjustment and, except under fault conditions, require very infrequent checking. Nine combinations of supply voltages are possible. The corresponding nine coefficients of frequency are all measured in a matter of half an hour by obtaining the period of one cycle of the difference frequency at 2.5 Mc/s, by use of a stopwatch or an automatic electronic timer. These methods are preferred for speed and accuracy. If the counting method of Fig. 1 were used, the gating time of 8 minutes would be necessary and this would require at least 72 minutes for measuring the nine coefficients.

The automatic recording method of Fig. 1 is being used for production testing of precision oscillators. Each oscillator under test is sampled in turn and its frequency difference is printed on a multi-channel recorder.

It would be helpful if a shorter gating time could be used without worsening the accuracy. The following suggestion for obtaining the difference frequency is therefore of interest.

Let the oscillator frequency be $(124 \times 10^3 + \delta)$ c/s. If this is multiplied by 20 and modulated by 2.5 Mc/s, the frequency $[2.5 \times 10^6 - 20\ (124 \times 10^3 + \delta)]$ c/s would result. If this in turn were multiplied by 125 and again modulated by the 2.5 Mc/s signal, the final difference frequency would be $125\ [2.5 \times 10^6 - 20\ (124 \times 10^3 + \delta)] - 2.5 \times 10^6$ c/s $= -2500\delta$2c/s. (The negative sign indicates that the final difference frequency is below the standard.) By contrast the signal modulation scheme yields a final frequency difference of $\frac{625}{31}(124 \times 10^3 + \delta)\,\text{c/s} - 2.5 \times 10^6\,\text{c/s} = \frac{625}{31}\delta\,\text{c/s}$. The double modulation scheme is therefore $2500 \div \frac{625}{31} = 124$ times more accurate, and consideration could be given to reducing the gating time.

Finally, the author would like to thank John H. Beesley for his effective paper design of the counter.

New Valve Voltmeters

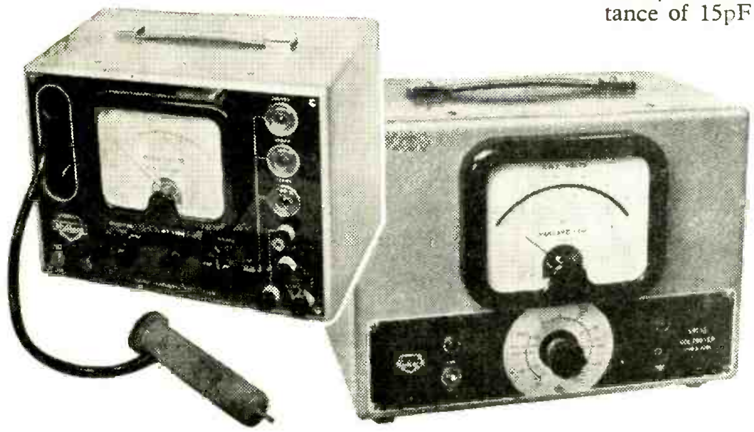
A Versatile D.C./A.C. Instrument and an Amplifier-type A.C. Millivoltmeter

IN the type E7555 valve voltmeter recently developed by Mullard, the d.c. amplifier is designed to be virtually independent of mains fluctuations and valve ageing. The circuit is a balanced type with two EF86s connected as a "long-tailed pair" and directly coupled to two cathode followers. The output from the cathode followers is connected to the grids of the EF86s and gives virtually 100 per cent negative feedback and high stability. Both positive and negative potentials with respect to earth can be measured.

For a.c. inputs a probe unit is provided with a double diode valve, one half for rectification and the other for balancing. A frequency response level from 30 c/s to 100 Mc/s is claimed. On the lowest range full-scale deflection on the 5-in meter is given by 0.5V peak (a.c. or d.c.). Maximum voltage is 15,000 in type E7555/2 and 500 in E7555/3.

At frequencies up to 50 kc/s the probe input resistance is 3.5MΩ, falling to 8.5kΩ at 45 Mc/s. The effective input capacitance is constant at 9pF.

The type E7556 meter incorporates a three-stage feedback amplifier, preceded by a cathode follower. A diode rectifies the amplifier output and the d.c. component is registered on a 5-in mirror scale meter. The limits of measurement of a.c. voltages are 0.5mV to 300V, with a total error less than 4 per cent. The frequency range is 20 c/s to 1 Mc/s. On the lowest range (10mV f.s.d.) the input resistance is 1.5MΩ at 20 kc/s and 0.75MΩ at 1 Mc/s, with an input capacitance of 15pF. The corresponding values for ranges of 3V f.s.d. and above are 1.9MΩ, 0.7MΩ and 6pF. A calibrating voltage of 10mV is provided at mains frequency from a bridge circuit with lamp stabilizing elements.



Two new valve voltmeters made by Mullard (Equipment Division). On the left is the type E7555 balanced d.c. meter, with a.c. probe, and on the right the amplifier type a.c. meter (E7556) reading from 0.5mV to 300V.

Phase-to-Amplitude Modulation

Variable Frequency Transmitter Based on Polyphase Oscillator

By BRYANT D. VIRMANI*

ONE of the less familiar methods of achieving efficient operation in a transmitter is known as phase-to-amplitude modulation. It was first described by Henri Chireix, a French radio engineer, in 1935† and has since been used in quite a number of transmitters, most of them on the Continent. The principle of operation is based on the fact that when two r.f. carriers of the same frequency and amplitude are phase modulated differentially and then combined the result is an amplitude-modulated carrier. For example, if the modulation causes the two carriers to be 180° out of phase they cancel each other and produce a trough in the a.m. output, and if the modulation causes them to be in phase they add together to produce a maximum in the a.m. wave. Thus, when the phase displacement is varied between 0° and 180° it produces corresponding variations between maximum and zero in the amplitude of the combined carrier wave.

This scheme makes for high efficiency in two principal ways. First of all, the phase modulation is done at low level, which avoids the need for a high-power modulating amplifier. Moreover, this low-level modulation can be used, if desired, with high-efficiency class-C r.f. amplifiers, which normally require high-level anode modulation. Secondly, the valves in the two phase-modulated r.f. channels can be driven to their maximum limits and will remain in that condition all the time, giving the maximum possible efficiency, because there is no variation in carrier amplitude produced by the modulation—only a variation in phase. The result of these two features is that for a given r.f. power output the phase-to-amplitude transmitter is much more economical in its consumption of electrical power than other comparable transmitters. Moreover, it occupies a smaller space and weighs a good deal less. The author, in fact, claims a saving in power consumption and in weight of anything from 40% to 70% and a saving in physical size of 30% to 70%, compared with a conventional class-C anode-modulated telephony transmitter.

Another method of achieving efficient operation which has a certain point of similarity with the phase-to-amplitude system is a well-known technique for obtaining single-sideband suppressed-carrier transmission. Here the economy results from the fact that no power is wasted in transmitting the redundant carrier and redundant sideband. The point of similarity with the phase-to-amplitude system is the use of two r.f. carrier components with a phase displacement (90° for s.s.b.) between them. (In the output the two sets of sidebands which result from modulating these r.f. carrier components are combined, and the phases are such that one sideband is balanced out and the other is augmented.) In fact, both the phase-to-amplitude system and the single-sideband technique require two r.f. carriers of the same frequency and amplitude with a certain phase displacement between them. In practice these carriers are usually derived from the same source through a phase-shifting network of capacitors and resistors—but the great disadvantage here is that the network is frequency-sensitive and consequently the frequency of the transmitter cannot be varied without changes in the circuit.

This particular disadvantage has been overcome in a 400-watt a.m. transmitter designed by the author which can be operated with either phase-to-amplitude

* Polyphase Electronics (Toronto, Canada).

† H. Chireix. "High Power Outphasing Modulation," *Proc. I.R.E.*, November, 1935.

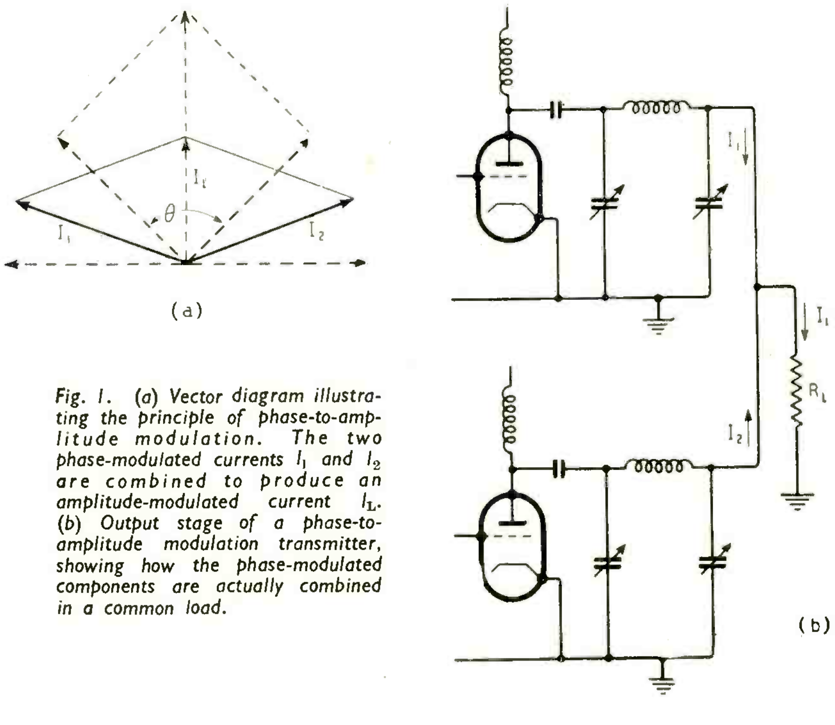


Fig. 1. (a) Vector diagram illustrating the principle of phase-to-amplitude modulation. The two phase-modulated currents I_1 and I_2 are combined to produce an amplitude-modulated current I_L. (b) Output stage of a phase-to-amplitude modulation transmitter, showing how the phase-modulated components are actually combined in a common load.

modulation or single-sideband suppressed-carrier—and therefore allows the similarity to be exploited to some extent. The conventional oscillator and phase-shifting network has been replaced by a polyphase oscillator, which not only gives the required phase-displaced outputs directly, but retains the correct phase displacement when the frequency of oscillation is varied. The result is possibly the first transmitter in which single-sideband operation has been achieved using a variable frequency oscillator.

Before describing the transmitter in detail it will be as well to look more closely at the phase-to-amplitude system of modulation and at the polyphase oscillator. A fairly recent version of the phase-to-amplitude system was devised by Webster for use in a 5-kW transmitter.* Here the principle of operation (Fig. 1(a)) is based upon two r.f. vectors, I_1 and I_2, with a phase difference of 135° in the carrier condition. They are phase modulated up to a maximum limit of $\pm 22\frac{1}{2}°$ by a push-pull audio amplifier. The resultant phase difference between the two channels could be 180° or 90°, depending upon which channel initially lags or leads the other.

When the two channels are 180° out of phase no voltage will appear across R_L, the common load shown in the circuit Fig. 1 (b). This condition constitutes, in effect, a short circuit of the output ends of both quarter-wave networks shown in (b). Then, due to the impedance-inverting qualities of the quarter-wave networks, the source ends of these networks appear as very high impedances and very little energy is supplied from the valves.

When phasing conditions are reversed, 100% positive peak modulation is obtained. Each channel then supplies energy to the load R_L. Owing to the effect of two sources of r.f. power feeding R_L the resistance "seen" by each channel at the output end of the quarter-wave network varies from zero to four times the load resistance required to obtain the correct carrier power. Then, again due to the impedance-inverting qualities of the quarter-wave networks, the power amplifiers themselves "look" into a load resistance which varies from an extremely high value to approximately one quarter that encountered at the 135° carrier condition. It is impossible to over-modulate because over-modulation will bring the two r.f. channels less than 180° apart, which is the condition for positive modulation.

Ninety-degrees System

Another version of the principle is due to Perthel† who takes two r.f. channels with a phase difference of 90° in the carrier condition and modulates each channel up to a maximum limit of ±45° by a push-pull audio amplifier. He connects the anodes of the final amplifier valves in push-pull. The phase difference due to modulation at the grids of the final amplifier could be zero or 180°. When the two channels are 180° out of phase full power output is delivered. But when the grids swing to a phase difference of zero degrees, the voltages developed at the anodes cancel out since the anodes are connected in push-pull. If the anodes are connected in parallel instead, the same results are obtained by completely reversing the phasing conditions at the grids.

To obtain two vectors with a phase difference of either 135° or 90°, phase-splitting circuits are conventionally employed, but, as was mentioned above, these are frequency sensitive. Therefore the systems of Webster and Perthel operate either on a spot frequency or over a very narrow range of frequencies. They are unsuitable for applications requiring a variable frequency oscillator to cover a very wide frequency range of the order of 1:10 or more in several bands.

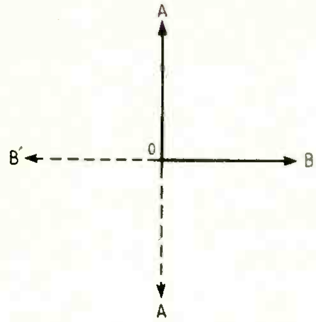


Fig. 2. Vectors illustrating the phase relationships of the four outputs from a four-phase oscillator such as the one in Fig. 3.

In Webster's phase-to-amplitude modulation system, the reactance modulator valves operate linearly over a relatively narrow range of phase angles, so frequency multiplication by a factor of three is used to secure the eventual phase swing of $\pm 22\frac{1}{2}°$. Moreover, to split an r.f. channel into two component vectors with a phase difference of 135°, using conventional phase-splitting circuits, it is necessary to use special measuring equipment. Furthermore, two quarter-wave networks ganged together are a little more difficult to adjust for best results than the simple push-pull circuit to be described.

The choice of two r.f. channels with a phase difference of 90°, as used by Perthel, is more profitable than Webster's system. The use of 90° vectors places at our disposal two additional types of transmission, namely, single-sideband (as already explained) and phase modulation. The carrier will be phase modulated if the two r.f. channels are swung in the same direction by a single-ended audio amplifier instead of a push-pull one. For c.w. or f.s.k. the modulator grids of the two channels may be driven by a keyed d.c. voltage.

In order to take advantage of the versatility offered by the Perthel system and adapt it for use directly with a variable frequency oscillator, all frequency-sensitive phase-splitting elements must be avoided. The logical solution of the problem lies in the use of a two-phase oscillator to generate two r.f. channels, with a phase difference of 90° as shown by the vectors OA and OB in Fig. 2. Now, in order to phase-modulate OA and OB by a pair of reactance modulator valves two additional channels, OB' and OA', in phase quadrature to OA and OB respectively, must be made available—and the reason for this is as follows. A reactance modulator valve is the equivalent of a capacitance or an inductance shunted across an oscillating tuned circuit. If the value of this shunt element is varied, the phase or frequency of the circuit (depending on the manner in which the reactance valve is connected) will also vary. Now the reactive voltage and current in a capacitance or inductance are in phase quadrature, so in order to make the valve simulate this condition the voltage applied to its grid must cause the anode current to be 90° out of phase with the anode voltage. In other words, the grid and anode voltages must be 90° out of phase. Obviously, then,

* N. D. Webster, "Economical 5-kW A.M. Transmitter," *Electronics*, May, 1951.

† B. Perthel, "An Unusual Phone Transmitter," *Radio and Television News*, August, 1951.

to get the required four vectors shown in Fig. 2, we must generate four-phase oscillations with a variable frequency oscillator. Such an oscillator must be very simple to adjust and operate and must be capable of working over a very wide frequency range in a phase locked condition.

Polyphase Oscillator

A circuit which satisfies these requirements is shown in Fig. 3—that is, the two valves V1 and V2 on the left-hand side. Each of these valves is a separate oscillator, but they both operate on the same frequency and are, in fact, locked together. The coupling between them in the common tuned circuit is such that they both settle down to a "mutual agreement" to differ by 90° in phase. Why is this so? The two inductors L_1 and L_2 are responsible for the coupling and they both carry oscillatory currents of the same frequency and magnitude. According to the laws of electromagnetic induction, L_1 induces a voltage of opposite polarity in L_2 and vice versa. When the sine wave in L_1 is at peak value, it is inducing a maximum voltage of opposite polarity in L_2, thereby suppressing any sine wave which might normally be building up in the last-mentioned inductor. As the sine wave voltage in L_1 begins to drop below the peak point, the opposing voltage induced in L_2 also begins to drop, so giving L_2 a chance to build up its sine wave voltage, which will reach its peak value when the voltage in L_1 has dropped to zero. In this way the two similar inductively-coupled oscillators mutually settle down to oscillate with a phase difference of 90°. Thus the output from the pentode anode of V1 is represented by the vector OA in Fig. 2 and the corresponding output from V2 by the vector OB.

The individual oscillators are actually modified versions of the two-terminal oscillator devised by Crosby* in which the required 360° phase shift round the loop is obtained by two valves instead of one valve and a transformer. In Fig. 3 the two valves of each oscillator are formed by a pentode section, with the screen grid acting as anode, and a triode section; the anode of the pentode being used merely to electron-couple the oscillator to whatever it is feeding (in this case a reactance modulator valve). The oscillators can be varied over a very wide frequency range by the gauged tuning capacitors, and they can be crystal controlled if required by connecting a crystal between the two cathodes of either V1 or V2.

Thus, if the pentode anode of V1 produces an output which can be represented by vector OA in Fig. 2, the cathode of the same pentode will produce the vector OA′, which is 180° out of phase. Similarly, if the pentode anode of V2 gives OB in Fig. 2 then the cathode will give OB′. Considering now the phase-modulator section of Fig. 3 (the right-hand side), the voltages represented by OA and OB are fed to the anodes of the reactance valves V3 and V4 respectively

* M. G. Crosby. "Two-terminal Oscillator," *Electronics*, May, 1946.

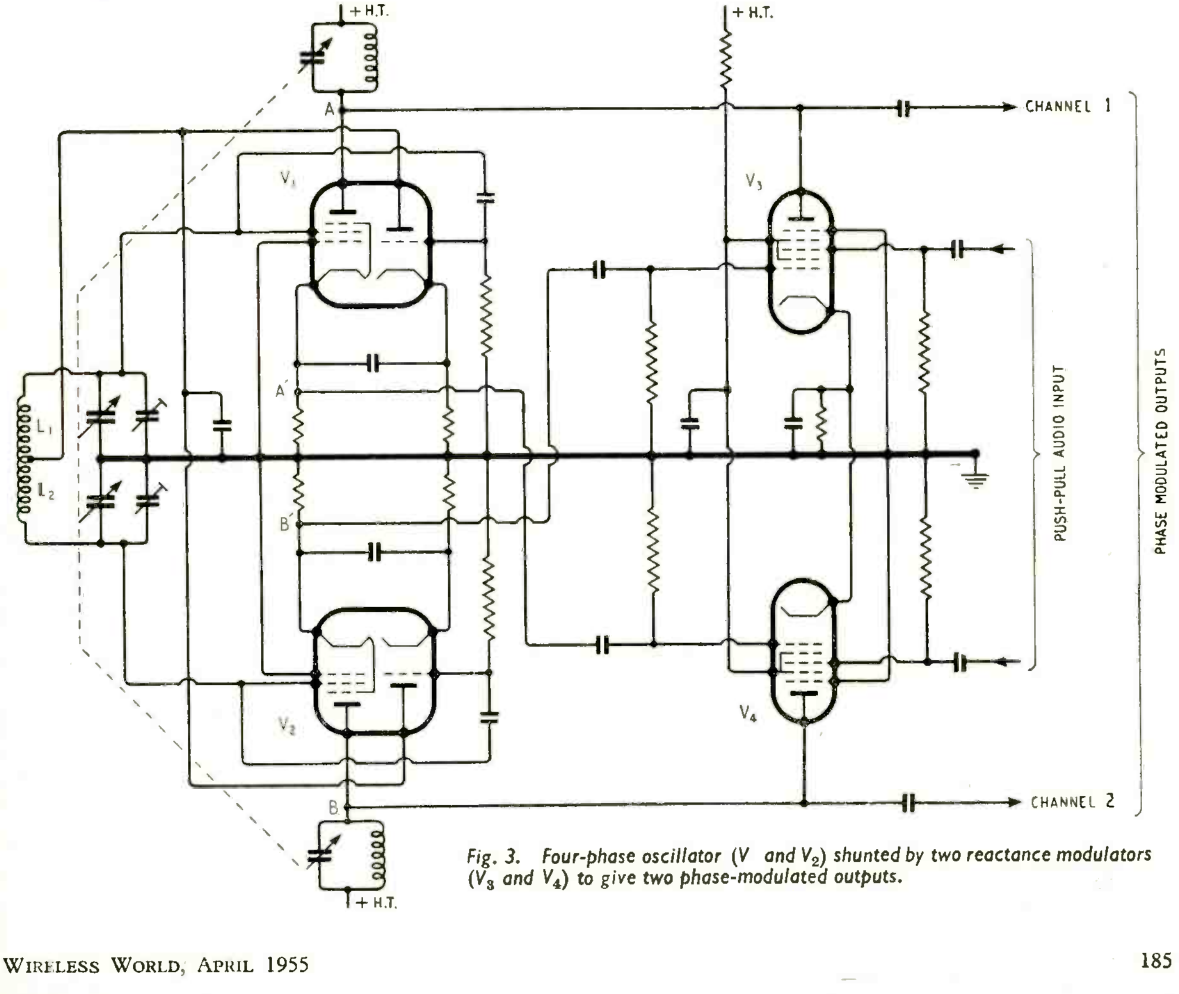


Fig. 3. Four-phase oscillator (V_1 and V_2) shunted by two reactance modulators (V_3 and V_4) to give two phase-modulated outputs.

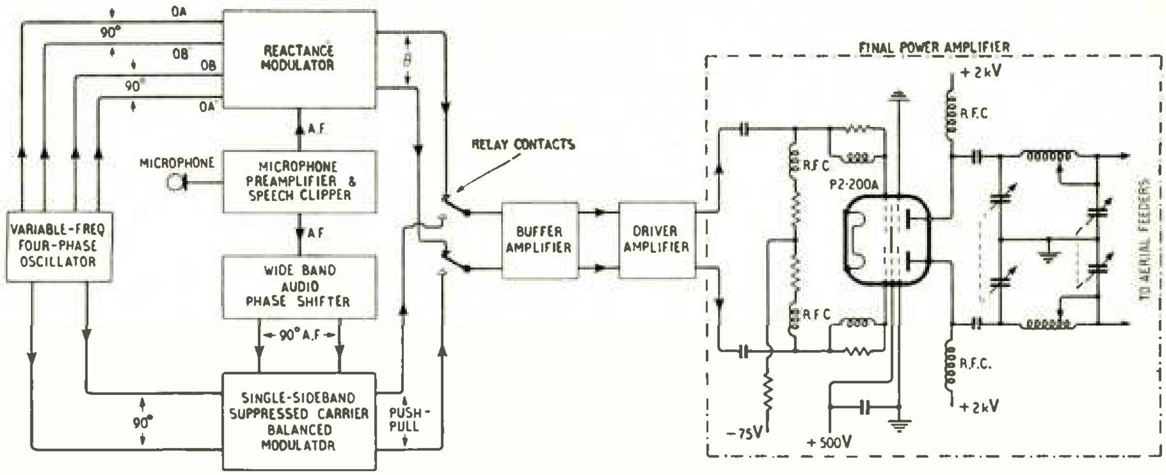


Fig. 4. Schematic (with simplified power amplifier stage) of complete variable-frequency 400-watt transmitter giving a choice of phase-to-amplitude modulation or single-sideband operation.

and the voltages OB′ and OA′ to the respective grids. Thus V3 has a voltage on its anode corresponding to OA, with an anode current, lagging by 90°, corresponding to OB′. This is equivalent to a reactance shunted across the tuned-circuit output load of V1 and its effect is to control the phase of the output signal from V1. De-tuning at the resonance point produces quite a rapid change of phase. The value of the reactance is controlled by the a.f. voltage applied to g_3 of V3 which thereby controls the phase of the oscillator output. Similarly, V4 has OB on its anode and OA′ on its grid and it operates to vary the phase of the signal coming from V2.

Thus the conventional frequency sensitive phase-splitting elements have been completely eliminated. The anodes of the two reactance valves and their respective grids remain always in true phase quadrature over the entire tuning range of the oscillator, whatever that may be. The reactance modulators are actually capable of swinging the phase of each r.f. channel linearly ±90°, so that the two channels could be combined to produce a total swing of ±180°.

Complete Transmitter

The circuit schematic of the complete transmitter is shown in simplified form in Fig. 4. Since the reactance modulators are each capable of swinging the phase linearly ±90° and we need only half of it, no frequency multipliers have been used. The transmitter has been designed to cover in three bands a frequency range of 3.5 to 8, 13 to 30 and 26 to 56 megacycles. The principal application in mind at the time of designing was for the amateurs in Canada and other countries where power output is limited by licence regulations to 500 watts. Since there is no amateur band between 7.5 and 14 Mc/s, no provision was made to cover it.

Fourteen crystals have been provided and they serve as band-edge markers for the seven amateur bands of 80, 40, 20, 15, 11, 10 and 6 metres. As the transmitter was designed to cover a wide frequency range, it was considered highly desirable to provide automatic amplitude control of the oscillations. This was done by means of diodes incorporated in each of the four 6AS8 valves used in the four-phase oscillator. The oscillators operate strictly in class A and generate good sine waves free from harmonics over the entire range of the transmitter.

The reactance modulator valves are triode heptodes type 6AJ8. The anodes of the heptodes are tied in parallel to the anodes of the oscillator valves, which are used for electron coupling as in Fig. 3. The quadrature voltages for the control grids of the heptode sections are obtained from the oscillator cathodes as already described. The triode sections of the 6AJ8s are connected as see-saw push-pull audio amplifiers and the amplified audio voltages at their anodes are fed into the reactance modulators through a transmission selector switch. The first position of this switch is for amplitude modulation, in which case the grids of the heptode reactance modulators are driven in push-pull. The second position is for phase modulation, and here the grids are connected in parallel so that the two r.f. channels swing together in the same direction. In the third position of the switch, the control grid of one of the a.f. amplifier triodes is earthed and therefore no audio signal is applied to the reactance modulators. Consequently the two channels cannot swing in phase. Simultaneously, when the switch is on this position, a relay operates and causes the contacts shown in Fig. 4 to connect the buffer amplifier to the single-sideband push-pull output.

Because of the inherent non-linear characteristics of the phase-to-amplitude system of modulation, it is necessary to pre-distort the audio signal in the interests of high quality transmission. For this purpose germanium diodes are inserted in the grid circuits of the triode a.f. sections of the reactance modulators; the amount of pre-distortion being adjusted by potentiometers which are shunted across them. The audio section is actually built on the unit system, and if the transmitter is needed for short-wave broadcasting the audio amplifier can be replaced in less than two minutes by another one of high quality type suitable for broadcasting purposes. The oscillator tuning coils are also plug-in types and so can be changed if the transmitter is required to cover a different frequency range.

When it is desired to transmit c.w. telegraphy or test the phase swings of the two r.f. channels the transmission selector switch is set on the second position. Here the third grids of the heptode reactance modulators are connected to a source of d.c. potential through the contacts of the keying relay. When the key is up, and the transmission selector switch is on the first position, the heptode grids are applied with d.c. potentials of polarities which cause the r.f. channels to swing to a phase difference of zero degrees. Then, because the final power amplifier anodes are connected in push-pull, no power output results. When the key is pressed, the polarities on the heptode grids are reversed and the two r.f. channels swing to a phase difference of 180°, in which condition the final power amplifier delivers full power to the aerial. When the selector switch is on the second position, the d.c. potentials swing the r.f. channels in the same direction, resulting in phase excursions which are equivalent to frequency shift keying.

The four valves used in the single-sideband suppressed-carrier balanced modulator circuit are triode heptodes type 6AJ8. The single-sideband output is push-pull and can be connected to the buffer amplifier by the relay contacts as shown in Fig. 4. The grids of the 6AJ8s receive phase quadrature r.f. voltages from the four-phase oscillator. The triode sections of the valves are connected in see-saw phase inverting circuits and the control grids of these triodes receive phase quadrature audio voltages over a frequency range of 130 to 3,600 cycles and $\pm 1°$ from a wide-band phase shifting circuit (half 12AU7). Upper or lower side-bands can be selected by a switch.

In the audio section, speech from a crystal microphone is passed through a pre-amplifier stage (6AU6) and the output is limited by a cathode-coupled speech clipper stage using a 12AU7 double triode. Since clipping generates harmonics, the clipper stage is followed by a band-pass filter, which is responsive over the speech band only. The filter terminates in two parallel-connected potentiometers. The output (slider) of one is connected through a switch to the reactance modulator. The output of the other potentiometer goes to the grid of an amplifier stage which has a wide-band phase-shifting network connected between its anode and cathode. This provides two audio frequency components with a phase difference of $90° \pm 1°$ over a frequency range of 130 to 3,600 cycles, which are fed to the single-sideband modulator.

A voice-operated send-receive switch has been added as a refinement for neat and fast two-way communications, and there is also a 1,000-c/s oscillator for testing and adjusting the transmitter and for transmitting tone-modulated telegraph signals.

Returning now to the r.f. section of the transmitter, the buffer amplifier comprises two 6BX6s used as class-A voltage amplifiers and the output of these can be controlled by a potentiometer in the grid circuits. The amplified outputs of the 6BX6s drive the control grids of a dual power tetrode type AX-6360 (QQE03/12), which operates in the class AB_1 condition. The final amplifier valve is a type P2-200A. It is a dual power pentode made by Société Française Radio Electrique of Paris and it operates in the class AB_2 condition with a grid bias voltage of -75 volts and an anode voltage of 2kV in continuous commercial service. It may be loaded to an input of 680/700 watts approximately. The previous valve drives the P2-200A to full output with an ample reserve of driving power. Normally about 400 watts is taken out of the valve, leaving about 75 watts in reserve. The output tank circuit is of the double π type, which has been designed to match any output impedance from 50 to 1,200 ohms. The anode tuning capacitors are a ganged pair of vacuum types and the rotary inductors are each 10 microhenries. For balancing the feeders a single r.f. ammeter is used with two external thermocouples, one on each feeder, and a double-pole double-throw toggle switch connects the meter to one or the other.

In the whole transmitter there are only three tuning controls: (a) oscillator frequency, (b) final anode tuning, (c) aerial loading. The operation of the transmitter has been reduced to extreme simplicity and it can be fully modulated by a carbon microphone without a pre-amplifier. The complete equipment, including all power supplies, has been packed into a vertical panel space of 24½ inches on a 19-inch standard width rack, and sits right on the operating desk alongside the communications receiver.

"CLEAN" VALVES

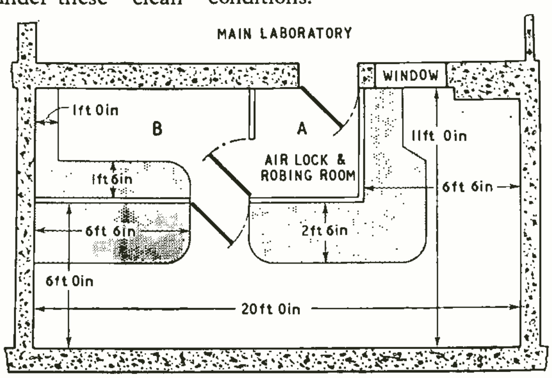
CERTAIN types of receiving valves have grids wound as closely as 500 turns to the inch, with electrode spacings of the order of one-thousandth of an inch. It is not hard to see that the performance and life of such valves can be impaired by the presence in the air, during the assembly process, of particles of dust and other solid impurities. These become attached as whiskers to the electrodes and cannot be removed entirely by any subsequent process. To improve the reliability of certain special valves of the type under consideration, "dust free" assembly shops have been built at the research laboratories of the General Electric Company.

One such assembly shop, shown in the sketch, comprises an area 20ft × 11ft divided into one "L"-shaped room and one smaller rectangular room with a small entrance lobby separated from the working part by an airlock. The lobby serves as a dressing room for the working staff.

Housed in a gallery above the work rooms is a heating and ventilating system which delivers fresh air, warmed when necessary, at the rate of 1,000 cu ft per minute and filters out all particles of dust larger than 5 microns in diameter (1 micron = 0.001 mm). A complete change of air is effected every 2½ min.

To prevent dust and "lint" being carried in by the operator's clothing, close-fitting nylon overalls, caps and special slippers are worn by the working staff and in-and-out traffic is reduced to a minimum.

Provision is made for extra filters to be installed which, should the need arise, would remove all foreign particles in the air over 0.2 micron. It is said that since these special workrooms have been in use a marked improvement has taken place in the quality of the valves assembled under these "clean" conditions.



Plan of the G.E.C. dust-free valve-assembly rooms.

Geophysical Research

International Investigation of Phenomena Affecting Radio Transmission

By R. L. SMITH-ROSE,* C.B.E. D.Sc., Ph.D., F.C.G.I., M.I.E.E.

MOST readers of *Wireless World* will be aware of the fact that scientists throughout the world are beginning preparations to participate in the International Geophysical Year, which is the term given to the period from July 1st, 1957, to December 31st, 1958. This will be the third time that physicists interested in the study of the earth and its atmosphere have conducted a detailed programme of world-wide experiments and observations during a "year."

International Polar Years.—The first enterprise of this nature was during 1882-83 and was termed an International Polar Year; it was followed 50 years later by a second co-operative effort under the same name. These, as their title indicates, were concerned specifically with investigating the special phenomena associated with the earth and its atmosphere in the polar regions. It was not normally possible to obtain frequent and regular scientific measurements in these regions, so expeditions were organized for conducting extensive observations on the earth's magnetic field, and on atmospheric conditions, including aurora.

During the second Polar Year (1932-33), radio technique was available for investigating conditions in the ionosphere at high latitudes, and a successful expedition was conducted under the auspices of the International Scientific Radio Union (U.R.S.I.), which appointed a Polar Year sub-committee with Sir Edward Appleton as chairman and Sir Robert Watson Watt as secretary.

In addition to the manning of special expeditions of this nature, a large number of countries arranged for detailed studies at observatories not in polar regions on specially selected "international days" as well as generally throughout the year. The British work was carried out in close co-operation with the D.S.I.R. Radio Research Station, and R. Naismith and W. C. Brown, who are still members of the staff of this station, were among those who spent the second Polar Year in Norway observing ionospheric conditions within the Arctic Circle. This particular programme of work gave a major impetus to the development of ionospheric research in Great Britain, and disclosed the close relationship between magnetic storms and abnormal conditions in the ionosphere.

International Geophysical Year.—It may now be asked why the title of this international effort has been changed, and why it is being arranged at half the interval between the first two "years." The reduction in the period from fifty to twenty-five years is an indication of the rate at which scientific research is advancing. New methods of investigation have been devised and the older ones considerably improved. The radio technique which was very limited in 1932 has now been extended to automatic methods of sounding the ionosphere and studying the effects of auroral discharges, as well as to techniques for detecting the incidence of meteors in the atmosphere and for measuring winds in the ionosphere. In 1932 the conditions in the ionosphere were relatively quiet, being associated with a minimum of solar activity; during the 1957-58 period sunspots are expected to be large and to occur frequently. This is important since many solar and terrestrial phenomena depend upon this sunspot activity, as those concerned with radio transmission and reception over long distances are only too well aware.

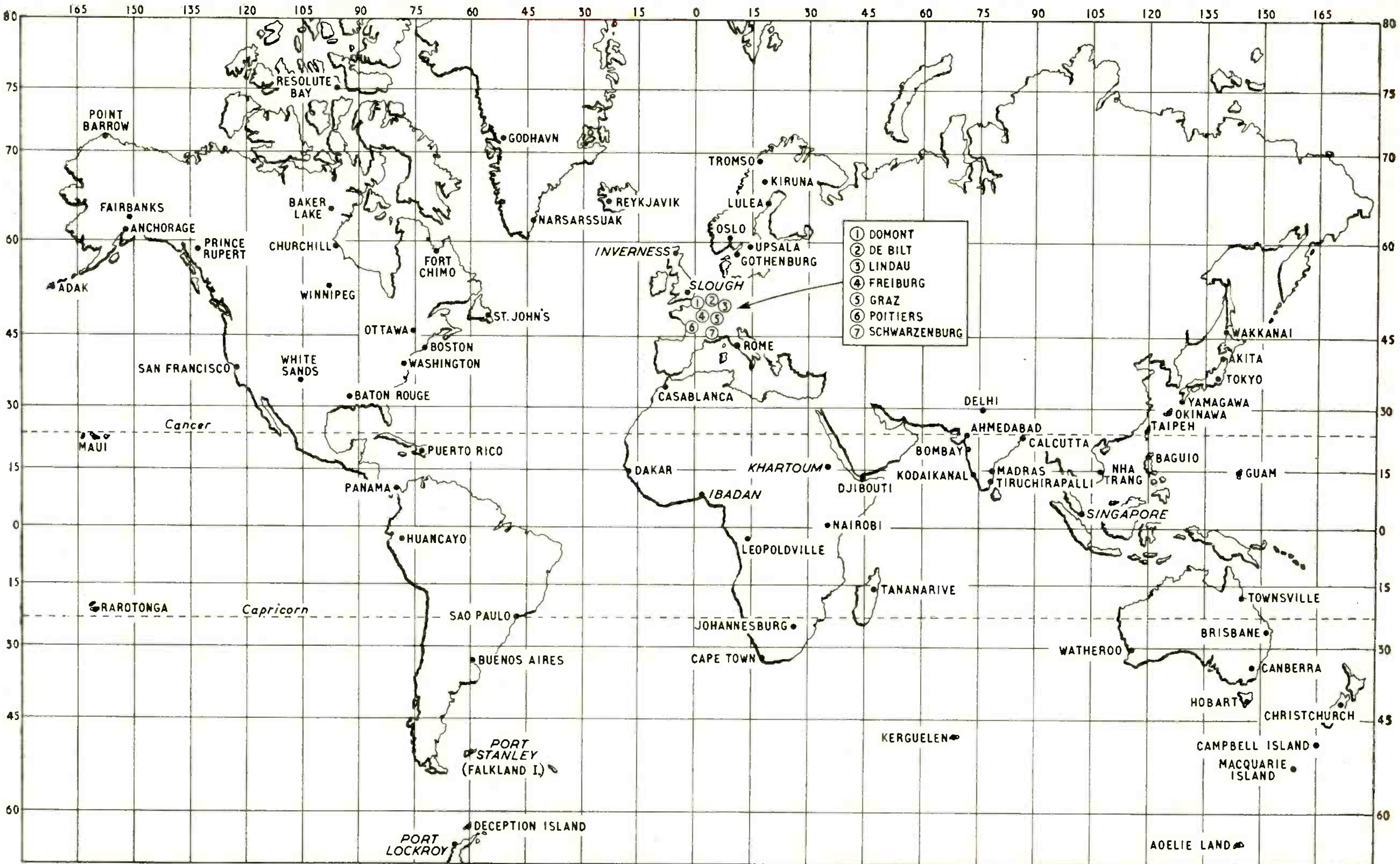
In recent years interesting and unexpected phenomena in the ionosphere have been shown to be associated with the earth's magnetic equator, so that observations are required at low as well as at high latitudes. Furthermore, there appears to be certain differences in the phenomena observed in Arctic and Antarctic regions, so that it is clearly desirable that the new investigation should cover the world as a whole; and this is indicated in the new title. The science of geophysics covers the study of all phenomena associated with the earth's surface and interior and also with its atmosphere. The radio scientist is mainly interested in the latter, since it is the lower atmosphere, or troposphere, which determines the propagation of very short waves over moderate distances, and the upper atmosphere, or ionosphere, which controls the transmission of short radio waves over great distances. The study of the effects of the troposphere and ionosphere on propagation must be conducted in association with research in meteorology, geomagnetism and solar physics. And it is in an active spirit of co-operation that scientific workers in all these fields will be engaged all over the world during the forthcoming international geophysical year.

While some observations will be conducted by automatic recording methods, and are thus virtually continuous, the major portion of the work during the I.G.Y. will be concentrated at certain periods, known as Regular World Days. In addition to these "days" periods of ten consecutive days, to be known as Special World Intervals, will be arranged quarterly at the solstices and equinoxes.

Radio Investigations.—Radio research will play a very important part in the general scheme of this international geophysical year. Efforts are being made by various countries to increase the number of stations which use vertical sounding technique for measuring the characteristics of the ionosphere.

As will be seen from the accompanying map, there are about eighty such stations in operation throughout the world. Seven of these are controlled directly or indirectly by the D.S.I.R. Radio Research Organization; they are at Inverness, Slough, Singapore, Khartoum (Sudan), Ibadan (Nigeria), Port Stanley (Falkland Islands), and Port Lockroy (Antartica). Normally these and most of the other stations take their observations at hourly intervals; but on the World Days described above, this procedure will be intensified to record the ionospheric conditions more frequently and if possible at five-

* Radio Research Organization, Department of Scientific and Industrial Research.



Disposition of the eighty-odd ionosphere sounding stations which will be participating in investigations conducted during the international geophysical year. The stations which come under the jurisdiction of the Department of Scientific and Industrial Research are shown in italics. Their regular observations will be intensified during the I.G.Y.

minute intervals. The work of these observatories is to measure, mainly by automatic methods, the height and density of ionization of the various regions of the ionosphere. In addition, measurements are made of the amount of absorption of energy suffered by the radio waves in travelling up to the ionosphere and back again to earth. At many of these stations the intensity of the earth's magnetic field is also continuously recorded, as this factor plays an important part in determining the state of the ionosphere for radio transmission.

For correlation with this radio work, all the necessary information on solar activity will naturally be obtained from the astronomical observatories, including the modern installations of the radio astronomers.

Several methods have been developed in recent years for detecting irregularities or disturbances in the ionosphere and the manner in which they travel horizontally and vertically. Observations will be made in this country and elsewhere by direct ionospheric sounding at spaced receiving points. Radio astronomy will also contribute to this investigation. The radiation from radio stars scintillates due to its passage through the upper part of the ionosphere, and observations of this scintillation are to be made in polar and equatorial regions, to provide further information on the irregularities of the ionosphere. Closely associated with this work will be the direct study of meteors, which in their passage through the atmosphere create a trail of ionization detectable by radio-echo technique. Observations on such meteors will be carried out by a chain of stations in the northern and southern hemispheres.

A relatively new technique for investigating conditions in the ionosphere over distant and even inaccessible localities, is that known as "back-scatter." In this method radio waves are transmitted at a low angle of elevation to be reflected by the ionosphere to a distant place on the earth's surface. Some of the energy is scattered from the ground at this place, or travels back over the same path to be received at the point of transmission. By studying the received echo on different frequencies and in different directions, valuable information about the ionosphere is obtained to supplement that from the vertical incidence recordings.

A field in which radio physicists and meteorologists have a common interest is that of atmospheric noise originating in thunderstorms and lightning flashes. A world network of stations measuring the strength of this noise on various radio frequencies has been in operation for some years past and this work will be continued during the international geophysical year. In some countries a group of direction-finding stations is used to locate the sources of these atmospheric disturbances; while in others an investigation is being made into the dependence of the waveforms of atmospherics on the distance and direction of transmission. During the I.G.Y., programmes involving close co-operation will be arranged to ensure the simultaneous observation in various places of special phenomena, such as the "whistler" type of atmospheric.

In collaboration with the meteorologists the radio scientists are seeking a knowledge of the variation with height of the refractive index of the atmosphere. It is proposed that this should be obtained by measurements made on masts up to a few hundred feet, supplemented by observations carried out in balloons, free or captive, up to at least 5,000 and, if possible, up to 30,000 feet.

Central Planning Control.—We have so far dealt with the investigations of direct radio interest that will form part of the whole programme of scientific work to be conducted during the year. The general planning of the programme in all fields is being carried out by a committee responsible to the International Council of Scientific Unions, which is the co-ordinating body for the various scientific unions concerned with astronomy, geodesy, magnetism, meteorology and radio. Professor S. Chapman is president of this international committee on which are representatives of the committees in the various countries collaborating in this vast enterprise.

Sir Edward Appleton is chairman of the special committee of the International Scientific Radio Union (U.R.S.I.) set up to advise on the radio work undertaken during the I.G.Y., and J. A. Ratcliffe is chairman of the British National Committee for Scientific Radio which represents this country on U.R.S.I. Among the members of the British committee for the I.G.Y. specially interested in radio research are Dr. W. J. G. Beynon, Professor A. C. B. Lovell, Professor H. S. W. Massey and the writer.

With the co-ordination of scientific effort thus obtained in radio and the allied fields, we may look forward to considerable advances in our knowledge of the various phenomena associated with radio propagation.

Club News

Barnsley.—At the April meetings of the Barnsley and District Amateur Radio Club, D. Westwood (G8WF) will speak on "The Whys and Wherefores of Q" (15th) and C. T. Malkin (G5IV) will speak on propagation (29th). Meetings are held at 7 p.m. at the King George Hotel, Peel Street, Barnsley. Sec.: P. Carbutt (G2AFV), 33, Woodstock Street, Barnsley, Yorks.

Chelmsford.—Meetings of the Chelmsford group of the British Amateur Television Club are held at 10, Baddow Place Avenue, Gt. Baddow, Essex, on the second Thursday of each month. Sec.: M. W. S. Barlow (G3CVO); address above.

Cleckheaton.—On April 6th D. Westwood (G8WF) will speak on modulation to members of the Spen Valley and District Radio and Television Society. Meetings are held at 7.30 p.m. at the Temperance Hall, Cleckheaton. Sec.: N. Pride, 100, Raikes Lane, Birstall, Yorks.

Coventry.—"Civil Communications" is the subject of a talk by G. Brown (G5BJ) to be given at the meeting of the Coventry Amateur Radio Society on April 25th. Lecture meetings are held on alternate Mondays at 7.30 p.m. at 9, Queens Road, Coventry. Sec.: K. G. Lines (G3FOH), 142, Shorncliffe Road, Coventry, Warwicks.

Romford.—Weekly meetings of the Romford Radio Society are held on Tuesdays at 8.15 p.m. at R.A.F.A. House, 18, Carlton Road, Romford. On April 12th Louis Varney (G5RV) will deal with the suppression of television interference. Sec.: N. Miller, 55, Kingston Road, Romford, Essex.

Southend.—Judging in the annual contests for the Pocock and Hudson Cups for home-constructed gear takes place on April 1st. Sec.: J. H. Barrance (G3BUJ), 49, Swanage Road, Southend-on-Sea, Essex.

An Apology

WE regret that due to an unforeseen delay in the despatch department of our printers the publication of our last issue was postponed for a few days.

DISTORTION

By "CATHODE RAY"

What Do We Really Mean By It?

IF there had been any doubt about there being a great many people intensely interested in what our American friends call "hi fi," that doubt was dispelled last autumn by Mr. Briggs when he sold the full capacity of the Royal Festival Hall (sitting and standing) in the first four days, on an announcement that he was going to demonstrate loudspeaker reproduction in comparison with direct musical performances. It has been necessary to arrange a second house. And I remember being mightily astonished when the Editor told me how many copies of the Williamson amplifier reprint had been sold. All this being so, there is naturally a demand for some scale of measurement for comparing one piece of sound-producing equipment with another. The advertisement copy writers' "perfect reproduction," "no trace of distortion," "impeccable fidelity," "thrilling tone," etc., cut no ice at all with *Wireless World* readers. They very rightly want some definite figures of performance.

So most of the advertisements nowadays say "distortion at 12 watts output is not more than 0.3%," or whatever it may be. That is certainly an improvement in principle, but we may be forgiven for asking some questions. Is 0.3% good, bad or indifferent? If another make of amplifier distorts 0.3% at 12 watts can its fidelity be assumed to be the same? If it were 0.1% how much better would it sound? And if it were 1%—or 5%—how much worse?

Twenty-five to thirty years ago people were already taking quite a lot of interest in this matter of fidelity of sound reproduction, but the data then consisted of a graph of output against frequency—what is usually called a frequency characteristic. If it was in an advertisement, the scales were chosen so as to make the graph look as nearly as possible like a horizontal line drawn with a ruler. The thing was then described as "distortionless." To the best of my recollection, percentages were not mentioned. "Distortion" was generally understood to mean frequency distortion—the unequal amplification of different frequencies. The reason for this was that the most obvious shortcoming of the very early gear was its frequency characteristic, which consisted of a violent peak in the middle or upper middle, and very little else.

So far as amplifiers were concerned, it was a fairly easy development to obtain their frequency characteristic curves and to improve their design so as to flatten out the peak into a nearly level plateau extending over the useful frequency range. And so began an era in which high-fidelity enthusiasts vied with one another in smoothing out the last fraction of a decibel (a unit which by then had come into vogue) often regardless of the vastly greater irregularities in the characteristics of the loudspeaker and the room in which it was heard. There *is* a good reason for aiming at a very level amplifier characteristic, but even now some enthusiasts may not realize that it is not the avoidance of frequency distortion as such (for on that count a peak of the order of one decibel is quite unimportant) but the obtaining of maximum undistorted output. If one narrow band of frequencies is amplified 1db more than others, as shown in Fig. 1, the whole level of output has to be lowered 1db (e.g., from 10 watts to 8 watts) in order to avoid overloading. In other words, moderate frequency distortion is bad, not as frequency distortion but as a potential cause of overloading or non-linearity distortion.

Non-Linearity

As time went on and gross frequency distortion was eliminated, the possibilities of appreciable improvement of sound by further levelling out of frequency characteristics dwindled. "Distortion" ceased to be frequency distortion and became non-linearity distortion (commonly but illogically called "non-linear distortion"). Now this is where we must be clear about the meanings of terms. "Non-linearity" means lack of straightness or proportionality of a characteristic, expressed as a graph. The particular characteristic understood in this connection is the input/output characteristic of any part of the equipment. Ordinary resistors are linear, because the voltage across them is directly proportional to the

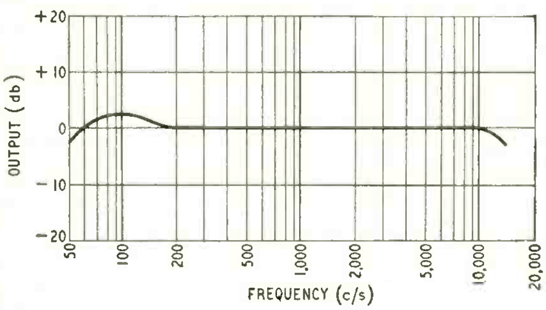


Fig. 1. Example of frequency distortion that is quite negligible as such, but should be avoided if the maximum undistorted power output is desired.

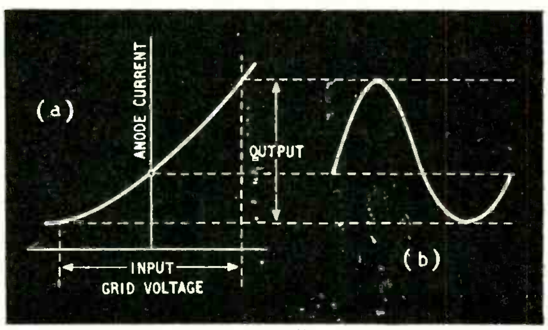


Fig. 2. Typical valve characteristic (a) with the curvature somewhat exaggerated we hope, showing the resulting distortion of a sine wave (b).

current through them; in other words, they obey Ohm's law. Valves and iron-cored coils do not. Fig. 2 (a) shows a typical sample of anode-current/grid-voltage characteristic. If the grid bias is set so that the working point is O, an input signal of sine-wave form will make the voltage swing equally on both sides of O as shown, and obviously the waveform of the output current so caused (b) is distorted, the positive half-cycle being bigger than the negative.

Harmonic Distortion

This is the effect we are now going to study. It is sometimes called "amplitude distortion," but that term has been allotted to a different effect, which may or may not happen at the same time as waveform distortion. Whereas waveform distortion is a result of non-linearity during each individual cycle, amplitude distortion means that the output level as a whole is not directly proportional to the input level. It is possible with a characteristic of the Fig. 2 (a) type, which obviously distorts the waveform, for the output to be proportionate to the input, the opposite disproportionateness of positive and negative half-cycles cancelling out and resulting in no amplitude distortion.

One of the first things we learn about non-linearity is that it creates harmonics. This has been explained so often that I needn't go into it fully. The usual line is to add together various sine waves whose frequencies are harmonically related (i.e., exact multiples of one particular frequency, the fundamental or first harmonic) and find that the results are distorted waveforms, some of which resemble those obtained by non-linearity. For example, in Fig. 3 a double-frequency or second harmonic (b) is added to a fundamental (a) and the result (c) is very like the output of Fig. 2. That is the synthetic method. Then there is the analytic method of breaking down a distorted wave (graphically or by experiment) into a fundamental and harmonics. It is then explained that the characteristic tone of each musical instrument depends on the amounts of the various harmonics it emits, relative to the fundamental, and that if these proportions are altered, either by frequency distortion or by adding harmonics by non-linearity, the characteristic tone is distorted.

True enough. But by now we are supposed to have got rid of frequency distortion that could drastically alter the proportions of harmonics; such frequency distortion, for example, as poor high-frequency response, which would tend to suppress them. And while such distortion might make a clarinet sound like a flute, it couldn't (even if it took place) account for the appalling sounds that result from severe overloading. The fact that the sounds produced by musical instruments listened to with pleasure contain a generous series of harmonics is evidence of that. An amplifier advertised to give 10% harmonic distortion would hardly find favour with "hi-fi" connoisseurs, yet what is 10% compared with the 50% or more generated by well-regarded pianos? If the only effect of non-linearity were to create harmonics, we should be at a loss to explain how such unpleasant reproduction comes with quite moderate harmonic distortion percentages.

It is now generally agreed that it is *not* the harmonics that are responsible for the worst of the unpleasantness. In *Wireless World* for May 19th, 1938,* I described a simple experiment for demonstrating this. On the assumption that copies of that issue may not be lying around to hand, I will briefly recap. A receiver is arranged with two separately-adjustable sine-wave input signals and an output meter. The low frequency, say 100 c/s, is adjusted to be 10 times the voltage (and therefore 100 times the power) of the other signal, say 533 c/s. In spite of this the 533-c/s note sounds about as loud as the 100 c/s, because the ear is so much more sensitive at the higher frequency. At first each signal can be heard as a clear pure note, as it was when alone. But at a certain setting of the main volume control a roughness of tone becomes noticeable; and at a still higher setting the higher note becomes indistinguishable, the whole output degenerating into a harsh rattling kind of hum.

* "Debunk'ng Harmonic Distortion."

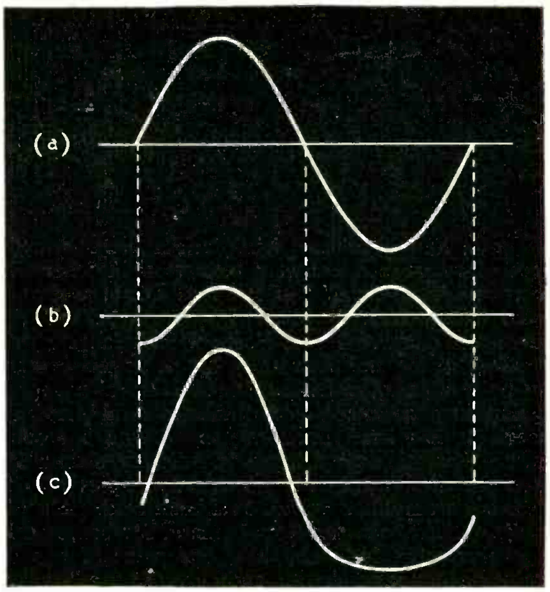


Fig. 3. Showing how the distortion in Fig 2(b) can be made synthetically by adding together a second harmonic to the original (fundamental) waveform.

If now the 100 c/s is switched off, the 533-c/s note is heard with perfect clarity. That is only to be expected, because it is weak enough to be well below the point of serious distortion. What might not be expected however is that when the 533 c/s is switched off the 100 c/s becomes quite clear and altogether different from its sound when both signals are on. This is so, notwithstanding that switching the 533 c/s off reduces the output power by only 1%, which by itself is not enough to make an appreciable difference to the amount of distortion. An increase of much more than 1% in the power of the 100 c/s alone has no such devastating effect as switching on the weak 533 c/s.

Intermodulation

The obvious conclusion is that some kind of distortion is taking place when both signals are being handled together by the amplifier which is not present with only one. Here again we come to a well-worn chapter in radio theory, of which Fig. 4 should be sufficient reminder. (a) is the undistorted two-signal input, and (b), assuming distortion of the kind shown in Fig. 2, is the distorted output. At the positive peaks of the "strong-low" signal the "weak-high" signal is amplified more than at the working point O, and at the negative peaks it is amplified less. So the weak signal is amplitude-modulated at the frequency of the strong. This can be seen more clearly if the strong signal is taken away (c). The said chapter of radio theory explains how this process introduces new frequencies, not necessarily multiples of either of the input frequencies, but "sum and difference frequencies." The Fig. 2 kind of characteristic, which creates mainly second-harmonic distortion of the low-frequency signal (f_1, say) causes the high-frequency signal (f_2) to wax and wane once per low-frequency cycle, and the frequencies created by modulation are mainly $f_1 \pm f_2$, known as the simple sum and difference or second-order intermodulation frequencies. In our experiment they would be $533 \pm 100 = 433$ and 633 c/s.

This distortion is the kind that one gets with a triode output valve, and which a push-pull circuit is used to balance out. If a pentode is used, or the push-pull system is over-driven, both positive and negative peaks tend to be affected in the same way. The result is that the third harmonic is the strongest, and third-order modulation frequencies, $f_1 \pm 2f_2$, 333 and 733 c/s in our experiment.

Generally distortion consists of a mixture of second and third, with smaller proportions of higher numbers, but most practical cases fall into one of two main classes, in which either second or third predominates.

Obvious ?

So far we have talked about the 100 c/s modulating the 533 c/s, but not the other way about. Why? Well, if one man fought another ten times as strong he might inflict something on him, but it would usually be negligible compared with what he received. In the same way we have neglected the modulation of the strong signal by the weak, though it does exist and is why the process is called *inter*modulation. When two signals going through the mill together are equally strong, each modulates as much as it is modulated.

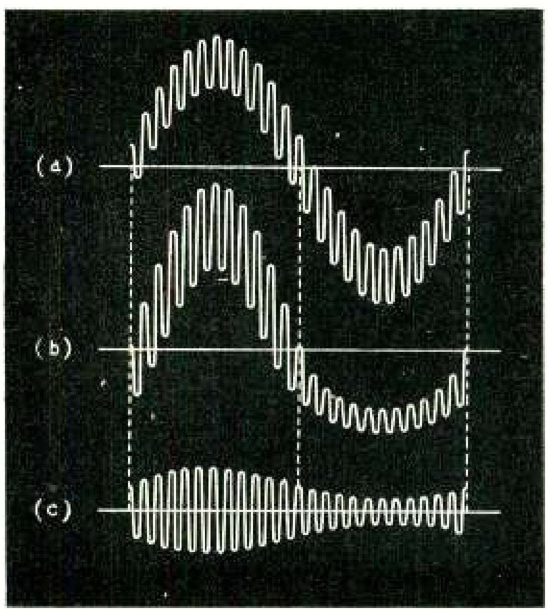


Fig. 4. When a higher-frequency but weaker sine-wave tone is added to the low-frequency signal at the input, the waveform of the combination is as at (a). After suffering distortion of the Fig. 2(a) type it comes out like (b), and by taking away the low frequency the damage to the higher frequency can be seen more clearly (c).

I said that the experiment made it obvious that intermodulation, not harmonic distortion, is responsible for nearly all the unpleasantness. That conclusion can hardly be doubted so far as the particular conditions of the experiment are concerned. But it is always risky to draw quick conclusions about the connections between physical causes and the resulting impressions on the senses. If a physical force acts on a lifeless object, the effect conforms to a simple equation covering all such events. But the impressions a human being receives as a result of physical causes often seem to bear no predictable or clear relation to them. A race of stone deaf men, though they might master the science of physical sound, could never discover what it was like to hear. Even where there does at first seem to be a clear connection, it may be misleading. For instance, it might seem definite enough that the higher the frequency of a sound the higher the pitch of what is heard. But even there it is not safe to assume that the two things run perfectly parallel, for it is found that the pitch of a note of constant frequency varies slightly with its intensity.

Still less safe is it to draw hard and fast conclusions about the relationship between unpleasantness of sound and the distortion that causes it. Our particular "obvious" conclusion—that intermodulation accounts for nearly all the unpleasantness caused by non-linearity distortion—when I expressed it in 1938 was immediately challenged. And it certainly is unwise to draw such a sweeping conclusion on the basis of one simple experiment. Does it hold for all different combinations of frequencies? And does it hold for typical programmes?

One typical programme is speaking. But speech is an extremely difficult type of sound to study for unpleasantness. Music is much easier, so we shall assume music is our staple diet of listening (whether as the food of love or not is unimportant just now). There do seem to be some clear-cut rules about combinations of musical sounds. One of them is this: that the smaller the whole numbers in which the ratio of the frequencies of two sounds can be expressed, the more harmonious the combination appears to the listener. To take one extreme, the ratio with the smallest possible numbers is 1 : 1, which means that both sounds have the same frequency, so are heard as one sound, without any disharmony or indeed any distinction at all between them (assuming, of course, that they are coming from the same source). The next simplest ratio is 2 : 1, which means that the frequency of one note is twice that of the other. Musicians say that it is an octave higher. Although of course the two notes are easily distinguishable when heard separately, they blend so smoothly together that most untrained listeners are unaware that more than one note is being played. People are said to be singing in unison even though the women are singing all their notes twice the frequency of the men. This being so, it should be pretty safe to say that even 100% second-harmonic distortion, *if it consisted only of the creation of second-harmonic or octave-higher frequencies,* could not cause harshness in the sound. It would certainly make the music sound "brighter" and as this would be different from the original it would have to be classed as "distorted," though to some ears it might be considered an improvement. The effect on a single sustained note can easily be tried if one has two a.f. signal generators that can be synchronized an octave apart and the higher one brought up from zero level. The effect is identical with that obtained with a single note through an amplifier which can be made to give pure second-harmonic distortion. The same effect on real music can be produced in organs, by bringing in a coupler that adds octaves to all the notes played. This is *not* the same, however, as playing the music through the distorting amplifier, because that adds difference tones as well.

And that, of course, is the crux of the whole matter. But before going into it, let us continue a little longer with our lesson in the theory of harmony. As a non-musician I shall have to be careful; but, on the other hand, musicians themselves seem quite unable to talk our language of frequencies, etc., so fail to tell us clearly what we want to know.

The next simplest ratio might be said to be 3:1. But in music the scale starts all over again at the end of an octave, and so a note 3 times the frequency of another may be regarded as $1\frac{1}{2}$ times the note an octave higher; consequently our next ratio is really $1\frac{1}{2}$ or 3:2. And the musicians would agree, I think, that this is the next most important "interval" to the octave, by virtue of which they name it the dominant. The original (lower) note they call the tonic, by the way. And when tonic and dominant are played together, we are conscious of hearing something more complicated than a single note, or even the "brightened" note made up of the 2:1 combination; yet it is undoubtedly "in tune" and harmonious. So is a 3:1 combination, such as a fundamental and third harmonic, because the harmonic lies in this "dominant" relationship to an octave higher than the fundamental, which as we have seen (or rather heard) is almost equivalent to the fundamental.

Harmonics and Harmony

It would seem, then, that the creation of third harmonics would by itself introduce no harshness or discord, nor perhaps even unpleasantness except to the musical connoisseur who would resent unison passages for flutes being given a harmonic accompaniment. The general effect would be to make the balance of tone still "brighter" and also somewhat "richer" by the addition of the new harmonies. "Nasal" is a description that is sometimes used to refer to the double effect.

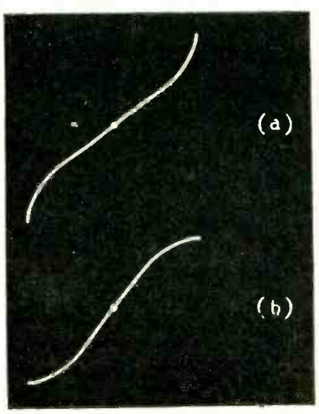


Fig. 5. Here, for comparison with the square-law characteristic of the triode, shown in Fig. 2 (a), are two varieties of the cube-law characteristic, typical of pentode valves and iron-cored coils.

Fourth harmonics are two octaves higher than the fundamental, and as regards harmony are therefore less conspicuous than third harmonics. The only serious effect would be if they were strong enough to make the music sound two octaves higher than it was supposed to be, but in practice this would hardly be so. Any distortion that produces fourth harmonic also produces much stronger second harmonic.

A similar principle holds with the odd harmonics; fifth is accompanied by much stronger third. But how do we expect the fifth to sound in relation to the fundamental? Relative to two octaves above the fundamental, its ratio is 5:4. And I think the musicians would still be with us if we declared that this

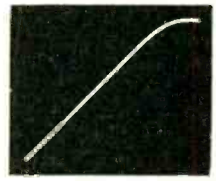


Fig. 6. When the characteristic has a sudden bend, like this, the higher harmonics are created at appreciable strength.

is the next easiest on the ear, after octave and dominant. Sol-fa practitioners identify it as "me" above "doh." If all four notes we have now considered are played together—doh, me, soh, doh—the combination is still harmonious and pleasant. It is, in fact, the "common chord." But I suspect that a musician would consider it a bit thick, in more senses than one, if every single note of his composition were replaced by this four-note combination; which is virtually what would happen if all harmonics up to and including the fifth were added. However, although it would not be a faithful reproduction of the composer's intentions, the non-musical hi-fi expert, without being able to compare it with the original, might (I suggest) be unable to recognize it as "distortion" in his sense of the word.

And so we could go on. Sixth harmonics are like thirds except for being an octave higher. But when we come to the seventh, the ratio to the next lower octave above the fundamental is 7:4. According to my untutored reckoning, this is B flat in relation to C. I don't know how it is rated by the musicians, but it sounds pretty discordant to me, even though my musical taste tends towards the modern. The eighth harmonic is three octaves above the fundamental, so may sound rather squeaky but certainly not discordant. The ninth, which after deducting the whole octaves is like sounding "doh" and "ray" together, is aggressively discordant. As we go higher up the series of *odd* harmonics the numerical ratio becomes more awkward and the musical sound more discordant. The even harmonics are not quite so, because the number can be simplified by dividing by 2, perhaps more than once, and that is musically equivalent to the interval of an octave, which harmonically hardly counts. Take the 12th harmonic; in relation to two octaves above the fundamental its ratio is 12:4, which simplifies to 3:2, and that, as we have seen, is a very easy harmony. But the 14th can only be simplified to 7:1, so it is the lowest discordant even harmonic.

What decides which harmonics are produced, and how much? As one can find out by making the same sort of comparison as Fig. 2 with Fig. 3, using different input/output (or "transfer") characteristics,

(*Continued on page* 195)

or, more elegantly, by mathematics,* it is the shape of the transfer characteristic that is responsible. The two most important are the square-law, with its smooth one-way bend shown in Fig. 2, which produces second harmonic, and the cube-law, with its S bend (but still smooth) shown in Fig. 5, which produces third harmonic. The sharper and more irregular the bends, the higher the harmonics created. The characteristics of valves worked under reasonable conditions are usually one or other of the first two (though less exaggerated) or a combination of both, and harmonics are therefore nearly all second or third or both. And we have seen that these are not in the least discordant. But if a valve runs into grid current at the signal peaks, or for any other reason has a characteristic with an abrupt corner, such as Fig. 6, the resulting harmonics are distributed well up the scale, including perhaps appreciable amounts of the discordant numbers. Incidentally, a practical way of seeing the shape of the transfer characteristic of an amplifier is to connect the input voltage across the X plates of an oscilloscope and the output voltage (phase-shifted if necessary to close the loop) across the Y plates.

It seems that unless the characteristic is so unsuitable that it brings in at least the seventh among the odd harmonics and the 14th in the even series, there should at any rate be no harshness, if harmonics were all that happened. However, there are intermodulation products to be reckoned with. And I am afraid that if we started to reckon with them at all seriously just now it would take up too much space. We shall have to put it off until next month.

* See "Relationships between Amplitudes of Harmonics and Intermodulation Frequencies," by M. V. Callendar and S. Matthews, in *Electronic Engineering*, June, 1951, p. 230, where the results are conveniently tabulated.

Output Transformer Design

For Amplifiers Employing Negative Feedback

By R. F. GIBSON*

IT is relatively easy to design a feedback amplifier with a flat response and good inherent stability to cover a range of 9 octaves. It becomes increasingly difficult, however, as the range is extended another one or two octaves, largely owing to instability troubles caused by the output transformer.

The basic requirements for a.f. transformers for use with negative feedback amplifiers, providing low-distortion power outputs, are well known but may be briefly recapitulated as follows:—

- High primary inductance.
- Low primary/secondary leakage inductance.
- High-frequency resonance at a frequency where the loop gain of the feedback section of amplifier is less than unity.

Some additional considerations of practical importance are:—

- Economical design.
- Adequate electrical insulation.
- Suitable choice of core material.
- Moderate I^2R losses.

Consideration of these requirements will show that the design features must effect as good a compromise as possible between several conflicting requirements, e.g., high primary inductance means a large number of primary turns which necessitates a large I^2R loss or a large winding space. A large winding space requires a highly sectionalized winding to keep down leakage inductance. This precludes economical design and increases the difficulty of maintaining adequate electrical insulation.

One way of reducing primary turns is to use a high permeability core material, but this solution is often ruled out on the score of cost.

* R. F. Gibson, Ltd.

The ordinary grades of silicon iron have a relatively low distortion coefficient but suffer from the disadvantage of very low permeability at low flux densities. This has a serious disadvantage when considered in relation to feedback amplifiers. Briefly, the very low primary inductance at zero signal level necessitates the amplifier designer using otherwise unnecessarily long time constants in his l.f. couplings to keep away from the 180° phase shift associated with a 12-db slope which would result in low-frequency instability. No doubt many readers will have had painful experience of this trouble.

Instability

One major cause of h.f. instability is resonance "inside" the range of significant loop gain, resulting in a reversal of feedback polarity within the pass band of the amplifier. This is usually produced by the increased leakage inductance associated with a large number of turns in conjunction with high inter-winding capacitances.

The foregoing remarks may appear to give a somewhat gloomy picture of the performance of an output transformer in a high-quality feedback amplifier. Fortunately, it is possible, by careful and adequate design, to obtain a performance which, in fact, leaves little to be desired, and some of the basic requirements of such a design will now be discussed.

1. *Core material:* There appears to be no better material at present available than silicon steel. There are, however, several varieties of this material the relative merits of which will be discussed later.

2. *Winding space to core cross-section ratio:* without going into the mathematics of this problem it may be stated that economic considerations inevitably lead

to the choice of a small window to core ratio; this choice also helps considerably in easing the problem of obtaining a high resonant frequency and low leakage inductance.

3. *Efficiency:* Once a small window space has been decided upon it will be found that the weight of copper which can be fitted into it is small and therefore it becomes fairly safe to assume that the I^2R losses will not be unreasonable, providing the primary wire gauge is large enough to handle the r.m.s. value of standing d.c. plus audio-frequency current without overheating and the I^2R loss ratio between primary and secondary is reasonably near 1 : 1.

4. *Primary Inductance:* An empirical formula which has been found useful in determining the primary inductance is—

$$L = \frac{R_l \times V\beta}{2 \times 10^3} \qquad (1)$$

where L is in henries, R_l = anode-to-anode load (ohms) and $V\beta$ is the feedback voltage ratio. In the case of push-pull EL84's with 26 db feedback, this works out at $\frac{8000 \times 20}{2 \times 10^3}$

5. *Flux density:* Again a simplified equation—

$$N = \frac{10^3\sqrt{WR_l}}{KfA} \qquad (2)$$

where N = number of primary turns, W = V.A input to primary, R_l = anode-to-anode load in ohms, f = frequency of bottom distortion limit, A = cross sectional area of core (sq. in.) and

K = 1.6 for intermediate grade } laminations
1.7 for high grade } laminations
3.3 for "Unidi" material† } laminations
3.5 for "C" cores

This formula gives a practical answer for ratings up to 25W if the core area is in the region of $\frac{\sqrt{W} \times 30.}{(0.5 + K) \times f}$

Empirical data plus a consideration of general requirements will then enable a suitable core to be selected.

Going back to a choice of a suitable core material, we have available, intermediate grade silicon steel, high-grade silicon steel and oriented-grain silicon steel, the last mentioned being available in the form of either laminations or "C" cores. "C" cores are expensive and show only a small advantage over "Unidi" laminations both as regards the coefficient in equation (2) and the primary inductance to AN^2 ratio. Oriented grain material does however show a very marked advantage over the other grades of silicon steel and in the case of laminations is reasonably economical provided that it is obtained in the form of "no waste" E and I laminations.

It now remains to select a core size which can be made to satisfy the requirements of equations (1) and (2) and the clause concerning temperature rise. In the case of a 12-watt transformer using push-pull EL84's, the "no waste" size 4, having a 1in. wide core and a 1½in. × ½in. window, fits the requirements when built into a square stack.

The simplest winding arrangement which will provide a level response up to 30 kc/s is as shown in Fig. 1. and this provides a d.c. resistance balanced with respect to A_1 to h.t. and A_2 to h.t. The inter-

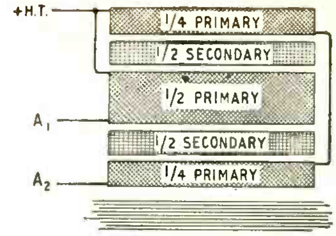


Fig. 1. Simple method of sectionalizing which gives adequate coupling

winding capacities are unbalanced but the overall coupling factor is good enough to take care of this. It should be noted that the winding layout shown is not suitable for a transformer having primary taps for the so-called "ultra-linear" circuit. One way of providing correct screen couplings is to transpose the primary and secondary windings.

Tests carried out on a transformer designed according to the foregoing data show that the expected results are well maintained in practice. The actual readings obtained were:—

Primary d.c. resistance 340 Ω; secondary 0.98 Ω; leakage inductance 24mH; initial inductance of primary, better than 130 H.

The measured performance is as follows:—

± 1 db from 25 c/s to 42 kc/s and the distortion limit on a sine wave trace is 28 c/s to 35 kc/s at 12 watts output from secondary, these figures being slightly over 1 octave better than can be obtained on the same size of core with intermediate grade laminations.

† Geo. L. Scott and Co., Ltd.

BOOKS RECEIVED

Television, by V. K. Zworykin, E.E., Ph.D., and G. A. Morton, Ph.D. Revised second edition covering fundamental physical principles, complete systems for monochrome and colour and details of camera and display tubes. Pp. 1037+xv; Figs. 698. Price 40s. Chapman and Hall, 37, Essex Street, London, W.C.2.

Radio and Television Engineers' Reference Book. Edited by E. Molloy and W. E. Pannett, A.M.I.E.E. Compendium of descriptive information, data and servicing hints in all branches of radio communication, contributed by 36 specialists. Includes chapters on sound reproduction and distribution, disc and magnetic tape recording. Pp. 1542+xx; Figs. 1117. Price 70s. George Newnes, Ltd., Tower House, Southampton Street, London, W.C.2.

Ibbetson's Electric Wiring. Edited by C. R. Urwin, A.C.G.I., A.M.I.E.E.; W. F. Parker, M.I.E.E., and F. G. Thompson, M.Sc. (Eng.), A.M.I.E.E. Ninth edition of this textbook of theory and practice for practical wiremen and students. Pp. 296+viii; Figs. 119. Price 11s 6d E. and F. N. Spon, Ltd., 15, Bedford Street, London, W.C.2.

Fundamentals of Transistors, by Leonard M. Krugman. Summary of design procedure and formulæ for the principal transistor circuit configurations, with an introductory chapter on basic semi-conductor physics. Pp.140; Figs. 110. Price 21s. Chapman and Hall, 37 Essex Street, London, W.C.2.

Radar Pocket Book by R. S. H. Boulding, B.Sc., M.I.E.E. Basic information on radar systems, components and circuits for the use of operators, installation and maintenance engineers. Pp. 176+vii; Figs. 156. Price 15s. George Newnes, Ltd., Southampton Street, London, W.C.2.

APRIL MEETINGS

Institution of Electrical Engineers

London.—April 5th. "High Speed Electronic-Analogue Computing Techniques" by Dr. D. M. MacKay at 5.30.

April 20th. "A Study of the Long-Term Emission Behaviour of an Oxide Cathode Valve" by Dr. G. H. Metson at 5.30.

April 21st. Kelvin lecture "Transistor Physics" by Dr. W. Shockley at 5.30.

April 22nd. Discussion on "Technical Training in North-West Germany" opened by Dr. K. R. Sturley at 6.0.

All the above meetings will be held at Savoy Place, W.C.2.

Mersey and North Wales Centre.—April 4th. Annual general meeting followed by "Special Effects for Television Studio Productions" by A. M. Spooner and T. Worswick at 6.30 at the Liverpool Royal Institution, Colquitt Street.

North-Eastern Radio and Measurements Group.—April 4th. Annual general meeting followed by "Thermionic Valves of Improved Quality for Government and Industrial Purposes" by E. G. Rowe, P. Welch and W. W. Wright at 6.15 at King's College, Newcastle-upon-Tyne.

Northern Ireland Centre.—April 5th. Faraday lecture "Courier to Carrier in Communications" by T. B. D. Terroni at 8.0 at the Sir William Whitla Hall, Queen's University, Belfast.

South Midland Radio Group.—April 25th. Annual general meeting followed by "A Transatlantic Telephone Cable" by Dr. M. J. Kelly, Sir Gordon Radley, G. W. Gilman and R. J. Halsey at 6.0 at the James Watt Memorial Institute, Great Charles Street, Birmingham.

Southern Centre.—April 1st. "Cold Cathode Valves" by J. R. Acton at 6.30 at the South Dorset Technical College, Weymouth.

British Sound Recording Association

London.—April 22nd. "Romance and History of the Gramophone" by P. Wilson at 7.0 at the Royal Society of Arts, John Adam Street, W.C.2.

Portsmouth Centre.—April 13th. "Tape Recording, 1948-1955" by C. Hardy at 7.15 at the Central Library, Guildhall, Portsmouth.

South-Western Centre.—April 13th. "High Fidelity" by P. D. Collings-Wells (Goodmans) at 7.45 at Callard's Café, Torquay.

Television Society

London.—April 1st. "A Flying-spot (Mechau) Telecine System" by J. L. Bliss (B.B.C.) at 7.0 at the Cinematograph Exhibitors' Association, 164, Shaftesbury Avenue, W.C.2.

April 21st. "Progress in Colour Television" by L. C. Jesty (Marconi's) at 7.0 at the C.E.A., 164, Shaftesbury Avenue, W.C.2.

North-Western Centre.—April 27th. "Progress in Colour Television" by L. C. Jesty (Marconi's) at 7.30 at the College of Technology, Manchester.

Society of Instrument Technology

London.—April 26th. "Magnetic Amplifiers as Industrial and Laboratory Aids" by R. J. Russell-Bates at 7.0 at Manson House, Portland Place, W.1.

Newcastle Section.—April 20th. "Electronic Computors" by A. St. Johnston (Elliott Bros.) at 7.0 at Stephenson Building, King's College, Newcastle-upon-Tyne.

British Institution of Radio Engineers

London Section.—April 13th. Discussion on "The B.B.C. v.h.f. Frequency-Modulated Sound Broadcasting Service" opened by Dr. K. R. Sturley and F. T. Lett at 6.30 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

April 27th. "Suppressed Aerials for the Aircraft h.f. Band" by K. J. Coppin at 6.30 at the London School of Hygiene and Tropical Medicine.

North-Eastern Section.—April 13th. Annual general meeting and "The Manchester University Universal Computor" by E. T. Warburton at 6.0 at Neville Hall, Westgate Road, Newcastle-upon-Tyne.

South Wales Section.—April 27th. "Some Technical Problems in Sound and Television Broadcasting" by Dr. K. R. Sturley at 6.30 at the Glamorgan Technical College, Treforest.

Scottish Section.—April 14th. An evening of films with an exhibition of electronic apparatus at 7.0 at the Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow, C.2.

Physical Society

Acoustics Group.—April 22nd. "Sound Absorption in Porous Structures and Suspensions" by Professor R. Morse at 5.30 at Imperial College, London, S.W.7.

Incorporated Practical Radio Engineers

Midlands Section.—April 6th. "Projection Television" by R. Lightwood (Philips) at 7.30 at the Crown Hotel, Broad Street, Birmingham.

SERVICING EXAMS

REPORTING on last year's servicing examinations organized by the Radio Trades Examination Board and the City & Guilds, the examiners draw attention to the "lack of knowledge of basic principles as they affect servicing." In the intermediate exam. for radio service work (C. & G.) only 129 (19%) of the 659 home candidates obtained a first-class pass and 241 (36%) second-class passes. Of the 244 overseas candidates only six obtained first-class passes and 63 a second-class pass.

Of the 370 candidates who sat for the R.T.E.B. Radio Servicing Certificate examination 144 passed and 96 have to re-enter for the practical test. The many failures in the practical test were said to be due to two main reasons: (1) incorrectly connecting a coaxial cable and (2) dry joints. Incidentally failure in the soldering test fails the candidate in the whole of the practical examination.

Only 104 candidates entered for the R.T.E.B. Television Servicing Certificate exam. Fifty-five passed and 20 have to retake the practical test. Summarizing the results of this examination the examiners state that considering it is the final in the servicing series conducted by the R.T.E.B. the standard of work was not very high.

RANDOM RADIATIONS

By "DIALLIST"

Is "Piping" the Solution?

THE B.B.C.'s scheme for country-wide f.m. transmissions may eventually provide us with interference-free-broadcast reception; but I see no similar way in sight of dealing with the problem of TV interference. Unless some means can be found of suppressing at the source the many different kinds of interference I'm inclined to believe that the only way out is to establish master receiving stations at sites remote from roads, factories, overhead power lines and so on, and to "pipe" the signal to viewers' homes. This is already being done, of course, in quite a number of the larger towns, and it is proving to be a very successful method. I don't see that either manufacturers or dealers need be afraid of it. Were piped TV more generally available, there's no doubt that there'd be a big jump in the number of licences taken out; and that would mean good business. What I have in mind is something like this. The company owning the master receiving station simply delivers a signal of guaranteed quality and strength to the customer's house in return for a weekly or monthly fee. The customer buys the receiver of his choice from his dealer, who installs and subsequently services it. As E. J. Gargini showed in his "'Piped' Scanning Waveforms" in the February issue of *W.W.*, the receiver can be a very simple affair, which should be much cheaper than the normal set. And that might be the key to the production of receivers of really excellent performance at "popular" prices.

Putting Up With It

IT'S surprising that non-technical owners of television receivers should so often be content with very poor pictures. A few evenings before this was written I dropped in on some nearby friends and found them looking-in. The very first thing that hit me in the eye was a prominent light vertical line. Yes, the set was ringing heartily; and every dark object had an additional white outline. But that wasn't all: there were dark horizontal bars due to sound-on-vision. They were obviously so delighted with the set's performance that I just hadn't the heart to suggest that anything was amiss. I don't think they even noticed the effects that shouldn't have been there. Again, I remember seeing in the house of other friends a picture in which everything near the top had a pronounced bend to the left. "It's always been like that," said my host; "but we've got used to it and it doesn't worry us as a rule." He seemed to think that it was just one of those things and was surprised when I told him that any competent service man should be able to put it right without spending much time on the job.

Indoor Aerial Oddities

WHAT queer effects indoor aerials can produce when used for either sound or television reception. In one room of my home there's a broadcast receiver served by a wire running along the picture rail. Just occasionally it picks up telephone conversations between my house and another not far away. Sometimes, again, there is a noticeable change in the volume when a light in another room is switched on or off, due probably to pick-up and re-radiation by part of the electric wiring. As for indoor aerials for television, there's no saying what they *won't* do. In one house that I know reception is quite good with the aerial in one precise position; but move it a mere six inches to right or left and both sound and picture almost disappear. The queerest case I've ever come across was that of a building in which the only place an indoor aerial would pick up an adequate signal was the basement. One firm which makes vast quantities of indoor and outdoor TV aerials tell me that they've had more than one similar case.

Expensive Switching

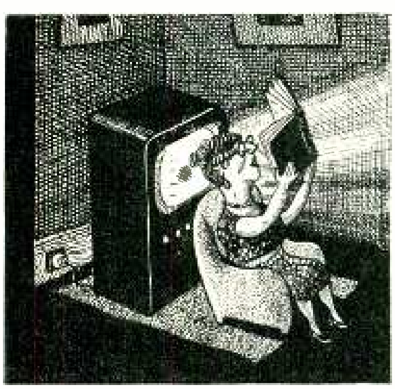
EVERY TV receiver instruction book ought to contain a warning about the risks taken when a set is switched off and then switched on again before it's had time to cool down. I expect you know people who do it quite often because they've found that it's one way of clearing certain intermittent faults for the time being. If it's switched on when still well warmed up, the set gets the father and mother of an electrical kick in the neck, for the conditions which normally ensure a more-or-less gradual build-up of heater and other voltages are absent.

The Intermittent Fault

THERE must, I suppose, have been more naughty words used over intermittent faults than over any other shortcomings of broadcast receivers. The most evil of all kinds is that which clears itself so quickly that you've no time to poke round with measuring instruments or an oscilloscope before it's gone. The best hope in such cases is to think out from the symptoms the only parts of the set in which there could be a fault and to go through them with a fine-toothed comb. As a desperate measure the substitution, one at a time, of components which might be guilty may be tried. The intermittent fault which occurs when the set has warmed up and stays in evidence until it is cooler is less maddening to deal with, though I'm not going to suggest that locating it is always easy. Eliminating, as before, the places where it could not be, you narrow down the field of search and, if you're lucky, you have a good chance of pinning it down sooner or later—it'll probably be later rather then sooner, if my experience goes for anything!

Alternative TV

VIEWERS in the London and Sutton Coldfield areas have a respectable chance of discovering whether or not they're likely to be able to receive the alternative television programmes, and, if reception seems probable, of discovering what sort of Band III aerial will be needed. A test-signal (of low power, admittedly, but still a test-signal) is going out fairly regularly on 180.4 Mc/s from Sutton Coldfield and, from April 1st, on 194.75 Mc/s from the temporary transmitter set up by Belling & Lee in South London. Much less fortunate are those who live in the north. The only thing the I.T.A. seems so far to have decided for that area is that it isn't going to use the Holme Moss aerial mast. It seems likely that there will be two transmitters, one for the eastern and one for the western part of the area; but where they're going to be hasn't been decided at the time of writing.



"I think we need a new tube, George."

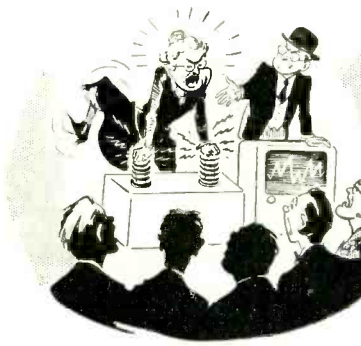
UNBIASED

By FREE GRID

Static or Kinetic?

WITH the example of George Washington ever before them, the Americans have always been such sticklers for truth that I cannot imagine how they ever came to use such a misnomer as the word "static" to describe what we always call atmospherics—or Xs if we belong to the older generation.

Surely if the electrical energy—



Certainly not static

be it natural or man-made—which causes noises in our loudspeakers and snowstorms on our television screens were indeed really static or motionless it would cause no trouble. This can quite easily be proved by standing a fully charged capacitor near a sensitive receiver.

This potential energy or static will cause no trouble no matter how great the capacitance of its container or how high the voltage of the charge. But if you convert it to kinetic energy by inviting your mother-in-law to bridge its terminals with her hands you will at once get all the trouble you can cope with, as I once proved to my own satisfaction. Surely then we should speak of man-made kinetic rather than static?

Connoisseur's Corner

MOST people who have met female film stars face to face after having been accustomed to seeing them on the screen are conscious of bitter disappointment. The reason is that these glamour girls when seen in the flesh don't possess anything that is particularly attention-compelling to distinguish them from their fellow females. In other words, the screen reproduction is a lot better than the original, or at any rate seems so. To use the modern jargon, the operative word here is "seems," for our critical faculties are so drugged by constantly looking at them on the screen that we grow to prefer all the shallow artificiality there portrayed.

My analogy is not a very good one, I'm afraid, but I find that much the same sort of thing happens when I ask people to listen to my high-fidelity receiver. It is as near perfect in its reproduction as it is possible to get and yet people are so used to the false tones—if that be the correct expression—imparted to speech and music by their ordinary sets that mine sounds disappointing. They are, as it were, drugged by constantly listening to indifferent reproduction and are thus like a confirmed toper who is unable to appreciate the delicate quality of a vintage port when it is set before him.

It looks, therefore, as though people need to be broken in gradually to high quality. I wonder if it would not be advisable for manufacturers to market hi-fi/lo-fi receivers in an effort to raise the rabble to real radio reproduction. A two-way switch should be fitted so that in the "lowbrow" position it would connect a fat capacitor across the loudspeaker and give the musical masses the mellow bellow they have been drugged to love.

Who'll Take My Money?

NOW that one of our largest recording companies has decided to issue tape records side by side with the conventional disc type I suppose we can look forward to the eventual appearance of radiograms and playing desks fitted with the necessary additional gear. We already have three speeds for discs and it is to be hoped that similar complications will be avoided in tape records.

I shall welcome the appearance of these "tapeograms" as I think it may prove the thin end of the wedge, the other end of which will be the coming of "all-in" 'grams able to record B.B.C. programmes for consumption when desired. At present we have to instal such equipment in untidy bits and pieces.

I am still bothered about the ethics of recording broadcast programmes despite the recent assurances of the Editor regarding the legality. I personally would be willing to pay a small fee to the composers, starving in their miserable garrets, but who'll take my money?

I put this question to some G.P.O. representatives recently when they spent the evening outside my house in one of the new TV detector vans. All I received was a suspicious stare from one of them as he licked his pencil and continued designing an attenuator from the formulæ given in the reference section of his 1955 *W.W.* Diary.

The Curse of Kissing

KISSING is not the sort of thing which one associates with doctors as there can scarcely be a more potent carrier of infection. I was, therefore, somewhat surprised to hear a doctor discuss the matter in a recent B.B.C. talk.

The only thing that interested me in the doctor's talk was his statement that he knew a married couple who caused an electric spark to jump from one to the other each time they kissed. Apparently this is not an isolated phenomenon, for when this statement was published in the Press several letters subsequently appeared which showed it to be quite common.

Quite frankly, however, I was still unconvinced and determined to investigate the matter myself; not by personal experiment—ugh!—but by going to places where couples congregate and taking with me a sensitive portable receiver. No sooner had I slipped on my headphones in the local cinema and switched on than I was startled by a truly appalling spate of interference. From my seat I could see in the dim light several offenders whose osculatory efforts coincided with the bursts of Xs in my phones.

On my way home I took a short cut through the local park and I soon found out the value of the d.f. properties of the frame aerial and had no difficulty in locating my

Potent kisses

quarry. Can any of you learned legal luminaries tell me if the P.M.G. has the power to make regulations to deal with this menace without further legislation. From a technical point of view I don't think it is possible to suppress this interference unless kissing is only permitted in specially screened apartments.