Wireless World

ELECTRONICS, RADIO, TELEVISION

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In This Issue

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New Tools

THE assimilation of electronic aids by industry and in the life of the community as a whole during the past decade has not been without its vicissitudes. On the one hand we have had somewhat reluctant "rise times" resulting from innate conservatism and, on the other, optimistic "overshoots" when enthusiasm has been allowed to outrun experience.

One can sympathize with works managers who, after a lifetime's reliance on tried mechanical and electrical aids, were only too ready to seize on early failures as an excuse for purging the production lines of what must have appeared to them to be fragile and unreliable gadgets. Time and the persistence of those with faith in the intrinsic capacity of electronic methods to deal with future demands of speed and complexity in competitive production have now produced instrumentation of a type which can take its place with and, more often than not, supersede older methods.

To any who may yet stand in need of reasoned argument to convince the sceptics of the inherent reliability of electronic apparatus, we commend Dr. Bell's analysis in this issue.

Examples of early difficulties and failures arising either from conservatism or over-enthusiasm are plentiful in the history of the application of radio aids to navigation. We may contrast the reluctance of masters to make full use of early direction-finders with their more recent ready acceptance of radar. To men accustomed to making full use of trained eyes there is no denying the compulsion of a continuous p.p.i. display as compared with a few figures on a slip of paper passed to the bridge from the wireless room. But it is now fully appreciated that appearances can often be as deceptive on a radar screen as they sometimes are in the wider sense when viewing the scene from the wing of the bridge, and that a new and specialized experience is as necessary in interpreting radar information as it was in knowing when and when not to rely on a radio bearing.

We shall never know how many collisions might have occurred, but for the use of radar. It is unfortunate but inevitable that wide publicity is given to those which do occur and which have been somewhat ironically called "radar-assisted."

As far as we know there has never been a case of collision which could be attributed to failure or lack of accuracy in the equipment itself, though it has happened that echoes have been lost in sea clutter or suppressed by maladjustment of the swept gain control. By far the most prevalent cause of error is faulty appreciation of the displayed information, sometimes through lack of knowledge or experience, but more often because there is just not the time to work out the true courses and speeds of the converging vessels after it has become apparent that a dangerous situation has developed.

The conventional radar display gives very accurate readings of distance and relative bearing, but the apparent changes in the course and speed of other ships are often the result of changes in the observer's own course and speed, and must always be read in conjunction with the ship's speed and course. Another difficulty is that at present radar cannot reveal, except at close quarters, the aspect of the other vessel, though it has been suggested that this might be overcome by the use of distinctive port and starboard reflectors. All this is not to say that conventional radar is unreliable or that correct appreciation cannot be made intuitively by experienced officers, but the only really safe way of avoiding error and ambiguity is to keep a running plot of true course and speed not only of one's own vessel but of all other vessels in the immediate vicinity. The technique is described in the textbooks and the practice is well established, but with the best will in the world there is unlikely to be sufficient time or enough navigators to cope with a rapidly developing situation involving a number of ships.

All this has been radically changed by the introduction of a new system of display (described elsewhere in this issue) which enables the true motion of one's own ship and all other vessels to be seen at a glance without plotting or calculation.

There can be little doubt that this is the kind of radar which the sea-going fraternity visualized in its early enthusiasm, and it affords one more example of the ability of electronics engineers to provide new tools for the job whenever the need becomes sufficiently pressing.

Flat Tube for Colour TV

THE idea for a flat television c.r. tube first came to Dr. Denis Gabor, F.R.S., in 1952. Since then he and a small team have been working on it at Imperial College, Kensington, with the financial support of the National Research Development Corporation. A complete and working tube has yet to be produced, but a great deal has been done on the development of the individual parts and the major problems have now been solved. This article, based on a recent Television Society lecture, outlines the principles of the new tube.

REVOLUTIONARY DESIGN AIMED AT SIMPLIFYING MANUFACTURE

THE main interest of the new tube is not only in its flat shape, which allows it to be hung on the wall like a picture or stood on the mantelpiece, but even more in its advantages as a colour tube. It is more complicated than a conventional cone-shaped monochrome television tube, but simpler to make than the known colour tubes and offers an even greater simplification in the associated equipment.

Fig. 1 is a partly sectioned view of the tube. It has the shape of a flat glass box, almost square. The total depth can be made about $3\frac{1}{2}$in for a screen with a 12-in diagonal, and about $4\frac{1}{2}$in for a 21-in screen.

The tube is divided in depth into two halves by a metal tray which carries the whole electron optical system and serves at the same time as a magnetic screen. The electrons start vertically downwards from an electron gun behind this screen which has three independently modulated cathodes, one for each colour, but with a common lens system for handling them. The three beams next pass through an electrostatic line deflection system which, of course, deflects them horizontally, then through two "trimmer" pairs of electrodes which serve for compensating misalignments, and from these into the "reversing lens." This can be considered as a lens with a curved optical axis of very unconventional design, which has four electron-optical functions. It converts the plane "fan" of rays issuing from the line deflector into another plane fan, but with about four times greater divergence. Moreover, it compensates the over-focusing effect which is inseparable from electrostatic deflection to such an extent that the beam remains in perfect focus throughout the whole scanning of a horizontal line, even though the divergence of the beams after leaving the reversing lens may be as much as

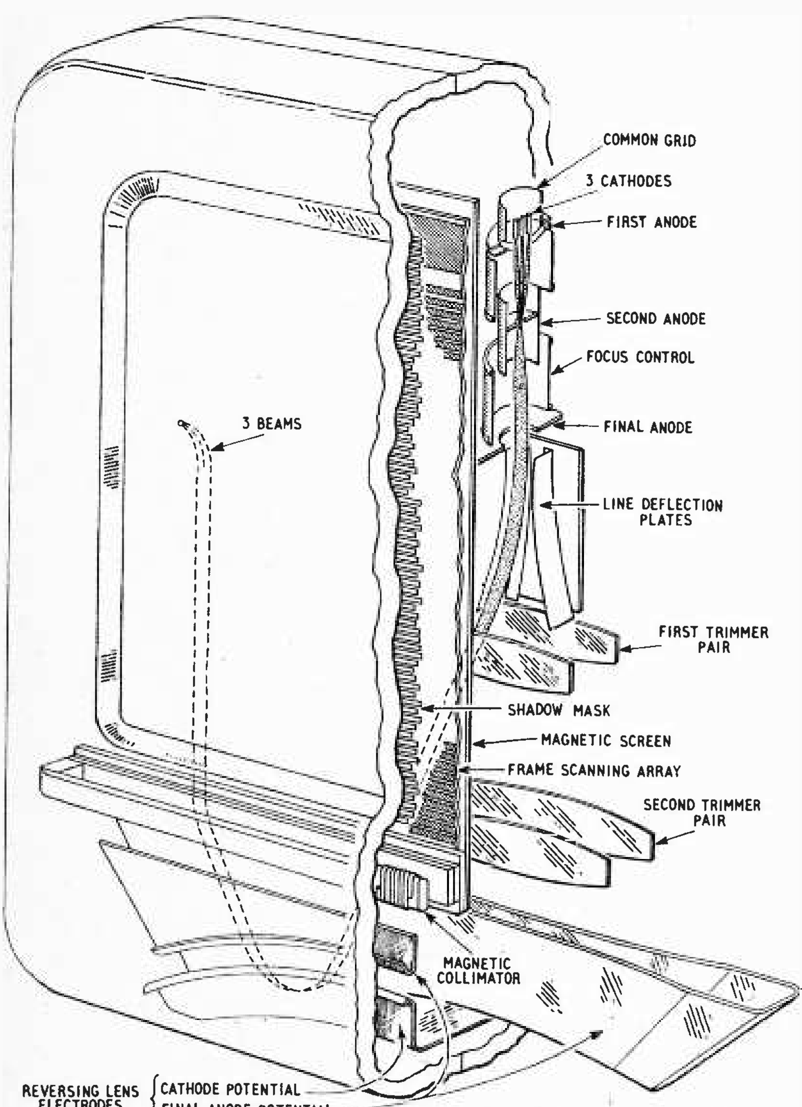


Fig. 1. Cut-away view of the complete tube.

110-120° — an unheard-of large scanning angle in electrostatic tubes.

The beams next pass through a "strong focusing" electromagnetic lens, called a collimator, which bends them back to the vertical so that they perform their scanning motion at the front side like vertical rods. Finally, on reaching a certain level the beams are bent towards the horizontal and fall on the screen.

This final bending and the vertical scanning motion is achieved in an essentially novel way which is illustrated in Fig. 2. In front of the metallic plate which acts as a magnetic screen, and at a distance of about ⅛in from it, there is a component called the frame scanning array. This is a system of parallel conductors printed on a flexible, insulating base. In the plane central part of this insulating foil the array consists of horizontal conducting lines. Their number is rather large, about 120, but it has no direct relation to the line number in the picture. At the two sides, where the base is bent round in two U-shaped loops, the conducting lines are staggered upwards as shown. They are not connected with anything; their charging and discharging is effected by the electron beam itself, as will now be explained.

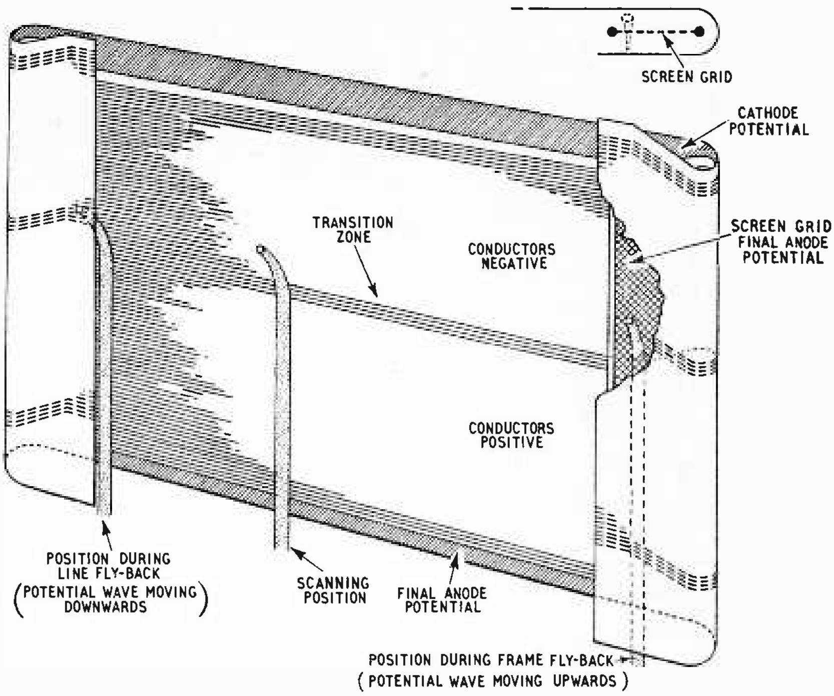


Fig. 2. Principle of operation of the frame scanning array.

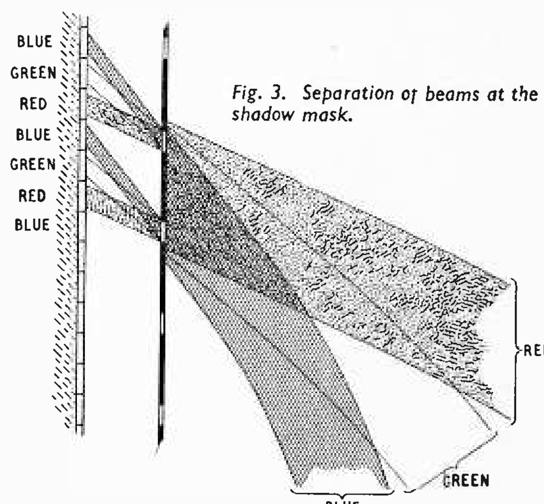


Fig. 3. Separation of beams at the shadow mask.

In operation, a potential wave is made to travel down the scanning array vertically, and the generation of this wave is achieved as follows. Assume, to begin with, that up to a certain level the conductors are charged up to the maximum positive potential. Above this, with a transition zone extending over a few conductors only, they are at about one-quarter of this voltage. When the beam electrons on their upward travel reach the transition zone, they are bent towards the phosphor screen (which is all the time at the maximum positive potential) and are focused at the same time because, as is well known in electron optics, a strong electrostatic deflection of an electron beam always produces a certain amount of focusing.

When the beam has completed a line scan, after a rapid fly-back it rests for a moment (5-6 per cent of the time) in the loop at the left of the array and falls on the conductors in the transition zone. These are partially discharged, thus moving the transition zone a little downwards. The current is so adjusted that this displacement is equal to one line width in the picture. Once started, the transition zone automatically runs down as a wave of potential variation until it reaches the bottom of the picture, leaving all the conductors above it discharged and negative.

The line scan is now stopped so that the beam comes to rest in the bottom of the right-hand loop. This is similar to the other loop, but with the difference that it contains a screen grid, held at maximum positive potential. At the "writing" point of the beams, secondary emission takes place and the flow of electrons to the screen causes the array conductors at this point to charge themselves up to the positive screen potential. As a result of this, and the "staggered" configuration of the array conductors in the loop, the bending-over point of the beams (determined by the electrostatic lens action) is moved slightly upwards so that fresh conductors become charged up. The process continues and the beams travel upwards, successively charging up more and more conductors. The action is, in fact, the reverse of what happens in the left-hand loop of the array. A transition zone is formed by the conductors being charged up from negative (instead of discharged from positive). This moves upwards (instead of downwards) as the lower positive area of the array is made progressively larger (instead of smaller) by successive addition of charged conductors and the upper area of discharged conductors grows correspondingly smaller (instead of bigger). Thus during the frame fly-back interval the beam travels up the loop to the top, and then the cycle is ready to start again.

This self-scanning process, though it unavoidably makes the tube more complicated, simplifies the circuit work as there is no need in the receiver for the usual blocking oscillator or multivibrator running at frame frequency.* The line-scanning generator is still necessary, but it requires far less power than the line generator for conventional television tubes.

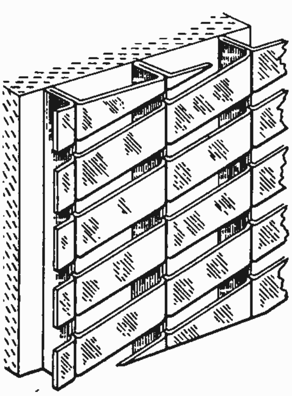


Fig. 4. Magnified section of the shadow-mask.

Fig. 1 shows that the three colour beams, issuing from independently modulated cathodes, merge during most of their course. This is an important feature of the new tube. In the conventional shadow-mask colour tubes the three beams start from three rather widely separated guns, which aim at one point. This requires great accuracy which in fact cannot be achieved without a great number of corrections (at least 9) and the adjustment is easily upset by local magnetic fields. In the new flat tube the three beams stay so closely together that local magnetic fields influence them substantially as if they were a single beam, that is to say, without upsetting the convergence, and their effect (strongly reduced in any case by the effective screening of the central plate) can be easily compensated by the "trimmer" electrodes.

The three colour beams separate only just before the final bend and at the end of this they come together again, but at different angles to the screen. This is the basis of the colour control, which is more clearly shown in Fig. 3. It is based on the shadow-mask principle, but with the important difference that, while in conventional tubes the distance of the shadow-mask from the phosphor screen is of the order of ½in, here it is only about 0.025in. (This is made possible by the large convergence angle of the beams and also partly by their slanting incidence.) Consequently it now becomes possible for the first time to fix the shadow-mask directly on to the phosphor screen and thus avoid all the difficulties which arise in other tubes from the necessity of very accurately aligning two independent, precision-made components.

Fig. 4 shows a suitable design of shadow-mask fixed directly on the screen. A thin metal foil (0.0013in-0.002in thick) is sharply bent in vertical folds so close together as to be invisible to the eye. These folds form ribs for the accurate spacing and fixing of the plane portion which carries a great number of slits, horizontal or slanting (40-60 to the inch). A slanting angle, as shown, is advantageous for the avoidance of moiré effects. The slits are produced by etching, either before or after the mask is fixed on the glass, a "resist" pattern being printed on the metal foil before the folding operation.

The preparation of the phosphor screen, which in present-day colour tubes consists of a long series of delicate processes, is very simple. The three finely ground phosphors corresponding to red, green and blue are dropped vertically from air suspensions through stagnant air on to the tacky surface, at three different inclinations of the screen to the vertical, through the slits of the shadow-mask. This operation would not succeed at the usual distance (½in) of the shadow-mask, but it gives very sharply defined colour strips with a spacing of the order of 0.0025in. One can make the strips 0.005in wide, or even thinner if desired in high-definition television systems.

Two other rather difficult technological problems had to be solved in the development of this tube. One was the preparation of the frame scanning array. A suitable if unconventional insulating support was found in glass fabric coated with a very heat-resisting silicone varnish known as MS 994 (made by Midland Silicones). The difficult problem of producing a printed circuit on this material was brilliantly solved by a new process of the Metropolitan-Vickers Research Department.

Another technological problem of considerable importance was posed by the flat screen. If this were made of ordinary annealed glass it would have to be about one inch thick in a 21in tube, which is prohibitive. The difficulty was solved by a prestressing (toughening) process which increases the apparent tensile strength of the glass by at least a factor of three or four.

The electron-optical development, which took up most of the time and is now nearly completed, has so far been carried out in demountable vacuum tanks. Further work is in progress with the ultimate aim of producing sealed-off tubes.

* A flat television tube in which the frame scan is effected by a travelling electric wave was independently invented by W. Ross Aiken, of the Kaiser Aircraft and Electronics Corporation, of Oaklands, California. In this tube the scanning array has only 7 conductors, and they are energized from the outside by 7 special valves. Kaiser's and the N.R.D.C. have pooled the flat-tube patents in a world-wide agreement.

"Electronic Computers"

THIS new *Wireless World* book is a non-specialist introduction to the principles and applications of electronic computers. It is intended for the reader who has no previous knowledge of the subject but has some familiarity with radio and electronics techniques. The treatment is fairly general in style, giving, in 167 pages, a broad background picture of the whole field of computing from which the reader can pass on to more advanced and specialized studies.

Both analogue and digital machines are covered, and comparisons are drawn between the two types. After tracing the evolution of the computer from the early mechanical devices, the book goes on to the general principles of analogue and digital computation, then continues with chapters on the circuitry, construction and applications of both types. It ends with a frankly speculative discussion of future developments and an appendix on business computer running costs.

Edited by T. E. Ivall, the book is well illustrated by 28 pages of art plates in addition to 40 diagrams. It can be obtained from booksellers, price 25s, or direct from our Publishers at 25s 9d including postage.

"Transistor D.C. Amplifier." In Fig. 6, p. 531 of the November issue the value of P_z should be 500Ω.

WORLD OF WIRELESS

Organizational, Personal and Industrial Notes and News

More Colour Tests

THE third series of colour television tests using a modified version of the American compatible N.T.S.C. system is being conducted by the B.B.C. for the next few months. The test transmissions are being radiated from Crystal Palace on Mondays, Wednesdays and Fridays from 11.10 p.m.

Whereas the earlier tests were mainly concerned with the problems of compatibility, the present series has as one of its main objectives the assessment of quality and acceptability of colour pictures produced by the complete chain of equipment from the studio to the colour receiver. The transmissions originate at Alexandra Palace and are fed by G.P.O. line to Crystal Palace.

Antarctic Radio Research

THE party of 21 which is to make meteorological and radio observations in connection with the International Geophysical Year at the Royal Society Base at Halley Bay (75° 31′ S, 26° 36′ W) left London on Nov. 15th in M.V. *Magga Dan*. They are taking with them a Decca wind-finding radar, an ionospheric sounding recorder and a pulse transmitter.

The ionospheric group will pay particular attention to the variations in activity of the E and D layers, which are of greater intensity and lower height at this latitude, and look for correlations with magnetic and auroral phenomena. Measurements will be made not only of height, absorption and drift of the ionospheric layers but of atmospheric noise in general at frequencies below 500 kc/s. Another group will study radio star scintillation, for which fixed Yagi arrays on 60 Mc/s will be set up to observe both North and South diurnal transits. Results will be compared with simultaneous observations in this country.

The three members of the ionospheric group are W. M. Bellchambers (leader), D. L. M. Cansfield and L. W. Barclay, while P. M. Brenan will be responsible for radio star observations, D. P. Harrison for measurements of meteor and auroral ionization and G. M. Thomas for visual auroral records.

Balance of Trade

A CONSIDERABLE improvement in the balance of trade, so far as the radio industry is concerned, was recorded for the first nine months of this year by comparison with the same period last year. As will be seen from the table, exports increased from £24M to nearly £29M, while imports decreased from £9.8M to £8.2M.

	Exports (£M) Jan.—Sept.		Imports (£M) Jan.—Sept.	
	1956	1955	1956	1955
Capital goods*	12.030	9.692	1.950	1.164
Components	6.114	5.246		
Sound equipment	5.322	4.541	4.281 (Components, Sound equipment and Domestic receivers)	5.944
Domestic receivers	2.754	2.728		
Valves and c.r. tubes ...	2.584	2.068	1.928	2.671
	28.804	24.275	8.159	9.779

*Transmitters, communications equipment, navigational aids, etc.

Component Show

THE continued growth of the annual component show organized by the Radio and Electronic Component Manufacturers' Federation has necessitated holding next year's (the 14th) in two sections. The four-day show (April 8th-11th) will be held in Grosvenor House and Park Lane House, Park Lane, London, W.1. Admission to the exhibition, which is essentially a trade show for those interested professionally in the use of components, will be by ticket obtainable from the secretary, R.E.C.M.F., 21, Tothill Street, Westminster, London, S.W.1.

Christmas Presents

READERS who, like our contributor "Diallist," are incensed by the poor definition of picture so often tolerated by viewers, may like to consider giving a copy of "Improve Your TV Reception" (price 5s) as a Christmas present to a non-technical friend. In the simplest terms it gives the viewer a complete guide on how to get the best out of his receiver.

EXPERIMENTAL tropospheric scatter transmitter installed by Marconi's at Great Bromley, Essex. The 30-ft reflector is energized by a horn mounted on the transmitter vehicle which is moved on an arc of railway track to "steer" the transmitted beam. The working frequency is 858 Mc/s.

It is a companion to the more technical "Correcting Television Picture Faults" (price 3s 6d) by the same authors, John Cura and Leonard Stanley.

The *Wireless World* Diary, which includes 80 pages of technical and general information, also makes an acceptable gift. It costs 6s (leather) and 4s 3d (rexine), including purchase tax. Our publishers also issue books on a wide variety of subjects, both for the professional and amateur.

PERSONALITIES

Sir Gordon Radley, K.C.B., C.B.E., Ph.D., this year's president of the I.E.E., has the distinction of being the first engineer to become director-general of the Post Office. He was engineer-in-chief from 1951 to 1954 having previously been controller of research for some years.

George A. Marriott, B.A., the new president of the British Institution of Radio Engineers, has been with the G.E.C. throughout his professional life and is manager of the valve and electronics department. He is also a director of the M.O. Valve Company. Mr. Marriott, who is 64, has served on the board of the British Radio Valve Manufacturers' Association (B.V.A.) since 1940. In his presidential address he spoke of the development of the transistor and its effect on the demand for valves. Mr. Marriott pointed out that there are many outstanding problems in material construction which affect the cost of production of semi-conductors; on the other hand the basic materials for these cost vastly less than the basic materials of a valve.

G. A. MARRIOTT

Dr. R. C. G. WILLIAMS

R. C. G. Williams, Ph.D., B.Sc.(Eng.), the new chairman of the radio and telecommunication section of the I.E.E., has been chief engineer of Philips Electrical since 1948. He was for fifteen years with Murphy Radio, originally as production manager and chief engineer and subsequently as general manager of the electronics division. On leaving Murphy in 1946 he went to the U.S.A. where he joined N. American Philips Inc. Dr. Williams is vice-president of the International Television Committee (C.I.T.).

G. Millington, M.A., B.Sc., this year's vice-chairman of the I.E.E. radio and telecommunication section, has been with Marconi's since 1931 specializing in theoretical and experimental studies relating to wave propagation. In 1953 he was appointed international vice-chairman of the C.C.I.R. study group investigating problems of ground-wave propagation.

To mark the 50th anniversary of his invention of the triode **Dr. Lee de Forest**, who is now 83, has received the Cross of an Officer of the Legion of Honour from the French Government.

Dr. William Shockley, "father of the transistor," together with two other American scientists, Drs. J. Bardeen and W. H. Brattain, share the 1956 Nobel prize for physics. Dr. Shockley, who was for nearly 20 years with Bell Telephone Laboratories, joined Beckman Instruments, of Fullerton, Calif., a year ago, and is now in charge of the Shockley Semi-conductor Laboratory.

R. Cockburn, C.B., O.B.E. M.Sc., Ph.D., deputy controller of electronics in the Ministry of Supply for the past 18 months, has been appointed controller of guided weapons and electronics. Dr. Cockburn, who is 47, taught physics at Portsmouth and West Ham Municipal Colleges before he joined the radio department at the Royal Aircraft Establishment, Farnborough, in 1937. Two years later he became head of the radio counter-measures division of T.R.E. In 1945 he transferred to atomic energy research, and three years later was appointed scientific adviser to the Air Ministry. He has been with the Ministry of Supply since 1954.

G. H. Metson, Ph.D., M.Sc.(Eng.), A.M.I.E.E., who joined the Post Office as a youth-in-training in 1925 and is now in charge of the thermionics group at the Dollis Hill Research Laboratories, has been promoted to deputy chief scientific officer. Since the war Dr. Metson has led a team developing long-life, high-slope, pentode valves for submerged repeaters and these valves are now in use in the Newfoundland to Nova Scotia section of the transatlantic telephone cable.

W. S. Barrell, B.Sc., who retired from the position of manager of E.M.I. Recording Studios at the end of last year and is now Recording Technical Liaison Officer for the E.M.I. Group, is the first person outside the U.S.A. to be elected an honorary member of the Audio Engineering Society of America. It was conferred "in recognition of his contributions to improvements in disc recording and the equipment used therefor."

G. G. Roberts, M.Sc., who joined Smiths Aircraft Instruments, Ltd., two years ago and was put in charge of the company's new guided weapons programme, has been appointed to the board as director of research. Mr. Roberts, who is 44, graduated at the University of Wales and, after a period of lecturing in London, went to T.R.E. where he was eventually in charge of a group responsible for airborne interception radar. From 1947 until he joined Smiths he was in the guided weapons department of R.A.E., Farnborough.

D. F. Page, who discusses transistor super-regenerative circuitry on page 606, graduated in electrical engineering in 1951 at Queen's University, Kingston, Ontario, Canada. He was then for three years with the Defence Research Board of Canada in the electronics laboratories of the Telecommunications Establishment in Ottawa. In September, 1954, he became a post-graduate student in the electrical engineering department of Imperial College, London, where, since receiving the College Diploma, he has been doing research concerned with transistor circuit applications.

G. W. Short, M.A., assistant press officer at Mullards since 1953, has joined the editorial staff of our sister journal *Wireless Engineer*, which in January becomes *Electronic and Radio Engineer*. After service in Royal Signals from 1944-47 he went to Oxford University where he graduated in 1951 and received his M.A. the following year.

OBITUARY

P. V. Hunter, C.B.E., Hon.M.I.E.E., director of a number of companies including B.I. Callender's Cables, T.C.C. and British Telecommunications Research, Ltd., died on October 22nd at the age of 73. During the first world war, while on the staff of the anti-submarine division of the Admiralty, he helped to evolve the Asdic detector system.

Dr. James Robinson, M.B.E., D.Sc., Ph.D., well known as the designer of the crossed-loop direction-finding system, died on October 21st at the age of 72. From 1906 to 1915 he was a lecturer in physics at various universities, including Durham where he graduated. In 1919 he joined the Royal Aircraft Establishment, Farnborough, where he took charge of the wireless department on its formation. Since 1925 Dr. Robinson had been acting as a consultant. He was vice-president of the Brit. I.R.E. from 1942 to 1947 and represented the Institution on the Parliamentary and Scientific Committee.

T. Wadsworth, M.Sc., M.I E.E., who was for many years, prior to his retirement in 1947, chief assistant to the head of the B.T.H. Research Laboratory at Rugby, died on October 12th while on his way to South Africa. He was 76. Mr. Wadsworth joined B.T.H. in 1924 to take charge of the section responsible for valve and valve circuit developments, prior to which he was head of the electrical engineering department at Coventry Technical College.

G. T. Baker, M.Sc., who was recently appointed a director and research manager (switching) of British Telecommunications Research, Ltd., Taplow, has died at the age of 48. He joined Automatic Telephone & Electric Company (one of the parent companies of B.T.R., Ltd.) in 1929, and on joining the Taplow organization in 1947 took charge of the electronic switching division.

IN BRIEF

Receiving Licences.—During September the number of television licences increased by 95,443, bringing the total to 6,139,773. The number of sound-only receiving licences, including 308,314 for car radio, was 8,257,950 making an overall total of 14,397,773 licences current in the United Kingdom.

I.T.A. Goes West.—Application has been made by the I.T.A. to build its South Wales and West of England transmitter on St. Hilary Down, Glam, a few miles west of Wenvoe, the site of the B.B.C. transmitters. It will operate in channel 10. A new company, to be known as W.W.T., Ltd. (Wales and the West Television), has been appointed to provide the programmes for the station which it is planned to bring into service towards the end of next year,

By making use of temporary equipment in portable buildings the B.B.C. was able to start transmissions from the site of the **Cumberland television station** at Sandale, some 14 miles south-west of Carlisle, on November 5th. The aerial, mounted on a temporary 100ft mast, is some 1,200ft above sea level, and radiates in Channel 4. Transmissions are horizontally polarized.

CLERK MAXWELL, who in 1864 propounded the theory of electro-magnetic waves propagated with the speed of light, was, for a short while (1856-60) professor of natural philosophy in the University of Aberdeen. To mark the centenary of his appointment, a memorial panel, incorporating a bronze portrait bust, was unveiled at Marischal College, Aberdeen, on October 15.

PUBLICATION DATE

Owing to the Christmas holiday our printing schedule has been rearranged and the publication of the next issue of *Wireless World* deferred from December 25th until January 1st.

One or two **research scholarships** for science graduates, valued at £385 per annum, are being presented each year by the B.B.C. The research must be in those fields of telecommunications or physics which have an application to sound or television broadcasting. Only one scholarship has been awarded this year and that was to P. C. J. Hill, from Birmingham University, who will work in the Department of Electrical Engineering at Imperial College under Dr. D. Gabor.

According to the I.T.A. the number of "**Band III homes**" in the London area reached a million during October. A further million are in the areas served by Lichfield and Winter Hill. During October the overall total increased by 204,000—about 7,000 a day. It is estimated that with the opening of the Emley Moor station the total will have almost reached three million (over ten million people) by Christmas.

East Anglia's television station at Tacolneston, near Norwich, is now using its permanent aerial on a new 500ft mast. The mast will also be used to radiate the 3-programme sound service on v.h.f. which it is planned to introduce before the end of the year.

Brit.I.R.E. Council.—As announced elsewhere, G. A. Marriott is the new president of the British Institution of Radio Engineers. Professor Emrys Williams, of the department of electrical engineering, University College, South Wales, is now a vice-president. The other vice-presidents are L. H. Paddle, J. L. Thompson and Professor E. E. Zepler. The new members of the council are Dr. A. D. Booth, director of the Birkbeck College Computational Laboratory, E. M. Eldred, of the Communications Branch of the Home Office, and R. H. Garner, Principal of Coatbridge Technical College, Lanarkshire.

V.H.F. Transistors.—The Technical Information and Documents Unit of the Department of Scientific and Industrial Research is now issuing the "T.I.D.U. News Letter" in which are included brief notes on recent research and development. In the first issue it is reported that a new type of "grown-diffused junction" transistor, produced in the United States by Texas Instruments Inc., is effective in amplification up to 250 Mc/s and can generate frequencies up to 400 Mc/s. They cost $34 in silicon and $20 in germanium.

A course of nine lectures on **High Quality Sound Reproduction** has been arranged by the Manchester College of Science and Technology for Monday evenings beginning January 7th. The organizing lecturer is J. Moir, and other *Wireless World* contributors are among the lecturers. A synopsis of the course, for which the fee is 30s, is available from the registrar. The college is also organizing a two-day course (March 8th and 9th) on Patents for Engineers. (Fee 25s.)

A one-day conference on **Automation, Education and Training** is to be held at the Royal Festival Hall, London, on December 4th, under the auspices of the British Association for Commercial and Industrial Education. Details are obtainable from B.A.C.I.E., 8, Hill Street, London, W.1.

V.L.F. in the Limelight.—For many years the very-low-frequency part of the radio spectrum (below 30 kc/s) has been virtually ignored. But now, new and interesting applications are coming to light, and a V.L.F. Symposium, sponsored jointly by the American Bureau of Standards and a professional group of the Institute of Radio Engineers, is being organized. The Symposium is to be held at the N.B.S. Laboratories at Boulder, Colorado, on January 23rd-25th.

What is believed to be the first **transatlantic television** transmission (since Baird's low-definition experiments in 1928) was achieved on October 25th. We learn from Dr. Lamont, of R.C.A. Great Britain, that a rhombic aerial was used to feed three Ekco 14-in receivers installed at the R.C.A. receiving station at Riverhead, Long Island. The received Channel I picture was re-transmitted from Long Island to the headquarters of the N.B.C. in New York.

An additional amateur band has been announced by the P.M.G. Amateurs may now use, except within 50 miles of the Joderell Bank Observatory, the 200-kc/s band centred on 70.3 Mc/s for both 'phone and morse with a power of 50 watts.

A total attendance of approx. 380,000 was recorded by the **Design Centre** (28, Haymarket, London, S.W.1) during its first six months—a daily average of nearly 2,500. Radio is well represented at the Centre, established by the Council of Industrial Design. Some 25 receivers and radiograms are included in the permanent, but constantly changing, display of "well-designed British durable consumer goods." To ensure the technical efficiency, as opposed to the outward form, of items selected by the Council, each industry has its own assessor.

In the report of the **Institute of Navigation**, presented at the Annual General Meeting on October 16th, it is stated that membership increased by 216 during the year ended June 30th, bringing the total to 1,633.

Radio and the Motorist.—With the introduction of radio-equipped patrol vehicles in the Belfast and Dublin areas, the Automobile Association now has 21 radio control centres in operation, covering an area of 36,000 square miles.

Reliability in Electronics.—The American I.R.E. and the Radio-Electronic-Television Manufacturers' Association are among the sponsors of the third National Symposium on Reliability and Quality Control in Electronics which will be held in Washington from January 14th to 16th.

The twelfth annual **Manchester Electronics Exhibition,** organized by the northern division of the Institution of Electronics, will be held at the College of Science and Technology, from July 11th to 17th next year. The honorary exhibition organizer is W. Birtwistle, 78, Shaw Road, Rochdale, Lancs.

The fourth **British Plastics Exhibition** and Convention will be held in the Grand Hall, Olympia, London, from July 10th to 20th next year. The exhibition, which has previously only included materials, plant and products of the United Kingdom and British Commonwealth, will include exhibits from other countries.

"Certificates and Awards" is the title of a new book published by the Radio Society of Great Britain giving details of amateur operating awards and certificates issued by member societies of the International Amateur Radio Union and other bodies. It costs 2s 6d.

A complete list of **New Zealand amateurs** is included in the June issue of *Break-in.* This issue of our contemporary, which is the official monthly journal of the New Zealand Association of Radio Transmitters, costs 3s 3d.

The centenary of the Morgan Crucible Company, of which Morganite Resistors Limited is a subsidiary, has been marked by the publication of "Battersea Works 1856—1956" in which the history of the company is traced.

The address of **F. R. W. Strafford** (see page 465 of the October issue) is "Woodcot," Mead Court, Waltham Abbey, Essex. (Tel.: Waltham Cross 3216.)

WHAT THEY SAY

Television on Tape.—"Because of the shortcomings of photographic recording systems, considerable work has been done on the development of a method of recording a television picture on magnetic tape . . . very promising results have been achieved, and the B.B.C. hopes shortly to have in use experimental equipment of this type."—Sir Harold Bishop, B.B.C. Director of Engineering.

Means and Ends.—". . . much depends on whether you use a loudspeaker to listen to music, or whether the music is merely a means of listening to a hi-fi loudspeaker."—P. J. Walker, in a lecture to the B.S.R.A.

Minorities.—"V.H.F. radio can narrow the gap between mass communication and the educationists' concern with the individual by permitting the direction of many more programmes to groups with a particular interest without depriving the many of their relaxation."—Sir George Barnes, in *The Times.*

Colour TV Maintenance.—"The very nature of the colour television receiver and its behaviour is reason enough to anticipate an almost continuous demand for service on a monthly, if not a weekly, basis for a long period of time."—*Radio and Television News* (New York).

Radio Interference.—"I personally would like to see it definitely stated on a [G.P.O.] complaint form that unless a good aerial is fitted the complaint will not be accepted."—M. Smith (Post Office Engineering Department) at a Brit.I.R.E. meeting in Manchester.

"**For Sale.**—Radio and television business, established 100 years. . . ." (Advertisement in provincial newspaper.)

BUSINESS NOTES

The Marquis of Exeter, better known as Lord Burghley, announced at the recent annual general meeting of **A.C. Cossor, Limited,** that the group had sustained a net loss of £94,424 during the year ended March 31st against the previous year's £248,157 profit. This is attributed largely to the cancellation of Government contracts which reduced the company's work for the Ministry of Supply to one-third of the volume in the preceding year. To extend the telecommunications interest of the group, Cossor Communications Co., Ltd., has been formed. Henry Chisholm is chairman of the new company, with T. S. Heftman as general manager and technical director.

An Australian company has been formed under the title of Bush Simpson, Ltd., to manufacture, under licence, Bush television receivers in Adelaide. A television test pattern generator, comprising eleven 6ft racks, has been designed and built by **Bush Radio** for installation in the Adelaide factory. It provides a test pattern and sound for each of the ten 7-Mc/s channels (between 49 and 216 Mc/s) to be used in Australia.

The Southern Gas Board's Southampton group is to equip eight of its maintenance vehicles with frequency-modulated radio-telephones. The equipment, which is being supplied by **Automatic Telephone & Electric Co.,** will permit full duplex working.

The **Decca** surveillance radar equipment, which has been in use at Gladstone Dock, Liverpool, since 1948, is to be replaced by the Decca Type 32 harbour radar. The installation will include a 25-ft scanner (giving a 0.3 degree beam, and a 0.05 μsec pulse) and the Decca "Interscan Display System."

A comprehensive public address system linking the head office, main aero engine works and four satellite factories of Rolls-Royce, Limited, Derby, is being installed by **Communication Systems, Limited,** associates of Automatic Telephone & Electric Co., Ltd.

Nine r.f. induction heaters have been supplied by **Redifon** to the U.K. Atomic Energy Authority, at Risley, for purifying corrosive liquids. A feature of the installation is that the generators will be nearly 40ft from the handling plant necessitating the use of unusually long coaxial cables.

Fry's Metal Foundries, Limited, have introduced a high-temperature flux for use with solders having a higher melting point than the normal tin-lead range. Known as Alcho-re soldering fluid Type S64, it can be used without carbonizing at temperatures of 50-100°C above the carbon point of resin fluxes.

Marconi's announce that recent radar contracts amount to approximately £400,000, the bulk for 50-cm crystal-controlled surveillance equipment (Type S232). This equipment, which is in use at London Airport, incorporates a moving target indicator system eliminating permanent echoes.

The name of **Goodmans** Viscount loudspeaker enclosure, which was introduced at the Radio Show, has been renamed the Canberra.

The Leadsman echo-sounder, designed by **Pye Marine, Ltd.,** for use in yachts, fishing vessels and small craft generally, was awarded a gold medal at the California State Fair in San Francisco. It has a depth range of from 3ft to 45 fathoms.

Two gold medals were awarded the **Trix Electrical Company** at the California State Fair for their Trixonic amplifier (800), and A720 table gramophone.

New showrooms and offices of the **Pullin** group of companies were recently opened at Electrin House, 93-97, New Cavendish Street, London, W.1. (Tel.: Langham 4551.)

Victoria Instruments, Ltd., Midland Terrace, Victoria Road, London, N.W.10 (Tel.: Elgar 7871-3), a new member of the Pullin Group, has taken over the control of Victoria Instruments, formerly operated by V.I.C. (Bournemouth), Ltd.

Parmeko's new research laboratory at Grace Road, Leicester, is equipped to carry out general research into all problems relating to transformers, magnetic amplifiers, saturable core reactors and other iron-cored devices.

An extension to Corran Works, Limited, the **Pye** domestic receiver factory in Larne, Northern Ireland, bringing the total area to well over 100,000 square feet, was officially opened on October 15th.

A.W.F. Radio Products, of 5-7, Tatler Chambers, Thornton Road, Bradford, have opened a branch wholesale warehouse at 170, Warwick Road, Kensington, London, W.14 (Tel.: Western 5201).

The Belfast offices of the **Marconi Marine Company** are now at Marconi House, 2, Corporation Square. (Tel.: Belfast 22250.)

Collins Electric Company, of Deramore Avenue, Belfast (Tel.: Belfast 42001) have been appointed sales and service agents for **Truvox** tape recorders and tape recording components and accessories.

Kolster-Brandes have opened a new depot at 41, Bent Street, Cheetham, Manchester. (Tel.: Blackfriars 3939.)

A Baird 30-line television receiver is a museum piece in the showrooms of **Cussins and Light, Ltd.,** of York, who are celebrating 35 years in radio by opening a new service department. Dr. W. D. Cussins, who was formerly with E.M.I., will be in charge of the service department.

A comparator unit, enabling prospective purchasers of amplifiers, pickups and loudspeakers to hear readily a variety of equipment, is being installed in the new audio showroom opened by **Camera and Cine Centre,** 14, Long Causeway, Peterborough.

OVERSEAS TRADE

Aerials.—Antiference announce that in a recent survey of receiving aerials sold in Denmark well over 50 per cent were manufactured by this company.

A report on the market for **sound and television receivers** in Luxembourg has been prepared by the Export Services Branch of the Board of Trade from information received from the British Embassy in Luxembourg.

Communications Equipment.—In addition to the £500,000 order for equipment for the Iranian police mentioned last month, Redifon, Limited, have been awarded a £100,000 contract for a radio network for the country's customs department. When the installation is completed key customs posts along Iran's frontiers and coastline will be in radio communication with the headquarters in Tehran.

Echo Sounders.—Fifteen trawlers being built at Lowestoft for the Soviet Union are to be equipped with the Pye Fishfinder.

Fixed and mobile **communications equipment,** to the value of £170,000, has been ordered by Pakistan from Cossors.

A Pye "Continental" **car-radio receiver,** which is designed for long-range reception, has been adapted for 24-volt operation for use in the Vickers Varsity aircraft converted for the personal use of King Hussein of Jordan.

Closed-circuit **industrial television** equipment linking the chief office of the English, Scottish and Australian Bank and a branch office (both in Melbourne) with the Ledger Posting Centre in another part of the city, has been installed by Pye. This system, which was installed experimentally at the Glyn Mills & Co.'s bank in London a few years ago, enables either the head office or the branch to have immediate access to details of accounts at the central accounting office.

CLUB NEWS

Acton, Brentford, and Chiswick.—Members of the Acton, Brentford, and Chiswick Radio Club are holding a surplus equipment sale at the meeting on December 18th. The club meets at 66, High Road, Chiswick, on the third Tuesday in each month. Sec.: W. G. Dyer (G3GEM), 188, Gunnersbury Avenue, Acton, London, W.3.

Barnsley.—At the meeting on December 14th of the Barnsley and District Amateur Radio Club, W. Williams will speak on "Scopes and wobbulators." Fortnightly meetings are held at 7.0 at the King George Hotel, Peel Street. Sec.: P. Carbutt (G2AFV), 33 Woodstock Road, Barnsley.

Birmingham.—S. R. Kharbanda will talk about the Labgear LG300 transmitter to members of the Slade Radio Society on December 7th. Meetings are held on alternate Fridays at 7.45 at the Church House, High Street, Erdington. Sec.: C. N. Smart, 110 Woolmore Road, Erdington, Birmingham, 23.

Bradford.—"Mobile working" is the title of the talk by F. E. Lancaster (G3BJP) to be given at the meeting of the Bradford Amateur Radio Society at 7.30 on December 18th at Cambridge House, 66 Little Horton Lane. Sec.: F. J. Davies (G3KSS), 39 Pullan Avenue, Eccleshill, Bradford, 2.

Coventry.—Meetings of the Coventry Amateur Radio Society are held each Monday at 7.30 at the club's headquarters, 9 Queen's Road. Sec.: N. J. Bond (G3IHX), 12 William Bree Road, Coventry.

Sidcup.—"Natural sound in the home" is the title of the demonstration-talk being given by L. Clinch at the meeting of the Cray Valley Radio Club on November 27th. Monthly meetings are held at 8.0 at the Station Hotel, Sidcup. Sec.: S. W. Coursey (G3JJC), 49 Dulverton Road, New Eltham, London, S.E.9.

Wellingborough.—At the meeting of the Wellingborough and District Radio and Television Society at 7.30 on December 13th at the Silver Street Club Room, R. M. Tilley (G3KSC) will give a general survey of amateur radio. Sec.: P. E. B. Butler, 84 Wellingborough Road, Rushden, Northants.

F.M. Multi-Path Distortion

Its Influence on the Design of Receivers and Aerials

By M. G. SCROGGIE, B.Sc., M.I.E.E.

THE object of the v.h.f. frequency-modulation service of the B.B.C.* is to provide better reception of sound broadcast programmes. One improvement—the most important, freedom from adjacent-channel interference—is obtained by leaving the overcrowded medium-frequency band for the v.h.f. Band II (87.5–100 Mc/s) with its wide inter-channel spacing and limited transmission range. A benefit consequent on this is that the wider r.f. channel permits wider audio-frequency acceptance at the receiver and hence higher fidelity. Another improvement—freedom from noise and common-channel interference—is obtained by the use of f.m. instead of a.m. It would be a pity if, having achieved a silent background and wide-band reproduction, the programmes were to be marred by serious distortion; yet that, in certain circumstances, is what is liable to happen. So as not to spread alarm and despondency at the very outset, however, it should be emphasized that (a) these circumstances are exceptional, and (b) where they exist their troublesome consequences can be rendered almost if not entirely unnoticeable. But it is desirable that the nature of this trouble should be well known, as otherwise it might cause considerable perplexity and frustration.

Its audible effects are likely to suggest that there is something loose somewhere, probably in the loudspeaker. In mild cases even a critical listener might notice no more than an occasional slight jarring; but in severe cases the distortion is quite intolerable—enough to make one wonder whether the loudspeaker cone has come adrift at the centre or grid bias has entirely gone from the output stage. The fact that some programmes may be badly affected and others not noticeably might at first prompt one to write an indignant letter to the B.B.C. Further experience would show that piano music is badly affected, orchestral music much less so, and speech hardly at all except in very severe cases. Turning down the volume does not, as one usually hopes with obvious non-linearity, reduce the proportion of distortion—a fact that may revive suspicions of the B.B.C. But comparison with someone else's reception may show that the same programme is perfectly clear with them—which lets the B.B.C. out and brings one's own set once more under suspicion.

The true cause, however, lies in the space between; the condition known as multi-path reception. With television it gives rise to "ghosts"—duplicate images displaced to the right on the screen. The fact that these are due to signals that have come by reflection over longer paths and have thereby been delayed is easy to relate to the observed results, but how such conditions would affect reception of f.m. sound programmes is less obvious.

Amplitude Modulation

Fig. 1 indicates the kind of situation in which multi-path reception can occur. For reasons that will appear, distortion is most likely to be severe when the path length difference is of the order of 5–15 miles. On some receivers it can be bad at 5 miles, if the delayed reception is as much as 10% of the direct ray; at 10 or 15 miles a much smaller relative signal strength can be troublesome. And while it is unlikely that a signal received over so much longer a path would be comparable in strength with the direct reception, it may be important if (as suggested in Fig. 1) the direct signal is attenuated by intervening ground or other obstruction.

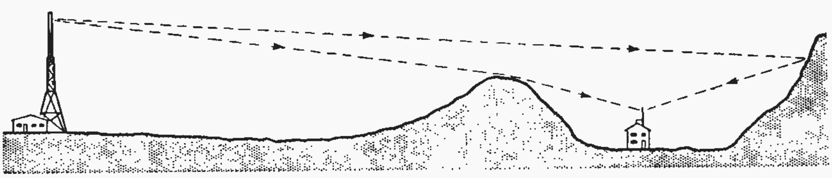


Fig. 1. Typical situation in which reception of a v.h.f. signal can occur via two paths simultaneously. The effect of the reflected signal is especially significant when, as shown here, direct reception is weakened by an obstruction.

Let us first consider the effect of a delayed signal when the carrier wave is unmodulated. The total signal received is the sum of the direct and delayed signals, which can conveniently be represented in magnitude and phase by the usual vector notation. In Fig. 2, OA represents the direct signal and AB a delayed signal of one quarter its voltage. The total signal voltage is represented in each diagram by the vector OB. At (a) the path difference is zero; at (b), quarter of a wavelength; at (c), half a wavelength; at (d), three-quarters: then (a) also represents one wavelength; and so on, indefinitely. Variations in path difference cause both voltage and phase of the total signal to vary, relative to the direct signal alone.

The cyclic variations in signal voltage as the path difference is increased are shown in Fig. 3 for two different signal frequencies. The wavelike curves are not sinusoidal, as might at first be supposed; the difference between them and a sine wave is most marked if the two signals are equal in strength, when the difference between the lengths of OA and OB in Fig. 2(b) and (d) is greatest (short of AB being greater than OA, when it would rank as the main signal) and becomes small when the signals are very unequal. At the frequencies illustrated, a change in path difference of as little as

*Described in a paper entitled "The B.B.C. Sound Broadcasting Service on Very-High Frequencies" by E. W. Hayes, M.I.E.E., and H. Page, M.Sc., M.I.E.E., which is to be read before the Radio and Telecommunication Section of the Institution of Electrical Engineers on 12th December, 1956.

1½ metres (5ft) is sufficient to bring the signal strength from a maximum to a minimum or *vice versa*. Quite large variations can be observed by measuring the signal strength in a receiver (before the limiter!) while moving its aerial about the room, where there are often strong reflections from such objects as metal curtain rods. In fact, it is sometimes possible to find positions where the signal is almost entirely cancelled out. These short path differences do not themselves cause the kind of distortion being considered, but indirectly may greatly influence it.

Fig. 3 also shows that when there is multi-path reception the net signal strength depends on signal frequency. With a path distance of only 15 metres, a change of frequency from, say, 90 to 100 Mc/s is needed to cause the maximum change of signal voltage. The longer the path difference, the smaller the change of frequency needed. It is shown in Appendix I that the frequency difference causing a change in total phase difference of half a cycle (and therefore sufficient to cause maximum change of total signal voltage) over a path difference of D miles is

$$f_{\frac{1}{2}} = \pm \frac{93,625}{D} \text{ c/s}$$

With a path difference of several miles the comparatively small frequency changes due to frequency modulation are sufficient to cause maximum signal fluctuations. In Fig. 4, signal voltage is plotted against change of signal frequency for path differences of 2 and 10 miles, assuming a 4 : 1 direct/delayed signal-strength ratio as in Figs. 2 and 3. Note that these curves are independent of initial signal frequency (i.e., carrier frequency). It has been arbitrarily assumed that the carrier frequency corresponds to an exact whole number of wavelengths over the path difference in each case, thus making the signal a maximum at zero on the frequency-change scale, but of course in practice it would be a matter of chance; the full change from maximum to minimum could be obtained by moving the aerial a few feet.

It is clear, then, that where multi-path reception occurs the signal reaching the receiver is not only frequency modulated but also amplitude modulated, the depth of a.m. depending on the ratio of delayed to direct signal strength. In Fig. 4 for example, it is 25%. The frequency of the a.m. is determined by the rate at which successive maxima and minima are encountered while the frequency of the radiated signal is being swung to and fro by f.m., and this depends not only on the f.m. modulating frequency (a.f.) but also—as Fig. 4 shows—on the path difference. We will go into the relationship between the spurious a.m. frequency and the legitimate f.m. frequency later, but first let us consider more generally the effect of this a.m. on reception.

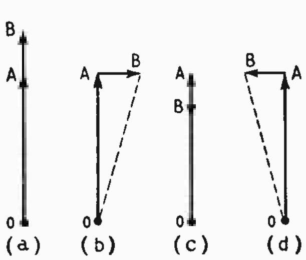


Fig. 2. Four successive phase relationships between the directly-received signal, represented by the vector OA, and the delayed signal, AB. The total signal reaching the receiver is represented by OB.

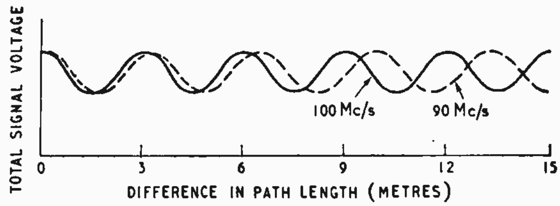


Fig. 3. The cyclic variations in the length of OB in Fig. 2 are here plotted against path difference for two different signal frequencies.

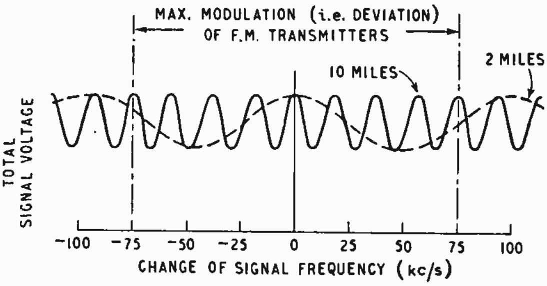


Fig. 4. The variations in total signal with frequency, shown for two frequencies in Fig. 3, are here plotted continuously against frequency, for two much longer path differences.

In a perfect receiver it should have no effect, for one of the functions performed in a f.m. receiver is the removal of any residual a.m. by signal-limiting. The only exception would be if, by extraordinarily bad luck, the signal received by the delayed path was equal in strength to that received direct, which would result in the total signal being periodically reduced to zero during each cycle of frequency modulation—a circumstance that could not fail to cause very serious distortion. Even a perfect f.m. receiver would reasonably regard the creation (at the right moments) of a signal it did not receive as being outside the scope of its duties. In receivers with less than perfect limiting, the occurrence of multi-path reception in any degree is bound to superimpose a certain amount of modulation at a frequency or frequencies different from those of the programme and thereby to cause distortion.

Remedies

The electrical magnitude of such distortion is obviously proportional to two factors: the ratio of the weaker to the stronger signal arriving, and the proportion of a.m. that the limiter fails to remove. These point to the two lines of attack against multi-path distortion. One can seek to reduce the signal ratio, or to improve the receiver limiting, or preferably both.

The second of these concerns the design of the receiver. At the present time most f.m. broadcast receivers on the market use a ratio discriminator. One of the main advantages of this type of discriminator—from the commercial point of view—is its inherent limiting property, which in normal circumstances enables a preceding limiter stage to be omitted. But in the abnormal circumstances now being considered its limiting is insufficient. Experiments carried out by the B.B.C. show that as little as 5% signal delayed by 10 miles can cause very unpleasant distortion in a typical broadcast receiver, although the reduction of a.m. averaged over the modulation band is of the order of 20 dB. Where a Foster-Seeley discriminator is used a preceding limiter is necessary, and it appears that this combination is usually rather better than the ratio detector, giving about 26 dB reduction. Nevertheless it is hardly sufficient, and a better system—and one which ought not to be impracticable in commercial receivers—is a ratio detector supplemented by a limiter stage. To ensure a high standard of reception in bad multi-path situations, a Foster-Seeley discriminator with two limiter stages may be required.

Listeners who are in multi-path situations must therefore choose their receiver with care, and it is to be hoped that manufacturers will give greater attention to their needs. Listeners who already have a receiver that is not good enough for their situation may ask what they can do about it. The answer is to consider the aerial.

Most broadcast receivers are fitted with some kind of internal aerial which, aided by the noise-and-

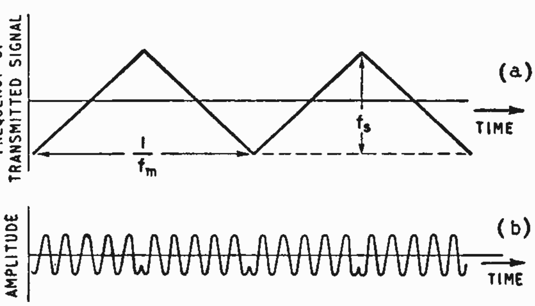


Fig. 5. Triangular low-frequency f.m. waveform (a), with constant rate of change of frequency, gives a constant (but not usually coherent) frequency of a.m. in the total received signal (b).

interference-suppressing capabilities of f.m., may be all very well in favourable situations where there is a strong direct signal. But so far from being any help in a multi-path situation it is likely to make the worst of it. In the first place, owing both to its low position and its inefficient size, shape and surroundings, its pick-up is relatively small, so at the minimum amplitude phases the signal may be brought below the level required for efficient limiting. Then if by chance the most suitable position for the receiver happens to put the aerial where the direct signal is partly cancelled out by local reflections, and the delayed signal is perhaps even reinforced by these reflections, the ratio can be greatly worsened as compared with the free-space figure.

A separate indoor aerial likewise may suffer from screening and local reflections, but at least there is more freedom as regards its design, siting and orientation.

However, where real trouble is being experienced with multi-path distortion it would be advisable to make use of an aerial with directional properties to discriminate in favour of the direct signal and against delayed signals. In a situation such as Fig. 1, for example, an aerial with a cardioid polar diagram giving a good minimum behind to cut out the reflected ray would be an obvious choice. Where the trouble is due partly to a weak direct signal, the aerial should be raised and situated outdoors; for instance, at roof level on the side of the house away from the reflected radiation. If an indoor aerial has to be used, it should preferably be high up and with the minimum of obstruction between it and the transmitter.

To sum up, then: if f.m. reception is distorted in a manner that agrees with the description, and it cannot be accounted for in any other way, the possibility of multi-path reception may well be suspected; and if improvement of limiting in the receiver is impracticable or insufficient to clear the trouble, the design and siting of the aerial should be given careful consideration.

Phase Modulation

Fig. 2 shows that multi-path reception causes not only undesired amplitude modulation of the received signal but also phase modulation. This aspect of the subject was treated in a recent issue by L. W. Johnson*, but apparently under conditions which permitted the assumption that the frequency of this modulation would for the most part be ultrasonic. In the circumstances considered here, with a relatively small indirect signal carrying the same programme over a distance greater by at least several miles, this would not be so. The phase modulation would have the same frequency as the amplitude modulation. Improvement of limiting would not avail against it, but any aerial modifications that reduced the indirect/direct ratio would. The experimental fact that improvement in limiting in typical receivers is sufficient to reduce severe distortion to imperceptibility leads one to conclude that under the conditions considered here the distortion is due predominantly to amplitude modulation.

And now in closing we may care to return to the question of the frequency of the a.f. components introduced by multi-path amplitude modulation, because that has an important bearing on the subjective assessment of the distortion; in other words, on how bad it sounds.

First let us assume that the carrier wave is frequency-modulated at such a low frequency (f_m) that the time delay via the longer path can by comparison with its cycles be neglected. For example, at 4⅝ miles path difference the time delay is 1/40,000 sec, which at $f_m = 1{,}000$ c/s is only one fortieth of a cycle of modulation. Let us also assume that the modulation waveform is triangular as shown in Fig. 5(a), so that the rate of change of carrier frequency (without regard for sign) is constant. Let f_s denote the frequency swing as defined in the diagram. Then the total frequency change during one cycle of modulation is $2f_s$. As shown in Appendix 1, the number of cycles of amplitude modulation caused thereby is $2f_s$ D/187,250, where D is the path difference in miles; and as these occur in $1/f_m$ sec, the frequency of amplitude modulation is

$$f_{am} = \frac{f_m f_s \text{D c/s}}{93{,}625}$$

The maximum value of f_s for the standard deviation of ± 75 kc/s is 150 kc/s; at full frequency modulation the frequency of a.m. is therefore

$$1.60 f_m \text{D c/s.}$$

*"F.M. Receiver Design," *Wireless World*, October 1956, p. 497.

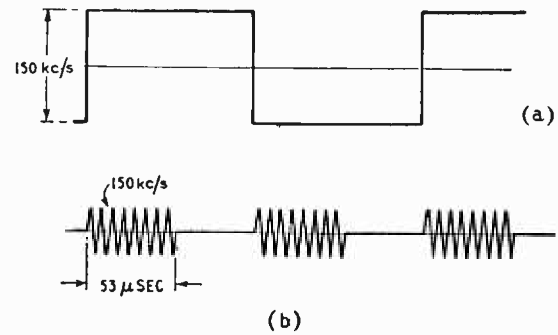


Fig. 6. When the rate of change of frequency is infinite, as in a perfect square wave (a), the time delay of the path difference causes the a.m. to have a maximum finite frequency, equal to the total frequency swing of the f.m. (b). Its duration is equal to the time delay.

It will be noticed that in general this is not an exact multiple of the modulation frequency, so the cycles would not, except by luck, be coherent; for example, if the swing were ± 50 kc/s (i.e., $f_s =$ 100 kc/s) and the path difference 10 miles, Fig. 4 shows that the a.m. waveform would be as in Fig. 5(b). Averaged over a number of f_m cycles, distortion at the frequency of the individual cycles shown in this diagram would tend to cancel out, and the distortion components would spread over a wide band of frequencies, comprising mainly high harmonics of f_m.

Since the frequency of the a.m. is proportional to rate of change of carrier frequency, it follows that with a sinusoidal modulation waveform the frequency of the a.m. is itself modulated cosinusoidally, as shown in detail in Appendix 2, yielding a complex band of frequencies. This being so, it is not surprising that very small percentages of distortion—according to the B.B.C. tests, less than 1%—can not only be detected but sound very unpleasant. It will be remembered that minute percentages of high-order harmonics are far more objectionable than much larger percentages of low-order even harmonics, which are concordant; and in general the same applies to intermodulation.

If the frequency-modulation depth is very low, or the path difference less than a mile, the total signal is swept over only about one amplitude cycle or less per cycle of f.m., so the main component of a.m. has the same frequency as the f.m., and distortion is not noticeable even though the percentage of delayed signal may be quite large. Subjective distortion increases more rapidly than path difference, other things being equal; so that, for example, 5% delayed signal at 10 miles is rather worse than 10% at 5 miles.

Since the most unpleasant distortion occurs when

APPENDIX 1.

Elementary derivation of relationship between a constant frequency displacement f c/s and the resulting phase displacement ϕ cycles over a time delay T secs caused by a path difference D miles.

Since a frequency change f is the number of cycles phase change per sec, the phase change in time T is fT cycles; i.e.,

$$\phi = fT$$

Because the velocity of the signal is 187,250 miles per sec,

$$T = \frac{D}{187{,}250} \text{ secs}$$

$$\therefore \phi = \frac{fD}{187{,}250} \text{ cycles}$$

Maximum amplitude change of total signal results from a phase change of half a cycle; i.e., $\phi = \pm\frac{1}{2}$. Call the corresponding frequency change $f_{\frac{1}{2}}$. Then

$$f_{\frac{1}{2}} = \pm\frac{187{,}250}{2D} = \pm\frac{93{,}625}{D} \text{ c/s}$$

APPENDIX 2.

Frequency of amplitude modulation due to multi-path reception.

Let the frequency displacement of the direct signal (f_1) be a function of time:

$$f_1 = F(t)$$

Then the frequency displacement of the signal delayed by T secs is

$$f_2 = F(t-T)$$

The fundamental frequency of amplitude modulation due to summation of the two signals is

$$f_{am} = f_1 - f_2 = F(t) - F(t-T)$$

E.g. 1 Constant rate of change of frequency. Let $f_1 = at$

$$\text{Then } f_{am} = at - a(t-T) = aT$$

E.g. 2 Sinusoidal frequency modulation. Let $f_1 = f_d \sin \omega_m t$, where f_d is the peak frequency displacement and $\omega_m = 2\pi \times$ modulation frequency.

$$\text{Then } f_{am} = f_d \sin \omega_m t - f_d \sin \omega_m (t-T)$$

$$= f_d[\sin \omega_m t(1 - \cos \omega_m T) + \sin \omega_m T \cos \omega_m t]$$

$$= f_d\left(2 \sin \omega_m t \sin^2\frac{\omega_m T}{2} + 2 \sin\frac{\omega_m T}{2} \cos\frac{\omega_m T}{2} \cos \omega_m t\right)$$

$$= 2f_d \sin\frac{\omega_m T}{2}\left(\sin \omega_m t \sin\frac{\omega_m T}{2} + \cos \omega_m t \cos\frac{\omega_m T}{2}\right)$$

$$= 2f_d \sin\frac{\omega_m T}{2} \cos \omega_m \left(t - \frac{T}{2}\right)$$

i.e., the frequency of amplitude modulation varies cosinusoidally, with a maximum equal to $2f_d \sin\frac{\omega_m T}{2}$.

Take for example a 1,000 c/s tuning note ($\omega_m =$ 6,283) frequency-modulating the carrier to the extent of ±30 kc/s. Then a time delay of 50μsec would cause the input to the receiver to be also amplitude-modulated at a frequency sweeping 2,000 times per second from 0 to $2 \times 30{,}000 \sin\frac{6{,}283 \times 50}{2 \times 10^6} =$ 9,400 c/s and back.

the frequencies of the distortion products are relatively high, it is perhaps hardly surprising that a very striking improvement can be obtained by using tone control to cut top frequencies. But in doing so one sacrifices the chief advantage of v.h.f. broadcasting. Conversely, the ability of "hi fi" to reveal distortion in all its horror was never more true than of this particular variety.

As the modulation frequency is raised, the indirect path delay prevents the distortion frequency from rising in proportion, so that in the limit, with infinitely high rate of change of carrier frequency—square-wave f.m.—the distortion frequency reaches a maximum equal to the frequency swing. Thus if, for example, the full deviation of ± 75 kc/s were used and the path difference were 10 miles, the result would be as shown in Fig. 6; this distortion, being above the audible limit, would be innocuous, provided that the bandwidth of the receiver was sufficient to cover it, for the reasons given by Johnson in the article already mentioned.

The courtesy of the B.B.C. in providing information and demonstrations, and in making some helpful criticisms of this article, is gratefully acknowledged.

DESIGN FOR A CAR RADIO

Circuit Details of a Home-Constructed Receiver

By S. W. AMOS,* B.Sc., A.M.I.E.E.

ALTHOUGH there are many excellent car radio receivers on the market today the author decided it would be an interesting experiment to construct one to his own design. Users do not often attempt to construct receivers of this type and the following description of the circuit used and the difficulties encountered may prove helpful in view of the scarcity of published information on the subject.

The complete equipment comprised four separate items, namely:

(a) the receiver proper which was mounted in one of the glove lockers,

(b) the h.t. unit, a motor-generator, which was bolted underneath the parcel shelf,

(c) the loudspeaker, a thin wafer type, which was mounted in the roof above the centre of the windscreen,

(d) the aerial, a vertical telescopic type, mounted on one side of the bonnet near the windscreen.

No useful purpose would be served in giving full constructional details of the set because it was "tailor made" to fit a particular make of car and is unlikely to be suitable for other models.

The article, therefore, is devoted to details of the

* B.B.C. Engineering Training Department.

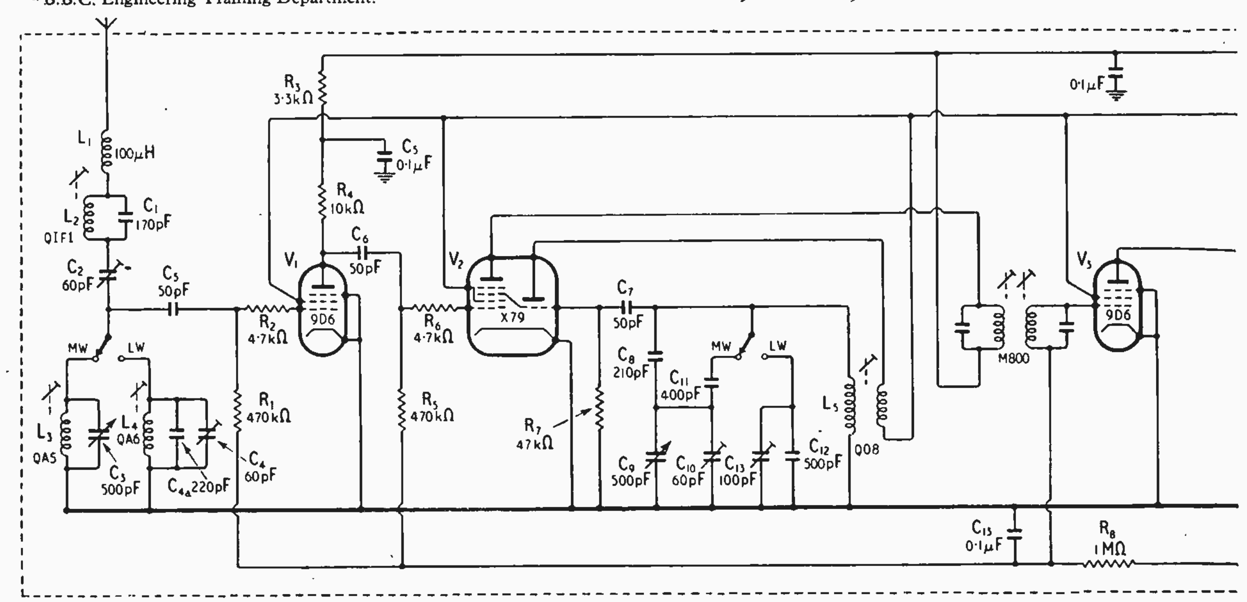


Fig. 1. Theoretical circuit of the receiver. Coils L_2, L_3, L_4 and L_5 are Osmor and the i.f. transformers are Wearite. If the set is fitted in a car with the negative of the battery to frame the filter capacitors C_{23}, C_{24}, C_{25} and C_{26} must be reversed and the −12V line becomes the +12V line

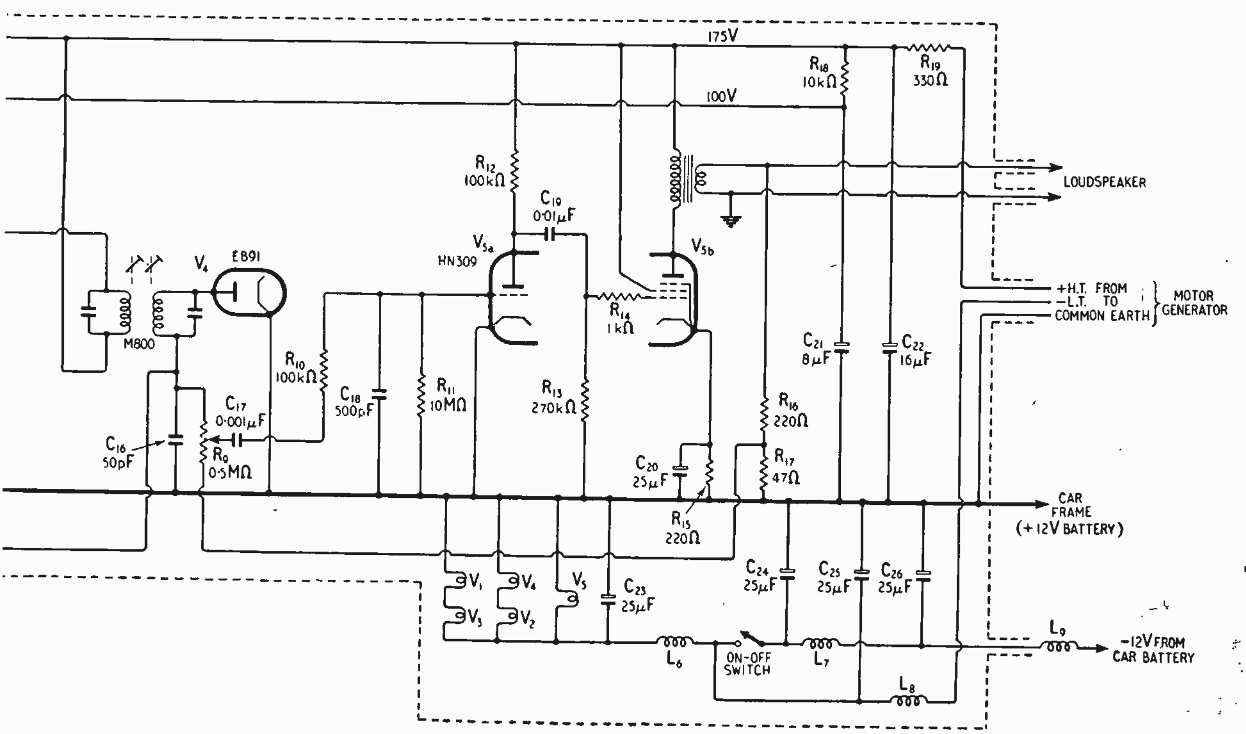
circuit, emphasis being laid on those aspects in which it differs from that of a domestic receiver.

The circuit diagram is given in Fig. 1; it is based on that of the mains-driven superheterodyne receiver described by the author in *Wireless World* for August 1956 but, because of the limited efficiency of the car aerial as a collector, more gain was considered desirable and an r.f. stage was added. A variable-mu pentode was used, its control grid being returned to the a.g.c. line to give a total of three a.g.c.-controlled stages. The very efficient a.g.c. so obtained is needed to offset the extremely wide variations in signal strength which can occur when the car is moving. To make full use of the r.f. stage, the anode circuit should be tuned by one section of the tuning capacitor but this necessitates a bulky three-gang capacitor and complicates waveband switching. The receiver had to occupy a volume not exceeding 7in by 5in by 3in and the r.f. anode circuit was made aperiodic so that a miniature two-gang capacitor could be used, one section tuning the aerial circuit and the other the oscillator circuit.

The aperiodic coupling limits the gain of the r.f. stage, but a stage gain of 20 can be achieved. As a further aid to economy in space, the HN309 triode-pentode valve was used; this valve stands only 2in above the chassis yet incorporates a triode section with a μ of 70 (used as 1st a.f. amplifier) and a pentode delivering 2 watts output. Moreover, it has a 12-volt heater which makes it ideal for use in a receiver such as this which operates from a 12-volt car battery. There was insufficient space for a 0.1-μF coupling capacitor in the grid circuit of the output stage and a miniature 0.01-μF component (C_{19}) was used instead. This has negligible effect on the audible frequency response, but it causes low-frequency oscillation if the whole of the secondary voltage of the output transformer is used for negative-feedback purposes as in the a.c. mains superhet. To obtain stability it was necessary to introduce the fixed potential divider R_{16} R_{17}. Nevertheless at normal settings of the gain control there is considerable negative feedback and harmonic distortion is very low.

Long-wave Provision

To receive the Light programme a long-wave range is virtually essential. The areas in which this programme can be well received on medium waves are limited whereas the long-wave transmission on 200 kc/s can be well received almost anywhere in England. There are few other signals on the long waveband and it was decided to make the receiver pre-set to 200 kc/s on this band. This simplifies design by eliminating the need for a long-wave oscillator coil; the medium-wave oscillator coil will readily oscillate at the required frequency (665 kc/s) if the waveband switch is arranged to add the necessary extra capacitance. Experiment showed that the heterodyne voltage generated at the oscillator grid was 10 volts peak (equal to the medium-wave value) in spite of the lower LC ratio on long waves. It was found, however, that a fine tuning control, capable of tuning the receiver over a limited range of, say, 10 or 20 kc/s, was desirable. This was achieved as shown in the circuit diagram. On medium waves C_8 (210 pF) and C_{11} (400 pF) are connected in parallel to give a padding capacitance of 610 pF in series with the tuning capacitor C_9. As explained in the August issue this is the value required for accurate tracking on the medium waveband. On long waves C_{11} is removed from the circuit leaving only C_8 (210 pF) in series with the tuning capacitor; at the same time a fixed capacitor of approximately 570 pF (C_{12} + C_{13}) is connected across the oscillator inductance. Because of the diluting effect of C_8 and C_{12} + C_{13} the tuning range



on long waves is only approximately 190 to 210 kc/s.

Because of the limited pickup of the car aerial, the coupling to the first tuned circuit must be tight and in this receiver the aerial is connected to the "top end" of the first LC circuit *via* a series capacitor C_2. For good voltage transfer this capacitance should be large but it must not exceed a certain value, otherwise it is impossible to tune the first LC circuit to the high-frequency end of the medium waveband. Moreover, if a trimmer is connected across this tuned circuit, to permit alignment with the oscillator circuit, it still further reduces the permissible value of C_2 and thus the voltage transfer of the aerial-coupling circuit. To obtain maximum voltage transfer a variable capacitor is used for C_2 and the first tuned circuit is aligned with the oscillator circuit by adjustment of C_2. Thus C_2 combines the functions of coupling and trimming capacitance; this arrangement is quite satisfactory provided C_2 is adjusted by a non-conductive tool during alignment of the receiver. Both plates of C_2 are at r.f. potential and, if alignment is carried out with a metallic screw-driver, the further capacitance added to the circuit during adjustment masks the optimum setting of C_2.

On long waves the tuning capacitor C_3, and the inductor L_3, are both removed from circuit and replaced by the inductor L_4 of approximately 2·3 mH which is tuned to 200 kc/s by adjustment of C_4.

One consequence of using an aperiodic r.f. stage is that there is very little protection against break in of signals on or near the intermediate frequency. Any such signals picked up by the aerial are amplified in the r.f. stage and enter the i.f. amplifier to cause interference. The only protection against such interference occurs in V_1 grid circuit and this is inadequate particularly if the receiver is tuned to the low-frequency end of the medium waveband, or to the long-wave station. The wavetrap, L_2 C_1, in the aerial circuit is included to add further attenuation of i.f. signals.

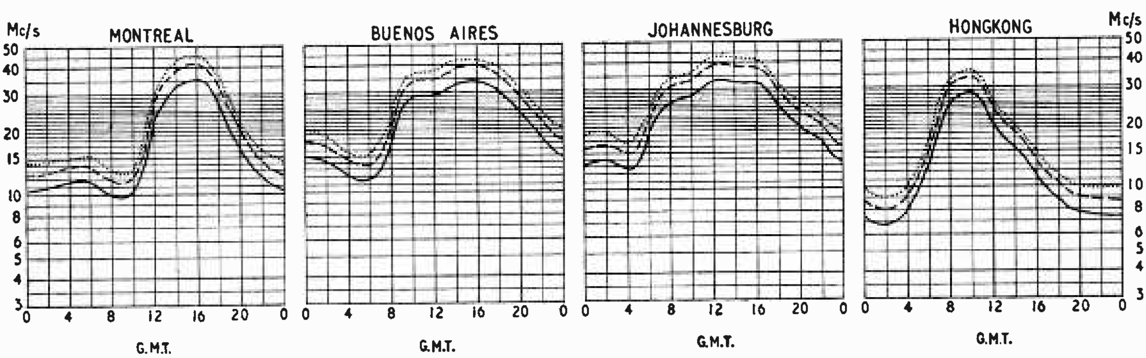
The h.t. supply for a car radio is usually supplied from a vibrator unit but for this particular receiver it was obtained from a motor generator. Originally this machine was designed to supply 200 volts at 65 mA from the 12-volt input but the receiver required only 175 volts at approximately 45 mA. The necessary adjustment was made by including 1,000 ohms in series with the h.t. output from the generator. Of this 680 Ω were included in the motor-generator case, the output being decoupled by a 0.25-μF capacitor, and the remaining 330 Ω were included in the receiver. With the capacitor C_{22} this latter resistance acts as an r.f. filter and attenuates any ignition interfering signals picked up by the leads from the motor generator to the receiver. Moreover the 1 kΩ added to the h.t. line gives additional smoothing and there is in fact no audible hum from the receiver.

Minimizing Interference

A number of precautions were necessary to minimize interference from the ignition system of the car engine. The chief measures adopted were the inclusion of the r.f. choke L_1 in the aerial lead and the series grid resistors R_2 and R_6 which attenuate interference signals on frequencies above the medium waveband. Interference signals can enter the receiver *via* the leads from the car battery and motor generator. R.F. filters L_9C_{26}, L_7C_{24}, L_6C_{23} and L_8C_{25} are included to minimize interference from this source and the leads to the battery, to the motor generator and to the aerial, as well as the receiver itself, are thoroughly screened. The filter chokes are Dubilier suppressor types, L_6 being a 1-A size and L_7, L_8 and L_9 are 3-A sizes.

Although the receiver is used mainly in the London area for the local B.B.C. programmes a number of Continental signals and provincial Home services have been received. These are generally good in open country but less satisfactory in the city. Such signals tend to be weak between tall buildings and are marred by receiver hiss; they are also subject to strong electrical interference when the car travels along a trolley-bus route.

SHORT-WAVE CONDITIONS *Prediction for December*



THE full 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 December.

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

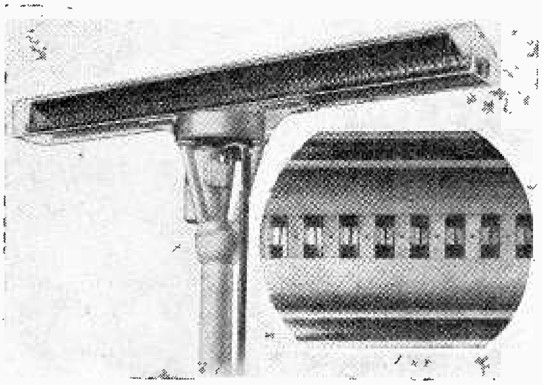
.... FREQUENCY BELOW WHICH COMMUNICATION SHOULD BE POSSIBLE FOR 25% OF THE TOTAL TIME

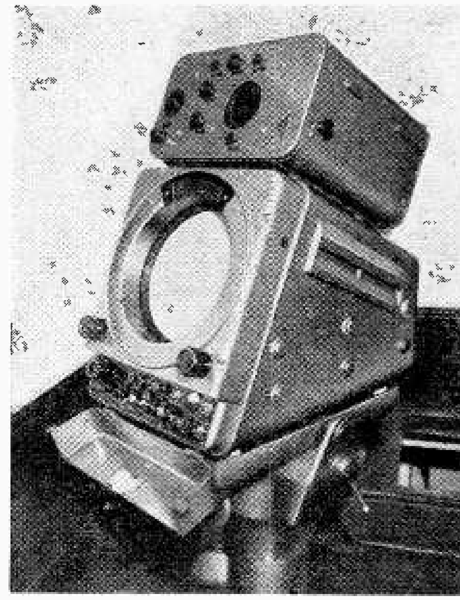
— — — PREDICTED AVERAGE MAXIMUM USABLE FREQUENCY

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

Marine Radar Developments

TECHNIQUES USED IN THE LATEST EQUIPMENT FOR SHIPS





Display and "Trackmaster" units of the Decca "true motion" radar Type TM46.

Left: Slotted waveguide aerial used with Kelvin Hughes Type 14 marine radar. Insert shows enlarged view of slots.

SOME new and interesting developments in marine radar technique were announced recently by two of the leading makers of this type of equipment. Decca have introduced what they describe as a "true motion" radar, and Kelvin Hughes have a new ship's radar which in addition to embodying a novel aerial system and printed wiring is very compact and reasonably priced.

The conventional ship's radar p.p.i. display shows relative motion only and all objects, whether stationary or moving, appear to be in motion on the face of the p.p.i. tube; only the ship itself is stationary, since its position is at the origin of the time-base scan. The apparent direction of movement is indicated by the luminous tail accompanying all "plots" and in order to determine the true motion of other vessels in the vicinity recourse has to be made to plotting the radar information on an appropriate chart. This takes time and is not always convenient to put into effect when navigating narrow and congested waters.

"True Motion" Display

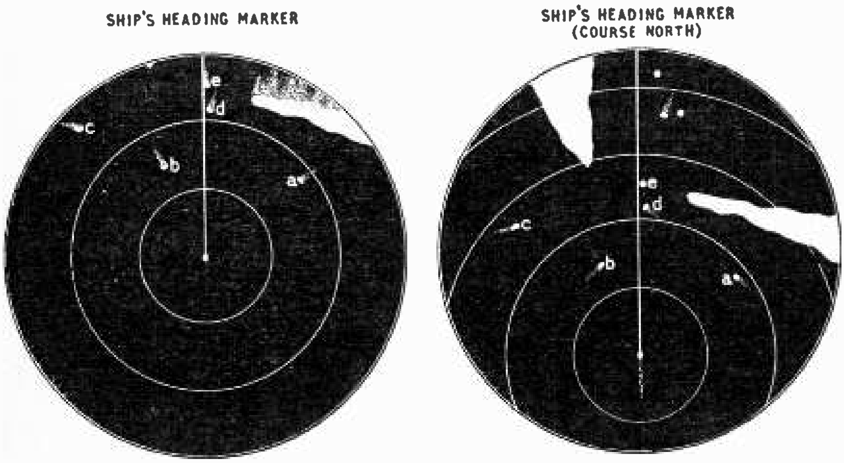
It is not immediately apparent from a ship's p.p.i. display if an object is in fact moving or is stationary and if moving its apparent speed may be deceptive unless careful observations are made. The purpose of the new Decca technique of "true motion" is to resolve these ambiguities and present on the p.p.i. display a true, as distinct from a relative, picture of movements in the immediate vicinity of the ship, and if required out to a range of 10 miles. Beyond this the conventional display satisfies most requirements.

In order to achieve this "true motion" display it is necessary to add certain equipment not normally required and most of this is contained in a unit called the "Trackmaster." Into this is fed the ship's speed, which can be done either manually or automatically from the log, and bearing information from the gyro compass. Compass and log readings are converted in the "Trackmaster" unit into "E-W" and "N-S" voltages, which when applied to the appropriate coils on the c.r. tube shift the origin of the p.p.i. scan in accordance with the ship's direction and speed of movement.

Although small errors may arise in the recorded speed of the ship, bearing information must be accurate and, as the range markers of the display are as independent as in any other marine radar, distances and bearings of other objects are as accurate as usual.

The visual effect of "true motion" display is that it presents a bird's-eye view of the situation, with land masses and buoys stationary, the observer's ship moving along its true course and all other moving objects travelling in their true directions. Direction of movement is indicated, as usual, by a luminous tail and in addition the "own" ship's course can be indicated by a luminous heading line. There are variations in the actual form of display that can be used and relative motion information, with the origin of the scan stationary in the centre of the tube, as in conventional systems, can be displayed when required.

A brief specification of the Decca TM46, which embodies the new technique, is as follows: operating frequency, 9,320 to 9,500 Mc/s; double-cheese aerial; horizontal beam width 1.2° and vertical 22°; peak power 20 kW; pulse width 1.0 or 0.1 μsec (by selection). Six ranges are provided, namely 1, 2.5, 5, 10,



Relative motion (left) and "true motion" (right) displays presented by the Decca Type TM46 radar. "Tails" show the apparent (left) and true (right) movement of ships. Note the apparent movement of the land (left) and the readily identifiable buoys (right), which have no "tails".

25 and 45 nautical miles respectively. "True motion" display is not available on the 25- and 45-mile ranges.

The new Kelvin Hughes marine radar Type 14 employs a novel aerial consisting of a length of waveguide laid horizontal and having a series of inclined slots cut in its narrow side. Vertical separators, external to the waveguide, divide one slot from another throughout its length and these are designed to form truncated sections of waveguide in front of each slot. One of their functions is to suppress spurious radiation and unwanted side lobes.

The basic principle of the slotted waveguide aerial has been known for some time* but this appears to be the first time it has been applied to a commercial-type radar. One of its advantages is that it enables the size of the rotating head to be kept reasonably small, the Type 14 radar's scanner, for example, measures about 6ft long and only a few inches for each of the other two dimensions. This aerial has a beam width of 1.3° in the horizontal and 27° in the vertical. A small pick-up head is mounted on an outrigger ahead of and just below the centre line of the scanner, rather like the "hog horn" of a reflector-type system. In this case it is not a horn, neither does it rotate with the scanner but is fixed to the scanner pedestal. It samples the radiation from the aerial each time the beam sweeps across it and displays, when required, a pattern of radiation on the p.p.i. tube.

Five ranges are provided, one continuously variable over ½ to 3 miles and four fixed at 6, 12, 24 and 48 miles respectively. Pulses of either 0.3 μsec or 0.1 μsec are generated and automatically selected according to the range in use, the narrower being employed on the short ranges where the highest discrimination is required. The peak power output is 60 kW.

Printed wiring is used extensively throughout this equipment, which, with "potted" components, is said to contribute significantly to the reliability and low initial cost. Orthodox wiring is confined mainly to cabling and inter-unit connections. A 9-in c.r. tube is fitted to the display unit and, while it is somewhat smaller than usual for equipment of this kind, it gives a clear, bright display and is the only concession made to keep costs down to a minimum. The total consumption is about 1 kW. As with other ships' radars the operating frequency is in the "X" Band (*circa* 3 cm), the range of adjustment being 9,320 Mc/s to 9,500 Mc/s.

The Type 14 was developed with an eye to its installation in the smaller, as well as in the larger types of vessel where compactness, economy of operation, reliability and low initial cost are important considerations; the price is £1,195.

* "Resonant Slots," W. H. Watson, M.A., Ph.D.; *Jour. I.E.E.*, Vol. 93, Part IIIA, No. 4, pp. 747-771.

Atmospheric Absorption at Millimetre Wavelengths

AS the wavelengths used in radar systems are extended downwards into the millimetre region absorption due to water vapour and oxygen in the atmosphere and to adverse weather conditions becomes increasingly important.

A simple new method of measuring this absorption has been developed at the Bell Telephone Laboratories* and applied to the 5-6 mm band. This is based on the measurement at the source of the microwave power reflected from a suitably spaced corner reflector.

A feature of the method is that the measurement of absolute values is avoided so that results can be obtained readily and with accuracy. Thus by using two spaced reflectors it becomes unnecessary to know the absolute aerial gains or power levels. Furthermore by suitably frequency-modulating the source and beating it with the reflected signal, it is possible to measure the reflected power using the same narrow-band amplifier and simple square law detector for each reflector. Owing to the use of a narrow-band amplifier high signal-to-noise ratio can also be obtained.

By this means the line breadth constant of oxygen at atmospheric pressure as used in the absorption theory given by van Vleck† has been accurately measured and the correctness of this theory tested. Some data have also been obtained on the influence of rain and fog.

REFERENCES

* A. B. Crawford and D. C. Hogg, *Bell System Technical Journal*, July 1956, p. 907.
† J. H. van Vleck. *Physical Review*, Vol. 71, 1942, p. 413.

"Automatic Wavemeter Calibration." On page 535 (top of right-hand column) of the November issue the pulse duration and time jitter requirements should be less than 10 and 1 *milli*-microseconds respectively.

Tropospheric Scatter Propagation

By J. A. SAXTON*, D.Sc., Ph.D., M.I.E.E.

REVIEW OF LATEST THEORIES: APPLICATION TO RADIO COMMUNICATION

IN the issue of this journal for January, 1956, the author gave an account of v.h.f. transmission by means of ionospheric scattering. In the same article brief mention was also made of the phenomenon of tropospheric scattering in order to draw attention to the different frequency ranges and distances of transmission for which the two mechanisms of propagation are important. Much information has recently been published concerning developments in the tropospheric field, particularly in the United States of America, and it therefore now seems appropriate to review the present state of our knowledge concerning long-range tropospheric propagation and its application to radio communication.

Notwithstanding the remarkable prediction made by Marconi in 1932 that communication considerably beyond the horizon by means of microwaves might well prove to be a future possibility, it was for many years after this thought that reliable communication in the v.h.f. band, and at still higher frequencies, would be confined to optical, or perhaps only very slightly greater, distances. Marconi's prediction was based on the fact that he had been able to communicate over a distance of 168 miles on a frequency of about 500 Mc/s, though not very reliably in view of the powers and aerials then available. During the 1930s other workers in Europe, Great Britain and the U.S.A. also noted that from time to time relatively strong signals were obtainable over much greater than line-of-sight paths at very high frequencies. Such signals were sometimes steady for considerable periods, but in general faded slowly over a wide range. It was soon realized that these transmission characteristics were closely linked with meteorological conditions over the paths concerned; and a great stimulus was given to their study when, with the use of higher powers and shorter and still shorter wavelengths for radar during the Second World War, experience of "anomalous propagation" (as it was then called) became much more extensive.

It has subsequently been shown that examples of abnormal transmission of the type discussed above, and which are now often observed when the weather is appropriate, are due to one or other of the super-refractive mechanisms which can occur in the troposphere. It is in fact such conditions which are responsible for one form of interference experienced at times in television reception. With the very high radiated powers which became available during and after the late war it began to be apparent that, at frequencies in the v.h.f. band and above, fields well beyond the horizon, whilst subject to fairly rapid fading, were on average persistently much in excess of those expected on the basis of diffraction round the earth; even in the absence of meteorological conditions known to be conducive to super-refraction. Speculations as to the reason for these relatively strong fields included right from the start the suggestion that they were caused by reflection (or scattering) from numerous small discontinuities of refractive index in the troposphere. A brief discussion of subsequent theories will follow later, but it cannot be said that the phenomenon is by any means yet completely understood. On the practical side, however, the reliability of these beyond-the-horizon fields has been firmly established, and much progress made in their use for communication purposes.

Review of Theoretical Background.—In the earlier article, referred to above, a description was given of the basic process of scattering, and it was pointed out that scattering of electro-magnetic waves must always occur when there is a change in the refractive index (or its gradient) of the medium through which the waves are travelling. If a number of scattering centres are involved the scattering may vary between the two extremes of incoherence and coherence (in which case reflection and refraction as ordinarily understood occur), depending upon the size of the centres in relation to the wavelength concerned and their spatial configuration.

Some six years ago E. C. S. Megaw in this country, and H. G. Booker and W. E. Gordon independently in America, suggested that the persistent signals well beyond the horizon were due to incoherent scattering caused by random fluctuations of refractive index in the troposphere, and that these fluctuations were produced by atmospheric turbulence. Quantitative developments of the theory, based on what was known at the time of the meteorological parameters concerned, showed that the magnitude of the observed signals could be reasonably well explained. This theory, together with its subsequent modifications of detail, has been accepted by many workers in this field, at least until comparatively recently, though other suggestions have been put forward. For example, T. J. Carroll considers that it is possible to explain the phenomenon by an application of the normal mode theory to an atmosphere in which the refractive index decreases monotonically from its value at the surface of the earth to unity at some specified height, above which it is maintained at unity. Though this variation of refractive index is in a general manner representative of what actually obtains in practice, except for the locally marked discontinuities of gradient which frequently occur at some height or other, the mathematical rigour of the theory has been seriously questioned.

Whilst the powerful stimulus to research and to

* Radio Research Station, D.S.I.R.

practical applications provided by the turbulence theory is freely admitted, there is now growing a feeling that, whilst some such process as that postulated by the theory may well occur, it does not represent the whole story, and a new approach to the problem is desirable. This view was expressed, for example, by several speakers at an international symposium on radio wave propagation held in Paris in September of this year.† The original theories of turbulent scattering contained the assumption of isotropic variations of refractive index, and it is now generally realized that this must be far from true. Soundings of the refractive index of the troposphere made by microwave refractometers provide evidence of the marked horizontal stratification which is nearly always present in some height interval. As a consequence there is a trend towards explaining long-distance tropospheric fields in terms of partial reflection and scattering from one or more layers in which there is a significant change in the gradient of refractive index with height from that occurring in neighbouring regions of the atmosphere above and below; and which may present a rough, or at times broken, surface to incident radiation, thus producing the observed fading characteristics. It is evident that much more work, both theoretical and experimental, remains to be done before a really satisfactory understanding of the problem is reached.

The mechanism of propagation is now so widely referred to as scattering that, even though it may ultimately transpire that the processes mainly involved are not those put forward in the early forms of turbulence theory, the term scattering will be used throughout the remainder of this article. Whilst the debate concerning the cause of long-range tropospheric signals may well go on for some considerable time, there is no doubt that this will not hold up intensive efforts to extend the practical applications of these signals.

Practical Aspects.—Whilst tropospheric scattering occurs at both lower and higher frequencies, it appears that the frequency range in which the most useful applications are likely to occur is from 400 to 500 Mc/s up to perhaps 5,000 Mc/s. Below this range the construction of suitable aerials becomes increasingly difficult; and above it the effects of absorption in the atmosphere begin to be steadily more important. Although it is possible to observe scatter phenomena with powers of only a few watts over one or two hundred miles if narrow-band sensitive receivers are used, powers of the order of kilowatts are required for longer-distance efficient wide-band systems. An essential feature of all scatter links is the use of highly directive transmitting and receiving aerials. (The reader should perhaps be reminded that scattering is in any case useful only for point-to-point communication.) The operation of such links is illustrated by Fig. 1.

† Reported elsewhere in this issue.—Ed.

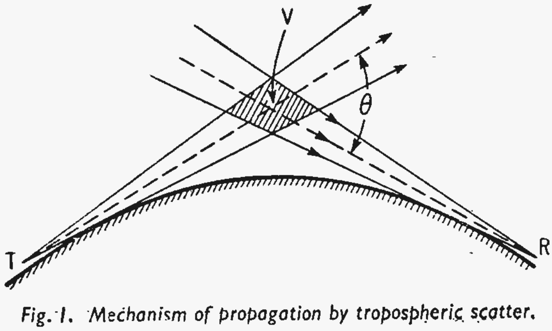


Fig. 1. Mechanism of propagation by tropospheric scatter.

A narrow beam is radiated from the transmitter at T, and the similar beam of the receiving aerial at R intersects the transmitted beam as shown, so defining a common volume V. Refractive index fluctuations of some form or other within the volume V cause scattering and produce the signal at R. The beams must be accurately aligned, and ideally the angle θ should be as small as possible: this means that care must be taken to select terminal sites which permit unimpeded low-angle transmission in the direction of the horizon and reception from that direction.

A signal propagated by means of tropospheric scattering is characterized by both rapid and slow fading. The rapid fading is an essential accompaniment of the superposition of a large number of randomly phased field components, and it conforms closely to a Rayleigh distribution of amplitudes. Most of the time the rapid fading is within a range of some 15 dB, and 30-dB fades, for example, would be expected to occur for only 0·1% of the time. The frequency of this rapid fading increases with increasing distance beyond the horizon and with decreasing wavelength: it is normally of the order of 1 to 10 c/s. The slow fading is caused by changes in the overall average refractive conditions in the atmosphere; and it is stated by K. Bullington that, at points well beyond the horizon, the variation in hourly median signal strengths (i.e., the values exceeded for 50% of the time in each hour), when expressed in a decibel scale, follows a normal probability law with a standard deviation of about 8 dB.

There are variations of the median signal level with time of day, season of the year and the weather. In general, the signal is stronger in summer than at other times of the year; and a range of variation in monthly median values of 10 to 20 dB, depending on frequency, may occur, the greater range occurring at the lower end of the frequency band under consideration. The diurnal variations, which are only a few dB, do not appear to follow any definite pattern.

It was at first thought that, on scatter links, the transmission loss relative to the free space value for similar aerials, did not vary much with frequency in the range 400 to 5,000 Mc/s but the much more comprehensive data now available show that there is a gradual falling off in the efficiency of the scattering process as the frequency increases. Thus, for a 200-mile path the overall median transmission loss (relative to free space transmission) is of the order of 70 dB at 500 Mc/s and 80 dB at 3,000 Mc/s. A similar trend occurs for other path lengths, at least up to 400 miles. These fields, although weak, are of course many magnitudes greater than those expected on the basis of diffraction round the earth in a standard atmosphere. The variation with distance does not appear to depend significantly on frequency, at any rate for the range 100 to 400 miles for which so far most experimental data exist; the relative transmission loss increasing by some 35 to 40 dB in this range. Although it was originally believed that the useful range of a tropospheric scatter link would not exceed 300 to 400 miles, recent work at the

Lincoln Laboratory of the Massachusetts Institute of Technology has shown that reliable communication may be achieved over a distance of perhaps as much as 750 miles with a frequency of 400 Mc/s; and it seems that for these greater distances there is an advantage in using the lower frequencies.

Although no very extensive investigations have been made, there are indications that the transmission loss does not vary with the state of polarization of the radiation; the polarization of any given transmission is substantially maintained over a scatter link.

Having discussed the general characteristics of tropospherically scattered signals, we may now pass on to consider the choice of system parameters.

System Parameters.—When choosing the frequency of operation for a scatter link, a number of factors must be taken into account besides the nature of the propagation mechanism itself: for example, the r.f. power available, the sensitivity of the receiver, and the feasibility of building aerials of the necessary directivity. (On the matter of reception it may be noted that space diversity may be used to advantage with aerials spaced 25 wavelengths, or more, normal to the transmission path.)

At the present time 50 kW (c.w.) of radiated power (not e.r.p.) is a possibility at frequencies of 400 to 500 Mc/s; at 2,000 Mc/s up to 10 kW may be achieved, but at appreciably higher frequencies the c.w. powers available are much smaller.

At frequencies below about 700 Mc/s it is possible, with a pre-amplifier using earthed-grid circuits with planar triodes, to improve the noise factor of a receiver; and between 400 and 700 Mc/s noise factors of 5 to 8 dB may be realized. At higher frequencies little or no improvement is at present possible over the performance of the best crystal diode mixers, and noise factors better than 8 dB cannot be expected.

As has already been mentioned, the efficiency of the scattering process tends to fall off as the frequency increases, and it appears that the efficiency is roughly proportional to the wavelength. On the other hand, highly directive aerials must be used: gains of 25 to 40 dB are required, which means, for example, the construction of paraboloidal reflectors having apertures of diameters 12 to 60ft at a frequency of 600 Mc/s. The beam width of an aerial of given aperture decreases in proportion as the wavelength is increased, and the gain of such an aerial is inversely proportional to the square of the wavelength. It is thus much easier to build aerials of a specified beam width and gain as the frequency is increased.

From considerations of the kind outlined above it would appear that the optimum frequency to use is somewhere in the region of 1,000 Mc/s, at least for wide-band links of 200 to 300 miles in length. For the longest paths envisaged, however, that is of the order of 600 or 700 miles, it is necessary to face the prospect of building very large aerials, with apertures some 60ft in diameter; and to use a frequency as low as 400 Mc/s in order to make use of the more effective scattering, the greater transmitter powers which are available and the better receiver performance. Even so, the bandwidth capacity of such long paths will be somewhat limited.

Aerial Performance and Bandwidth Capacity.—On the turbulence theory, as has been shown by W. E. Gordon, the scattered energy is distributed

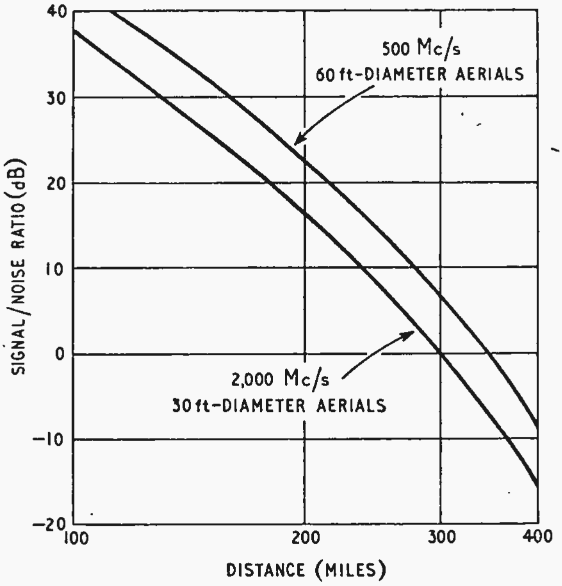


Fig. 2. Performance curves of scatter link based on signal/noise ratio exceeded for 99% of the time; transmitter power 10 kW; receiver bandwidth 100 kc/s and noise factor 10 dB.

over a small angle when it arrives at the receiver. When the width of the aerial beam exceeds this angle, the maximum bandwidth which can be transmitted without distortion depends primarily on the properties of the tropospheric irregularities which determine the angular spread of energy, and so the effective scattering volume; for it follows that under such conditions the whole of the volume V (Fig. 1) cannot be effective. On the other hand, if more directive aerials are used, so that the aerial beams are narrower than the angular spread of the scattered radiation, the maximum useful bandwidth of the transmission is determined by the dimensions of the volume V, or more precisely by the difference between the longest and shortest possible path times *via* the volume V. This aspect of the theory has been developed by H. G. Booker and J. T. de Bettencourt, and clearly, to achieve large bandwidths the volume V must be made small, which requires aerials with very narrow beams.

There is, however, a price to be paid for the increase in bandwidth capacity, for, when the aerial beams become narrower than the angular spread of the scattered radiation, any further increase in aerial directivity produces relatively little increase in received power. There is introduced what Booker and de Bettencourt call an "aperture-to-medium coupling loss"; or, in other words, the effective gains of the aerials are less than their full plane-wave gains. Looked at another way, the aerial directivities have become so great that the whole of the scattering volume which, by virtue of the nature of the scattering process, could contribute to the signal is not being utilized. This loss in gain begins in practice to be apparent when gains of the order of 35 dB are reached. Experiments at Lincoln Laboratory, M.I.T., have shown that, with aerial beams 0.6° wide, and at a frequency of 3,670 Mc/s, bandwidths of the order of 5 to 10 Mc/s are possible on paths of about 200 miles; provided that no multi-path effects arise other than those due to the atmosphere itself. These results are in reasonable agreement with the theory. Severe multipath effects, with resultant distortion of wide-band signals, can, however, be caused by aircraft flying in or near to the aerial beams: the chance of this happening is also obviously reduced by the use of really narrow beams. Other things being equal, the maximum bandwidth of a scatter link becomes less as the distance is increased.

The curves of Fig. 2 are an indication of the performance which may be expected with tropospheric scatter links. They are based on published American data, and, since there is some variation between the results given by various workers, the curves cannot be regarded as being accurate to better than several decibels. A single paraboloidal reflector-type receiving aerial, identical with the transmitting aerial, is assumed: at least 10-dB improvement in signal-to-noise ratio should be possible with dual-diversity reception, and perhaps a further 8-dB improvement could be obtained by the use of triple-diversity.

Modulation Techniques.—Both f.m. and single-sideband amplitude modulation have been used in American investigations. Although f.m. does not make the most effective use of bandwidth, there are some features which make it particularly useful in scatter transmissions: for example, the relative freedom from distortion and insensitivity to rapid fading as long as the signal exceeds the threshold level. On the other hand s.s.b. modulation is much more economical from the bandwidth point of view; it is better for the reception of very weak signals, and requires the use of lower average power than f.m. Disadvantages are that s.s.b. equipment necessitates high-linearity amplifiers and very good frequency stability.

Conclusions.—Although the exact mechanism by means of which tropospherically scattered signals are transmitted far beyond the horizon is not yet completely understood, great advances have been made during the past few years in making use of such signals for communication purposes. Links operating on the scatter principle are capable of carrying wide-band information and are, for example, suitable for relaying multi-channel telephony over paths of a few hundreds of miles. It seems probable that the reliable transmission of television signals will follow as the technique develops, though, in view of the bandwidth required, the length of a link for this purpose will generally be less than is possible for telephony and telegraphy. The reader interested in obtaining more detailed information on the practical aspects of scatter links will find it profitable to consult the symposium in the October, 1955, *Proceedings of the Institute of Radio Engineers*, New York.

BOOKS RECEIVED

Linear Transient Analysis Vol. II, by Ernst Weber. Extends the basic mathematical processes of the Fourier and Laplace transforms, which were applied in Vol. I to lumped-parameter networks, to active and passive fourpoles and transmission lines. Includes appendices on basic matrix algebra, functions of a coupled variable and a glossary of mathematical terms. Pp. 452; Figs. 137. Price 84s. Chapman and Hall, Ltd., 37, Essex Street, London, W.C.2.

Transistors I. Collection of 41 papers (31 not previously published) and 48 abstracts dealing with work by the Radio Corporation of America on the theory, fabrication and application of transistors and semiconductor diodes. There are six sections—General, Materials and Techniques, Devices, Fluctuation Noise, Test and Measurement Equipment and Applications. Pp. 676; Figs. 416. R.C.A. Laboratories, Princeton, N.J. Obtainable from Arthur F. Bird, 66, Chandos Place, London, W.C.2. Price 40s.

Frequency-Modulated Radio, by K. R. Sturley, Ph.D., M.I.E.E. General principles of frequency modulation are analysed as an introduction to a consideration of the design of f.m. receivers. Hints on the alignment of receivers are given and in a concluding chapter the features of combined f.m./a.m. receivers are discussed. Pp. 120; Figs. 78. Price 15s. George Newnes, Ltd., Southampton Street, London, W.C.2.

Frequency Modulation Receivers, by J. D. Jones. Stage-by-stage guide to the design of f.m. receivers with worked examples illustrating calculation of component values. A concluding chapter gives circuit details of a complete receiver. Pp. 114; Figs. 29. Price 17s 6d. Heywood and Co., Ltd., Russell Street, London, W.C.2.

Frequency Modulation, by L. B. Arguimbau and R. D. Stuart. Monograph on the application of f.m. to communication systems, with particular emphasis on performance in the presence of interference. The importance of studying the frequency spectra involved is stressed and also the need for adequate bandwidth in the discriminator. Pp. 96; Figs. 58. Price 8s 6d. Methuen and Co., Ltd., 36, Essex Street, London, W.C.2.

V.H.F. Television Tuners, by D. H. Fisher, A.M.I.E.E. Guide to the design, construction and testing of switched and turret tuners and their associated circuits. Pp. 136; Figs. 60. Price 21s. Heywood and Co., Ltd., Russell Street, London, W.C.2.

Niederfrequenz- und Mittelfrequenz-Messtechnik für das Nachrichtengebiet, by Dr. Ing. A. Wirk and Dipl. Ing. H. G. Thilo. General treatise on measuring techniques at audio frequencies with particular emphasis on bridge methods. Pp. 234; Figs. 224. Price 28 DM. S. Hirzel Verlag, Birkenwaldstrasse 185, Stuttgart N., Germany.

Marine Radar, by D. G. Lang. Textbook covering the syllabus of the Ministry of Transport Radar Maintenance Certificate examination, and giving a succinct description of the functions and component parts of a radar system. Pp. 229; Figs. 129. Price 30s. Sir Isaac Pitman and Sons, Ltd., Pitman House, Parker Street, Kingsway, London, W.C.2.

Analysis of Bistable Multivibrator Operation, by P. A. Neetson. Deals exhaustively with the dynamic phases of the switching cycle in the Eccles-Jordan "flip flop" circuit and includes a chapter on design considerations. Pp. 82; Figs. 34. Price 15s. Cleaver Hume Press, Ltd., 31, Wrights Lane, London, W.8.

Musical Acoustics, by C. A. Culver, Ph.D. Fourth edition of a textbook for students of music giving the elements of physical acoustics as applied in the analysis of musical instruments and sounds. Chapters are included on the theory of hearing, architectural acoustics and sound reproduction. Pp. 305; Figs. 214. Price 45s. McGraw Hill Publishing Co., Ltd., 95, Farringdon Street, London, E.C.4.

Reliability of Electronic Apparatus

By D. A. BELL, Ph.D., M.I.E.E.

SOME STATISTICS AND THEIR IMPLICATIONS

IT is often said that although electronic brains are marvellous one should as far as possible exclude electronic apparatus from industrial plant because all electronic devices are fragile and unreliable.

There is more in the question of fragility than can be dismissed in a generalization of this kind. Properly designed electronic apparatus can work in conditions which no human being would tolerate but it cannot compete with simple mechanical structures in this respect. On the other hand the reliability in terms of average fault rate is good. In this connection we should credit electronics with the fact of requiring no routine maintenance comparable with the replenishment and replacement of lubricants in a mechanical device, and that the proportion of the electronic device which suffers appreciable deterioration is very small.

Consider, for example, the small motor-car engine, in which most of the moving parts will have suffered noticeable wear after 60,000 miles, which is only 2,000 hours at an average speed of 30 m.p.h. Yet in a well-designed valve amplifier one might get a trouble-free life of 10,000 hours or more, and be able to restore it to perfect condition by replacing only those valves which had deteriorated with use. There is in fact no mechanical device which gives a longer life than electronic apparatus will give *when you are lucky*—and there's the rub. If a car of popular make collapsed in the road through fracture of the chassis when it was less than a year old, the manufacturer would not save his reputation by saying that this was the only case out of 50,000 cars of that model, which represents a very low failure rate: he would be told he must be certain of the soundness of *every* chassis. Unfortunately the manufacturer of the strictly electronic devices—thermionic valves and transistors—is still in the situation of being unable to give a complete guarantee of every specimen; and although great progress has been made in reducing the average failure rate, it does not satisfy the unlucky user to know that his misfortune now represents one case in 40,000 as against one case in 1,000 formerly. It is the unpredictability of the very occasional failures which causes the whole to be labelled unreliable.

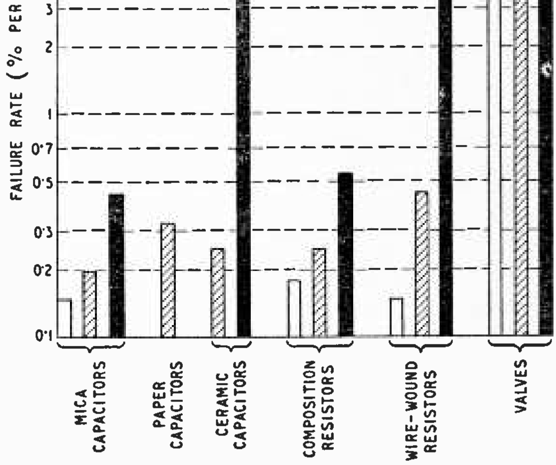
Analysis of Failures

Two recently published papers have reviewed available data on the frequency of occurrence of failures of electronic apparatus, one giving average figures for military and for two classes of civilian equipment[1], and the other analysing the effect of equipment design on the frequency of failures of electronic equipment used in the United States Navy[2].

Turning first to the latter set of data, the histograms (block diagrams) in Fig. 1 show the way in which failure rate is related to severity of duty imposed on the component for various types of resistor and capacitor and for valves. The figures have all been expressed in terms of a common unit of "per cent failures per 5,000 hours." In terms of industrial equipment working one shift per day, but excluding Sundays and holidays, the period of 5,000 hours will cover nearly two years; but on the basis of 24 hours a day and seven days a week 5,000 hours will be covered in a little over six months.

With paper condensers it is unwise to design the circuit for use of a condenser at the manufacturer's full rating and in Fig. 1 a failure rate is quoted only for 50 per cent of the rating. This does not necessarily mean that the manufacturer's rating is wrong. Remembering that paper condensers are used as reservoir, smoothing or bypass condensers in association with the anode power supply of the equipment, and that power-supply regulation is not perfect, it is highly probable that the voltage across a

Fig. 1. Failure rates for various components under negligible, moderate and heavy loading (after Harris and Tall, reference 2.) For capacitors the load conditions are an applied voltage which is (a) negligible, (b) 50% or (c) 100% of rated voltage; for resistors, (a) negligible, (b) 50% and (c) 100% of rated power dissipation; for valves, (a) low electrode voltage and negligible dissipation, (b) 90% of rated electrode voltages and 70% of rated electrode dissipations, and (c) 100% of rated voltages plus 100% of rated dissipations. The failure rates are plotted to a logarithmic scale.



paper condenser will periodically exceed the nominal value for that point in the circuit. If this occurs when the nominal voltage is equal to the rated working voltage of the condenser, the manufacturer cannot be blamed for failures arising from temporary over-voltage. At the other extreme the failure-rate in mica condensers is not greatly dependent on applied voltage and must presumably be due to inherent defects in the dielectric which ultimately cause breakdown, either through electrolytic action or through the cumulative heating effect of leakage current.

It may come as a surprise to see that for moderate or heavy loading the wire-wound resistor is more prone to failure than the carbon-composition resistor. High - value wire-wound resistors employ very thin wire, and the danger points are (a) the connections of this thin wire to the terminals and (b) possible inhomogeneities in the wire itself. Some specimens of high-value wire-wound resistors have been known to show "current noise" (an increase of noise above Johnson noise when a steady current flows through the resistor) and any resistor which shows this effect is not to be trusted.

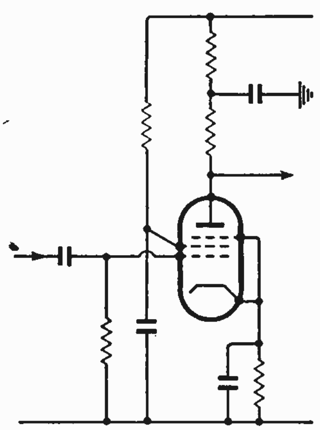


Fig. 2. There are usually many more other components than valves.

Complete failure in a carbon-composition resistor is no doubt due to a gross fault in its internal structure, such as a fissure in the body of the resistor or poor contact between termination and body of the resistor. What does not appear in the data is the change in value of a composition resistor, without catastrophic failure, and this is undoubtedly affected by the loading.

By conservative rating of resistors and capacitors it should be possible to achieve a failure rate amongst them of not more than ½ per cent per 5,000 hours. In contrast, the failure rate for valves is 12½ per cent per 5,000 hours even for light loading. It appears that the valve is usually happy at 70 per cent of rated dissipation and 90 per cent of rated voltage, but pushing it to the limit of the ratings doubles the failure rate. The moral is obvious. The circuit of a simple resistance-coupled amplifying stage in Fig. 2 shows that typically there may be nine components associated with a single valve, and the result is that the risk of failure of some component in the circuit is no longer much smaller than the risk of failure of the valve. Dummer[1] quotes recorded values of overall average failure rate (see Fig. 3) for three conditions of use of electronic equipment: (a) test of equipment to military specifications, (b) normal laboratory use and (c) an electronic computer in which great care will obviously have been taken to provide good working conditions for the components. From the figures suggested at the beginning of this paragraph for components and valves separately, and a nine-to-one ratio of their numbers, one would predict an average failure rate of 1.7 per cent per item which is consistent with the figure which Dummer reports for an electronic computer.

Valve Life

It appears, then, that the failure rate could be roughly halved if valves were as reliable as resistors and capacitors. But the present performance of valves is very good by pre-1939 standards: 12½ per cent failure per 5,000 hours represents a mean life of no less than 40,000 hours, and none would grumble if valve failures could be eliminated by replacing valves every 10,000 hours. The trouble is that although the average over large numbers is a life of 40,000 hours, the failure of any single valve may occur with practically equal probability at 1,000 hours or 100,000 hours.

Catastrophic failures (cracked glass, weld failures, open-circuit heaters) have been greatly reduced in "special quality" valves by the combination of improved mechanical design and meticulous care in manufacture, so that one may hope that an increas-

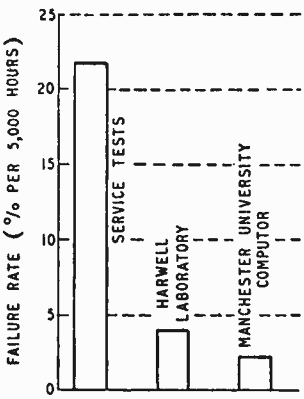


Fig. 3. Failure rates per component (valves included) under different types of service, plotted to a linear scale.

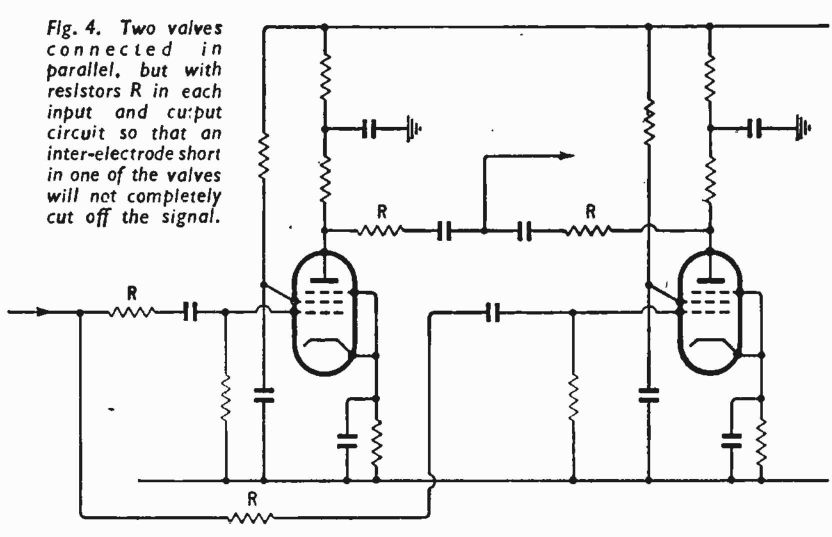


Fig. 4. Two valves connected in parallel, but with resistors R in each input and output circuit so that an inter-electrode short in one of the valves will not completely cut off the signal.

ing proportion of the ultimate failures will take the form of "loss of emission." One *hopes* for this, because it is likely to give warning before the deterioration has become great enough to stop the equipment working: dying valves can then be detected by the technique of marginal testing, and replaced. The cause of death has been given as "loss of emission" in inverted commas, because the trouble may in fact be due to the formation of a high-resistance layer between cathode tube and oxide coating, rather than true loss of emission, but the two phenomena cannot be distinguished simply. This interface effect is tied up with the use of silicon as an activating agent[3] and can be avoided if one is content with a smaller emission current from a given size of cathode. This is how it is hoped to secure a life of 20 years for valves submerged in the transatlantic telephone cable.[4]

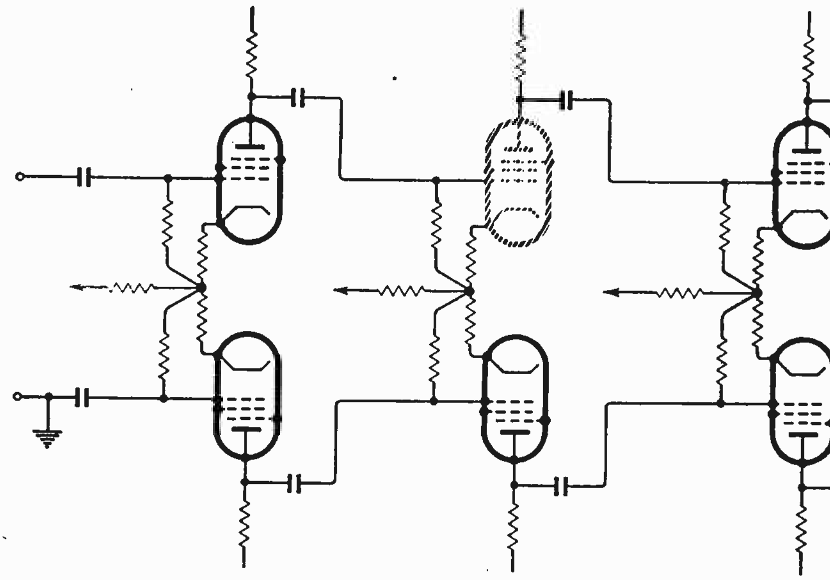


Fig. 5. Push-pull amplfier using long-tailed pair in each stage. Failure of any one valve will not prevent the signal from being passed on by the other valve in that stage and shared between both halves of the amplifier in the next stage.

The steps which the user can take to minimize failure rate all cost money, and his choice will be governed by the premium which he is prepared to pay for reduced failure risk. The obvious ones are to use components which will be operated well within their ratings, to use special-quality valves where available, and to use components which have passed the rigorous mechanical and climatic tests required for military use. In industrial electronics it is rarely necessary to use valves of exceptionally high performance; but in a wide-band amplifier it may be essential to use a valve having high ratio of mutual conductance to electrode capacitance and desirable to use a valve with a high ratio of mutual conductance to anode current. Such a valve may not be available in the "special quality" range, because its performance is obtained by taking risks with grid-cathode clearance, cathode current-density or anode dissipation. The user must either accept a greater failure risk as the cost of high performance, or possibly redesign his circuit to use several valves instead of one, or to include power supply and cooling for a valve of considerably higher rated dissipation.

How far can the user protect his electronic apparatus from the hazards of industrial life? In many applications the hazards from vibration, temperature and dirt can be almost eliminated by mounting the greater part of the equipment in a suitable enclosure remote from operations: one would not set an automatic telephone exchange in the middle of a foundry with nothing but slide-on covers to protect it from the dust-laden atmosphere, so why should electronic apparatus be expected to put up with this sort of treatment? Presumably because it is so much more rugged and reliable than electro-mechanical equipment! Anything in the nature of a detector head must remain on site, and for this hermetic sealing, a properly designed anti-vibration mounting and possibly artificial cooling by either air blast or water jacket may be advisable.

Neither is it necessary to tolerate widely fluctuating supply voltages for electronic equipment. There are on the market various devices which accept an input range of say ± 20 per cent and give an output stabilized to something between $\pm 2\frac{1}{2}$ per cent for one of the simplest devices to ± 0.1 per cent for the more elaborate. Since, however, the Central Electricity Authority allows frequency to run down at the same time as voltage during periods of peak load, it is as well to enquire into the frequency characteristic of the stabilizer which one proposes to buy.

Judicious Redundancy

Finally, there is the possibility of preventing a single component failure from putting the whole equipment out of commission by incorporating redundancy in design. This is Nature's way of dealing with the risk in the nervous equipment of animals, but is less attractive in electronic apparatus where the additional components have to be bought with hard cash, and do not just grow up with the organism. Condensers may be duplicated in series as a precaution against breakdown, but to give protection also against the risk of an open circuit one would have to use a group of four in series-parallel. Resistors can be split into two in parallel, but operating conditions will change if one half fails. Valves should not be connected directly in parallel for fear of inter-electrode shorts, but should have the signal fed to them separately through resistors (Fig. 4), and this introduces attenuation.[5]

Alternatively, continuity is ensured by employing a "long-tailed pair" in each stage of a push-pull amplifier: if one valve fails (Fig. 5) the other phase of that stage will continue to work and the signal will be divided between both phases again in the next stage. The drastic drop in gain resulting from failure of part of a redundant circuit can, of course, be reduced as far as may be desired by incorporating overall negative feedback. But one must beware of the law of diminishing returns—if for the sake of redundancy and negative feedback one were to increase the number of components by ten times, the risk of local failure would also have been increased ten times.

The conclusion is that it is possible to make electronic equipment just about as reliable overall—and far more reliable per component—than any other type of equipment, but at a cost: the cost of better components, and still more important the cost of putting a good deal of forethought into the design.

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FERRITES

A SURVEY BASED ON THE RECENT I.E.E. CONVENTION

IN many ways the ferrites can be regarded as complementary to semi-conductors. Both are products of recent extensions of our knowledge of the structure of matter in the solid state, and the resources which are today being applied throughout the world to the discovery and improvement of ferrite magnetic materials are comparable to those which have been devoted to the semi-conductors used in transistors. But whereas in transistors the essential processes are those of electrical conduction, in ferrites the aim is to achieve the highest possible resistivity so that eddy current loss does not occur when the material is operated in an alternating field.

Molecular Structure

The intrinsic magnetic energy of all forms of matter is high and is primarily due to elementary dipole magnets (Bohr magnetons) formed by the movement of the charge of individual electrons spinning on their own axes. The movement of the electrons around the nucleus of an atom also gives rise to a magnetic field, and the resultant magnetic state and properties of any material depend upon the degree to which these elementary magnets are aligned and their behaviour under the influence of external magnetic fields.

Our knowledge of the ordering of the magnetic structure of atoms and molecules has been greatly advanced by the technique of neutron diffraction. In the past, X-rays and electron beams have given much information about the structure of molecules and crystal formations, but any data provided on the internal magnetic state of matter is either indirect or is obscured by the effects of the electric fields. The neutron has an intrinsic magnetic moment but no resultant charge and can be used to give direct information by the manner in which a beam of these particles is deflected and scattered in passing through a specimen of the material.

In ferromagnetic materials such as metallic iron, nickel and cobalt the elementary magnets are aligned in the same direction; in ferrimagnetic substances such as magnetite (a natural ferrite) most of the elements are paired off in opposition, but a few are unpaired and give rise to the residual external magnetism.

The ferrites are mixtures of oxides which are sintered together and may form solid solutions one with another. Their composition is chosen to give minimum electrical conductivity in combination with the maximum magnetic effect desired for any given application. Not all the losses are resistive and due to eddy currents; some may result from reversible internal changes in the ordering of the molecular and crystal structures. These are responsible for a reactive component in the permeability of the material.

Chemical formulæ have less than normal significance in dealing with ferrites, which are often complexes of compounds and mixtures. It is sufficient here to state that oxygen plays a vital part in all ferrites and that iron is common to most of those with practical applications. Manganese, zinc and nickel oxides are used to produce the core materials used in telecommunications, while magnesium and manganese oxides are the constituents usually added to ferric oxide in the preparation of ferrites with "square" hysteresis loops for switching in computer memory stores, and for waveguide elements in microwave switches, isolators and directional couplers. Recently developed ferrites in this field include aluminium and chromium oxides.

The possible number of permutations of even the more promising elements in various proportions is staggering and gives some measure of the effort which is being directed into the research. Many of the papers read before the Convention included tri-axial composition diagrams in which the magnetic and electrical constants had been measured for all possible combinations of three oxides and from which the appropriate proportions could be selected for any given compromise between conflicting parameters. Even so, these diagrams represent only one specified method of preparation and heat treatment.

The importance of the physical state of the finished material was repeatedly underlined during the Convention. It was shown that permeability is a function of grain size and that in manganese-zinc ferrites a sevenfold increase of permeability resulted when the grain size was increased from 2.5 to 10 microns. Variation of grain size has also shed light on the origin of one type of resonance effect at radio frequencies. It has been suggested that this may be due to displacements in the walls between adjacent crystal domains, and support for this theory is given by the fact that the resonance disappears when the material is milled to grains of a size less than that of the normal average domain.

At frequencies of the order of kilomegacycles/sec a much sharper resonance effect is observed in the permeability/frequency response. This is due to interaction between the applied field and the elementary fields of the spinning electrons, which, due to their kinetic energy of rotation, are not displaced linearly by the applied field, but develop a conical rotation of their axes (wobble) which is known as precession—a term borrowed from the dynamics of gyroscopes.

Two forces (fields) external to the electron are necessary to build up the precessional rotation. One is a sustained field with a component parallel with the axis of spin and the other the alternating field at right angles. The strength of the steady field is one of the factors which determine the resonant frequency. It is not necessary to apply a steady field external to the specimen to produce a resonance if the internal field due to the ordering of atoms in a crystal lattice is coherent and of sufficient strength. It is a characteristic of crystal structures that their physical properties are anisotropic; i.e., not the same in all directions, and it is possible in single crystals of some paramagnetic salts to distinguish different resonant frequencies according to the direction of the alternating field relative to crystal axes. In polycrystalline substances like the ferrites the application of an external polarizing field produces a sharpening of the resonance and some control of its frequency.

When a linearly polarized electromagnetic wave is propagated through the body of a ferrite in the presence of a magnetic field in the direction of propagation, interaction between the electron spins and alternating field causes rotation of the plane of polarization. This can be explained by considering the linearly polarized wave as the resultant of two circularly polarized components rotating in opposite directions. One of these components, because of its direction of rotation relative to the steady magnetic field, causes a more violent precession of the spinning electrons than the other. As a result it is propagated at a different velocity, producing an increasing phase difference between the two components throughout the ferrite, so that when they finally emerge and recombine into a linearly polarized wave the resultant plane of polarization is rotated.

The phenomenon is known as Faraday rotation, because it is basically similar to the effect discovered by Faraday when he passed a beam of polarized light through a piece of dense glass in a strong magnetic field. The amount of rotation is dependent on the length of the ferrite specimen and the strength of the d.c. magnetic field.

Quite a number of applications for this Faraday rotation effect have been found in microwave apparatus and various new waveguide components have been developed with pieces of ferrite inside them. Perhaps the most commonly used is the "isolator." This is intended to isolate, say, a source of electromagnetic waves (e.g., a klystron) from the rest of the waveguide system to which it is connected in such a way that the normal forward propagation is allowed but any backward transmission (of, say, reflected energy from a load mismatch) is suppressed. The usual arrangement consists of a short length of waveguide, of circular section in the middle tapering to rectangular section at both ends. A cylindrical "pencil" of ferrite is mounted coaxially inside the circular section, which is surrounded by a permanent magnet giving an axial field. Also mounted inside the waveguide are resistive attenuator vanes, one on each side of the ferrite.

The rotation produced by the ferrite and magnet is normally arranged to be 45°, and to allow for this the output rectangular section of waveguide is twisted (relative to the input section) by 45° in the same direction. This permits the normal propagation to proceed unhindered. With any energy returning in the opposite direction, however, the rotation is such that the wave arrives back at the input section with its plane of polarization at right angles to the normal. It cannot therefore be supported by the input section and is absorbed by the attenuator vane (placed parallel with the electric field of the wave). Thus an effective one-way device is achieved.

Gyrators and Circulators

A similar component is the "gyrator." Here the Faraday rotation in the ferrite is arranged to be 90° and the two end sections of waveguide are twisted in relation to each other by the same angle. The result is that in one direction the propagation is normal, while in the other direction a 180° phase reversal is imparted to the wave. Faraday rotation is also utilized in components known as circulators. These are rather like isolators in construction without the attenuator vanes but with extra input and output sections arranged at suitable angles. A typical application would be as a duplexer, where a common aerial is used for both transmitting and receiving. Waves from the transmitter entering input A would be rotated so as to emerge from output B connected to the aerial, but received signals from the aerial going back to B would not be returned to A but rotated still farther to C, feeding the receiver.

Variable attenuators for waveguides can be constructed by using electromagnets instead of permanent magnets and varying the applied d.c. magnetic field so that the wave polarization is brought into greater or lesser alignment with resistive attenuator vanes. High-speed switching can be achieved by pulsing the electromagnets, while the phase of circularly polarized waves can be changed on the principle mentioned earlier. Normally the Faraday rotation angle is somewhat dependent on the frequency of the wave (except at well above the ferromagnetic resonance frequency) but a fairly flat response over about a 1-Mc/s band can be achieved in these components by surrounding the ferrite pencil with a cylinder of dielectric material.

In addition to the Faraday rotation effect, the ferromagnetic resonance mentioned earlier can also be utilized in waveguide components. For example, in an isolator using this principle the d.c. magnetic field is applied transversely to a flat slab of ferrite in the waveguide, and an absorption of energy from the incident wave occurs at the resonance frequency. As already stated, this resonance frequency can be varied by adjusting the strength of the d.c. magnetic field. Another isolator is based on what is known as the field-displacement effect. In this the respective field patterns of the forward and returning waves are pulled to opposite sides of the waveguide by two pieces of ferrite in a d.c. magnetic field. This occurs because the permeability of each piece of ferrite depends on the direction of the r.f. magnetic field and hence on the direction of propagation. A coating of resistive material on the "return-wave" ferrite will thus attenuate the backward transmission.

Another field of application given some prominence at the Convention is that made possible by the "square" hysteresis-loop material mentioned earlier. Here the uses are mainly in switching and storage devices for digital computers, telephone exchanges and other data processing equipments. Small toroidal cores are commonly used, and these, by virtue of the "square" hysteresis loop, have two well-defined states of remanent magnetization—positive and negative, depending on the direction of the magnetizing field. By applying suitable m.m.fs through windings, a core can be made to switch rapidly from one state to the other. Usually a saturating m.m.f. is applied, and when the magnetizing current is removed the core relaxes to the remanent state, which has a flux density only slightly less than the saturation value. It then remains in that condition until a reverse m.m.f. is applied. Thus the core becomes an effective two-state device capable of storing and switching binary information like the Eccles-Jordan valve circuit.

Matrix Stores

Most of the storage devices described were of the matrix type. Here the toroidal cores are threaded on to a grid of x and y energizing wires at all the intersection points, and a particular core is switched only when there is a coincidence of currents in the x and y wires passing through it. Reading-out of information is achieved by applying a m.m.f. in a particular direction through a third wire which threads all the cores. This leaves unaffected all the cores in the corresponding state of magnetization but switches all those that are in the opposite state.

Similar results can be obtained from a matrix store in which the wires are threaded through holes drilled in a single block of ferrite, and this has a great advantage in simplicity of construction. Here the squareness of the hysteresis loop is not so good as with individual cores, but very much less current is needed for switching and the device can be driven directly from valves or transistors.

In switching circuits, a pick-up winding is added to the driving winding on the core. This links with the rapid change of flux produced by the switch-over from one state to the other and gives an output signal for driving the next core. Usually this output signal has to be amplified by a transistor first, and transistor-core circuits have been developed in which a positive feedback winding on the core gives a regenerative action to facilitate the switch-over. If a "square-loop" core is used as a transformer to convey pulse signals, a gating effect can be obtained by applying a heavy biasing m.m.f. through a third winding, which takes the core so far into saturation that the switch-over action is inhibited.

Commercially, the most important applications for ferrites are in the domestic radio and television field. Here the various uses are so well known as to need little comment. Ferrite rod aerials, high-Q r.f. coils, transformers of reduced size and greater efficiency, television deflector-coil yokes—all are familiar components nowadays. Two likely developments for the future are ferrite rod aerials for v.h.f., and ferrite cores of high saturation flux density for use in power transformers. The possibility of controlling the permeability of the cores (and hence the inductance of the coils) by d.c. polarizing windings may lead to interesting developments in tuning and frequency-modulating devices.

High-Fidelity Test Record

AUDIO enthusiasts may be interested in a record produced by Vox (No. DL130) called "This is High Fidelity." This is a 12-inch 33⅓ r.p.m. record containing special recordings designed to illustrate some of the problems in the recording and reproduction of music, and to give some information about the make-up of the orchestra and the structure of music itself. It is supplied with an explanatory booklet.

On the first side of the record there are many illustrations of the effects of frequency losses and of the common resonances at both ends of the audio spectrum. These are followed by examples of the various forms of distortion.

The second side begins with a very useful frequency test recording extending discontinuously from 15 kc/s to 30 c/s. We then have illustrations of the structure of orchestral sound and musical themes and finally there are some examples of the problems of studio acoustics and microphone placing.

This is apparently the only record of its kind available in England, but that is not the only reason for drawing attention to it. Listeners need have no fear that the faults illustrated will show up only on the best equipment for these have been exaggerated and most should be audible on what might be described as only medium-quality apparatus. The various sorts of frequency and non-linearity distortion, together with recording problems, are well and interestingly illustrated and most people would be likely to learn something from them. The explanatory booklet is much better than such things usually are and both explains and adds to the recorded information.

This record is good enough to deserve some slight detailed criticisms.

One point is that more quantitative information might have been given on the extent of the various distortions, with some additional examples in which the amount is too small to be audible on any but the best equipment. A much better judgment could then be made of the listener's own apparatus. This would, of course, have taken up more time but then surely the information on rhythm, tune and harmony was too elementary to be worth giving. The make-up of the orchestra also is much better illustrated in Benjamin Britten's "The Young Person's Guide to the Orchestra." As regards the booklet, it is a pity to see loudness controls advocated. These surely rest on the incorrect idea of trying to reproduce an orchestra as it would be heard a long way away with the frequency balance as it would be audible much closer; and this cannot possibly lead to natural results. M. G. L.

I.T.A. GROWTH—

—AND THE NEW TRANSMITTER AT EMLEY MOOR

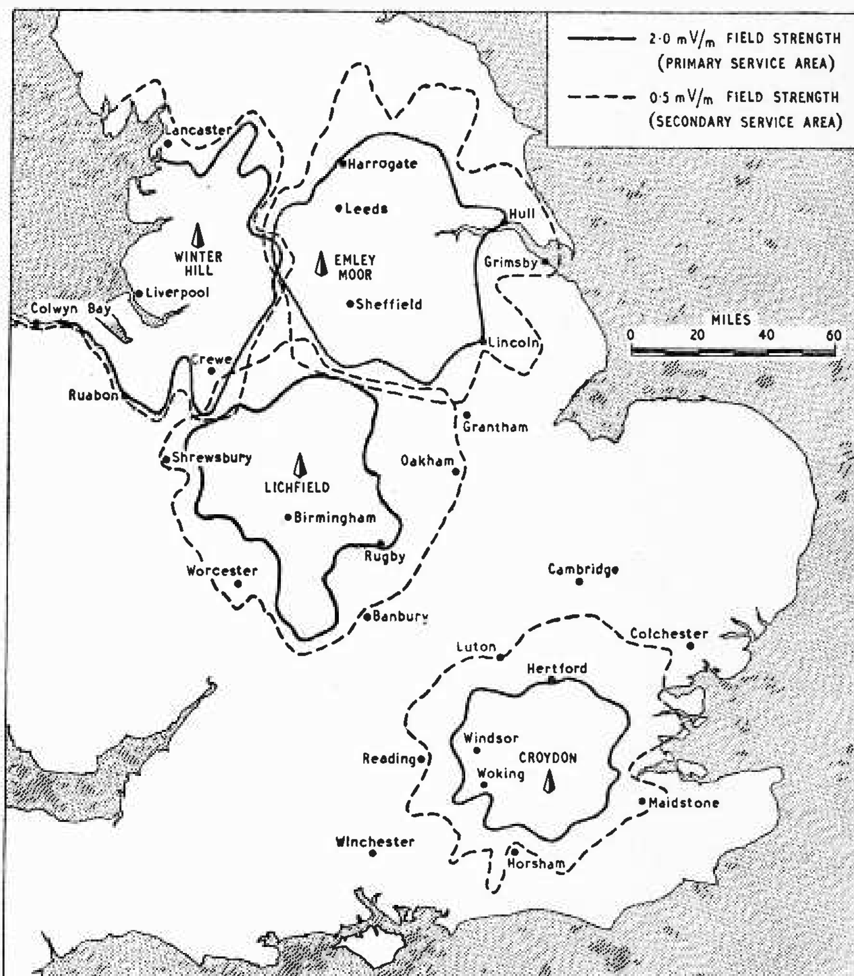
IN April, 1955, at the beginning of the period covered by the last I.T.A. report,* virtually only a first temporary station at Croydon had been begun. With the start of full transmissions from Emley Moor on November 3rd, 1956, the I.T.A. has four stations in operation serving roughly three-fifths of the population of the United Kingdom. Details of this coverage and of the stations themselves are shown in the accompanying map and table.

This period then has been one of very rapid development, which has been helped by the Authority's methods of standardization and, where the time factor necessitated it, of partial improvisation. Thus the new transmitter is essentially a duplicate of that at Winter Hill which is, in turn, the production version of the original prototype equipment at Croydon (described in *Wireless World* of October, 1955, p. 470). While the new aerial is original, the aerials and masts at Winter Hill and Lichfield are also duplicates. At Winter Hill and Croydon a calculated risk was taken in opening the service with only a single transmitter, a standby being installed some months later.

In choosing a site for a station the most obvious solution for the I.T.A. is to follow the B.B.C. and site a transmitter near enough to the B.B.C. to give similar coverage, but far enough away to avoid mast reflections. This was, in fact, done at Croydon and Lichfield.†

However, for the northern region using the highest available site near Holme Moss 200-300 kW e.r.p. with an 800-ft aerial would be necessary on Band III to give similar coverage to the B.B.C. The building of such a transmitter and aerial system would have taken about two years. This time factor was the main reason for the decision to build two stations, one on each side of the Pennines. The transmitter powers could then be less, the aerial masts smaller, and the sites more accessible; at the same time the two-station scheme led to useful standardization of the kind already mentioned and a general lessening of the engineering problems involved. Furthermore, the resultant coverage is, in fact, better than it would be for a single transmitter.

It must not be forgotten that in this rapid development the G.P.O. is responsible for the provision of the necessary interconnecting links in the system and some account of this has already been given in this journal (May 1956 issue, p. 223). For the Emley Moor transmitter a radio link is used and owing to the hilly terrain a repeater station



Coverage of I.T.A. Stations: November 1956.

* "I.T.A. Annual Report and Accounts, 1955-56," H.M.S.O., 2s 9d.

† Some details of the Lichfield station were given in *Wireless World*, December 1955, p. 577, and *Wireless World*, March 1956, p. 111. The possibilities of actual co-siting were discussed in *Wireless World*, March 1955, p. 120.

with a 325-ft aerial mast was necessary to connect with Telephone House in Manchester.

Even with the two-station plan for the north of England the problem of obtaining full coverage from the Emley Moor transmitter was considerable. Most of the population to be covered live in the valleys below the Pennine heights; but there are the important areas of Hull some fifty miles away on the east coast, and of Sheffield nearly due south from the station. In all sixteen possible sites were considered and measurements taken from four of these (using a test transmitter lifted by an R.A.F. balloon) before Emley Moor was finally chosen. Even so, to obtain satisfactory service in Hull it is necessary to have an effective radiated power in an easterly direction of about 200 kW using an aerial about 450ft high. The radiation of such a power in a westward direction into the thinly populated Pennine barrier would have been wasteful and produced overlap with the Winter Hill transmissions. To avoid this Marconi's, who were responsible for the whole of the Emley Moor station, developed a special high-gain (13 dB) directional aerial which has a nearly semicircular coverage.

This aerial has an array of sixteen vertical dipoles stacked in line one above the other at intervals of one wavelength. The dipoles are divided in the middle into two equal groups which are separately fed, suitable phasing between these two groups

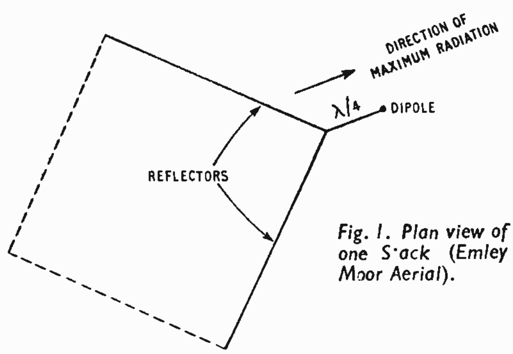


Fig. 1. Plan view of one Stack (Emley Moor Aerial).

giving the direction of maximum radiation a slight downward tilt to the horizontal. There are two identical transmitters, one being kept as a standby, and aerial switching arrangements permit either of them to be connected to either of the eight stacks, or either to both stacks. The latter arrangement—one transmitter feeding both halves of the aerial—is normal. This "split" aerial arrangement, also used at Winter Hill and Croydon, provides minimum loss of power during partial transmitter or aerial failure.

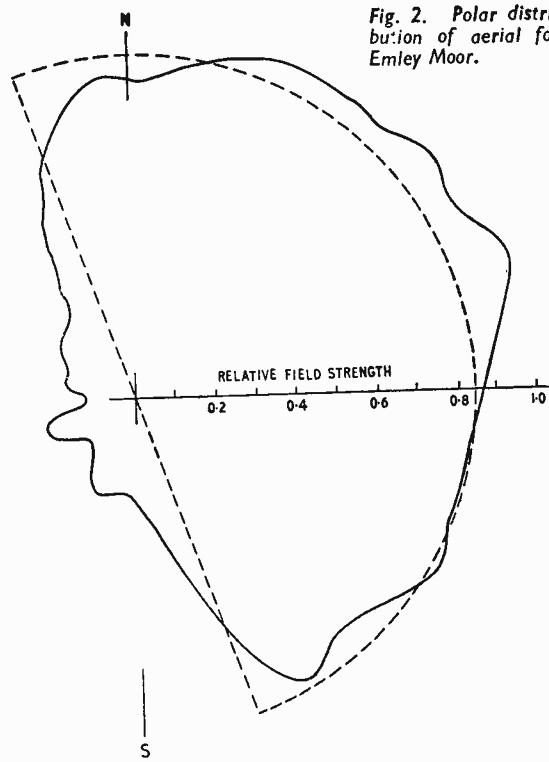


Fig. 2. Polar distribution of aerial for Emley Moor.

Each aerial stack has the dipole supported a quarter wavelength from the apex of two reflectors placed at right angles to each other. These reflectors consist of a grid of vertical rods and lie on adjacent faces of a square tower of five-foot sides, the dipoles being outside the square along a diagonal. A plan view of this arrangement is shown in the accompanying sketch (Fig. 1).

This design results in a forward radiation lobe nearly 180° wide with a rapid fall-off beyond this angle and with an average departure from circularity of only ±0.7 dB in field strength within. This is in contrast to the usual omni- or nearly uni-directional diagrams; or to those which are cardioid shaped, and thus involve considerable radiation loss at the sides. Some experimental results on this aerial are shown in Fig. 2.

As regards general future developments, the I.T.A. plans to open, before the end of 1957, two further stations to cover central Scotland and South Wales, thus increasing the proportion of the population served to three-quarters.

DETAILS OF I.T.A. STATIONS

Station	Population in both service areas, millions	Frequency Mc/s		Transmitter Power kW		Polarization	Aerial			Site Height above sea level ft	Opening Date
		Vision	Sound	Vision (Pk.Wh.)	Sound (Carrier)		Gain	No. Stacks	Height above ground ft		
Croydon	11.2	194.75	191.25	20	5	V	6	8	175	375	22nd Sept. 1955
Lichfield	5.7	189.75	186.25	20	5	V	12	16	400	500	17th Feb. 1956
Winter Hill ...	7.2	194.75	191.25	10	2.5	V	12	16	400	1,450	3rd May 1956
Emley Moor ...	4.9	199.75	196.25	10	2.5	V	24	16	400	850	3rd Nov. 1956

NOTE:—To avoid mutual interference with Winter Hill the frequency at Croydon is actually offset from the nominal figure given in the table by +6.75 kc/s for vision and +20 kc/s for sound.

LETTERS TO THE EDITOR

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

Transatlantic Television

THE approach of the maximum phase of solar ionizing radiations, with the consequent increase in the maximum frequency refracted from the ionosphere and returned to earth over long-distance paths, has aroused some interest in the possibility of receiving American television in this country. Reception of U.K. television sound has already been reported from U.S.A. It is unfortunate that hopes of similar reciprocal direction reception on this side of the Atlantic may be governed by two factors that are likely to reduce the chances of satisfactory reception here to a minimum.

The maximum usable frequency (m.u.f.) for 50 per cent or more of days in October, in the peak, mid-afternoon period, has been about 39 Mc/s from New York, with the usual possibility of this being exceeded on a smaller proportion of days. In November, 1956, the corresponding m.u.f. is expected to reach 42.3 Mc/s, and in December 43 Mc/s, at about 1600 G.M.T. On a few, exceptional days in each of these months, the m.u.f. may well be in excess of these figures by about 10 per cent. On these "high" days, the chances of receiving the lowest frequency U.K. television (Channel 1: vision 45 Mc/s, sound 41.5 Mc/s) in New York should be quite good. This channel is shared by only two television stations—Crystal Palace, near London, and Divis, in Northern Ireland—with differently polarized emissions and with *the same programme*.

The conditions for reciprocal reception of U.S.A. television are much less favourable. Channel 1 is not used for television in U.S.A., having been allocated for other radiotelephony usage. The lowest frequency granted for television transmissions is therefore Channel 2 (54-60 Mc/s). The possibility that this higher frequency will sustain transatlantic reception is very much less. Moreover, this channel is shared by numerous transmitters in U.S.A., of which at least five are located near the Eastern seaboard and are likely to give equal chances of simultaneous reception, possibly with different programmes. Thus, the channel frequency and the channel sharing factors must be taken into account in assessing the likelihood of worth-while reception in either direction. The problem of interference from local transmissions is an added difficulty.

H. V. GRIFFITHS.
Engineer-in-Charge, B.B.C. Receiving Station,
Tatsfield, Kent.

Radar Displays

YOUR recent article on Aeronautical Radio Developments (*Wireless World*, October, 1956) contains a reference to radar displays which does less than justice to the considerable effort devoted to this branch of radar engineering by a number of laboratories.

Throughout the war-time years it was customary to achieve the rotating scan of a PPI display by means of a moving coil linked to the aerial turning mechanism. Other scanning methods were later developed which including rotating electric or magnetic fields derived from a pair of orthogonal deflecting plates or coils respectively. These techniques were conveniently summarized as long ago as 1947 by L. J. Howarth in "Radar System Engineering," Volume I (McGraw-Hill, 1947).

In the years since the war engineering attention has been focussed on the radar display with the object of providing not merely improved radar pictures but rather a synthesis of the maximum of raw radar data in association with ancillary editing information included to make the operational situation more readily assimilable to the controller. In this way rapid and accurate control action can be taken in any military or civil flying situation.

The fixed, cross-coil rotating magnetic field PPI system has proved the most convenient technique for achieving this desirable operational objective and in consequence variants of the system have been developed by a number of laboratories. In this country the first perfected comprehensive fixed coil display system was developed and produced by Marconi's Wireless Telegraph Company in association with the Radar Research Establishment. It is this display system which has found extensive application in the radar defence work executed by Marconi's on behalf of the Royal Air Force.

Marconi's W.T. Company, Chelmsford, Essex. E. EASTWOOD.

"Too Old At—?"

M. G. SCROGGIE, in his article in the September issue, mentions that a young person's high-frequency hearing which extended to 20 kc/s was well within the r.f. communication band.

I can remember, at the age of 21, hearing the call signs and rhythmic time signals from the Rugby long-wave transmitter by simply connecting an aerial and earth with a parallel tuned circuit resonant at 16 kc/s across the input of a gramophone amplifier. Using a 3-inch moving-coil loudspeaker the high-pitched tone of the carrier was clearly audible as it was keyed, and it was possible to read the call letters.

Clifton, Bristol. W. R. BRADFORD.

"Power By Radio"

IN the Editorial of your November issue you refer to an article "Free Power Receivers," by H. E. Hollmann; *Electronic Industries*, Sept., 1956. May I draw your attention to the July issue of the *Short Wave Magazine* in which my article "Crystal Receiver with Self Powered Transistor Amplifier" appeared. I think it anticipated each point made by Dr. Hollmann.

The idea of the wanted station supplying power for amplifying its own signals is not new and a circuit for doing this appeared in the American journal *Electronics* (April, 1955). Although the increase is worth while it cannot by its very nature be very large. Twice the output does not sound twice as loud. However, the power gain on weak signals is much more interesting, as the final power output can compare with that of the local "power" station.

I have now overcome most of the limitations of the system with a receiver incorporating (*a*) a storage system, (*b*) class B output. By using three chargeable 60-mA/hr cells the aerial power (in my case 3 mW from the Third Programme transmitter) is stored, except when the receiver is in use. When receiving signals the steady drain is about 10 mW rising to perhaps 50 mW on signal peaks. Comfortable loudspeaker reception of several stations is thus possible whether or not the "power" station is radiating. Listening is limited to something less than one-fifth of the time that the "power" station is charging accumulators, and I have not had to provide any other form of charge during the four months the receiver has been in use.

Stowe, Bucks. J. M. OSBORNE (G3HMO).

Low-distortion F.M. Discriminator

I WOULD like to correct a statement made by M. G. Scroggie in the April, 1956, issue with reference to my article on "Mobile FM Broadcast Receiver Design" in the May, 1954, issue of *Electronics* magazine. Mr. Scroggie states that "Another receiver, this time for broadcast transmissions, was also designed for a comparatively high i.f. (50 kc/s) with the object of rendering tuning non-critical. . . ."

This is not true. The reason for using a high i.f. is dictated by the fact that an extra wide bandwidth is necessary for the reduction of multi-path and co-channel interference.

New York, U.S.A. KERIM ONDER.

The Author Replies:

As the following quotations from Mr. Onder's article show, both purposes were indicated:

"No afc is required, since the limiter-counter response is wide; hence, frequency drift in the oscillating detector will not affect the quality of reproduction."

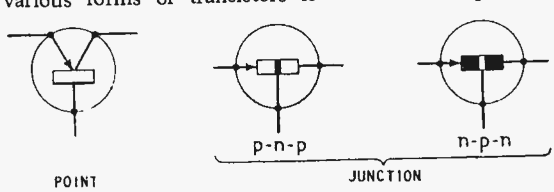
". . . no centering device is necessary for proper tuning. In addition, it is relatively free from multipath and co-channel interference. . . ."

Moreover, the use of wide bandwidth for linear as well as non-linear stages (Mr. Onder's Fig. 2) implies the object of non-critical tuning, for, as Mr. Onder himself points out, for reduction of interference a wide band is not necessary (or, it should be said, even desirable) in the linear (i.f.) stages.

I am sorry, nevertheless, if my inclusion of additional references at the last minute misrepresented Mr. Onder's intentions. M. G. SCROGGIE.

Transistor Symbols

THE need for symbols discriminating between the various forms of transistors is evident from previous



correspondence. My sketch deals with current types, and it aims to identify them in a circuit by their general shape, as with valves. The internal oblong is, of course, the crystal; the arrow head identifies the emitter.

With junction transistors it will be easy to remember which part to black-in by our experience with electrolytic capacitors: "n" = negative, "p" = positive.

London, S.E.1. H. J. COOKE.

Television Picture Quality

AS a photographer I personally feel that too much attention is paid to the technical means by which the television picture is obtained and not enough stress to the photographic quality of the picture.

When opening the Regent Street Polytechnic School of Photography Exhibition in July, 1955, Dr. Kenneth Mees, director in charge of research at Eastman-Kodak Company, Rochester, U.S.A., was outspoken on the subject of quality in the photographic print and remarked that the television engineers in the U.S.A. could well do with a course in photographic print quality where they could learn to appreciate and judge the correct rendering of the subject tones.

London, N.6. K. C. SOUTTER.

Is Distortion Unpleasant?

AS a musician I have been very interested in the discussion of the possibility of arriving at an empirical evaluation of cross-modulation distortion that tallies with the sensation of pleasantness or unpleasantness in the human ear.

There seems to be a general assumption that all discordant sounds are necessarily unpleasant. Discordance is a relative term, since the ear can be schooled to regard as pleasant sounds which, when first heard, are unpleasant. For instance, the chord known to musicians as the Dominant Seventh was at one time regarded as a discord, though it is now regarded as very pleasant, and tends to be overworked.

It is difficult to see the point of enquiring into the pleasantness or otherwise of the pattern of secondary tones produced by two pure tones when the ear regularly listens to such sounds in the worst possible combinations, judged from a theoretical point of view. When, for instance, a note is played or sung with vibrato while the same note is being played on a piano without vibrato, with possibly the octave being played at the same time. Here, although the difference tone could be relatively strong, the fact that it is continually wavering does not seem to upset the ear in the slightest. Again, pianos and organs have to be deliberately mistuned so that they may play equally well in all keys. There are very many people who, in spite of the alarming patterns of difference tones produced, are not even aware of the mistuning. A trained ear may be conscious of the beating effects produced, but does not find this an unpleasant sensation.

As for muddiness induced by difference tones lying low in the audio range, there are many fine and beautiful effects produced by famous composers (by no means necessarily modern) who have deliberately placed close-spaced chords low down to produce a thick, muddy effect; it is to be admitted that such passages do not always sound pleasant, but it is surprising how many do.

It seems obvious that the behaviour of the human ear in the presence of cross-modulation effects is extremely complex, and it would be difficult to predict the circumstances in which such sounds would induce a feeling of unpleasantness. If on the other hand it is known that the harmonic distortion figures of a piece of audio equipment are comfortably low, one can feel reasonably sure that the human ear would not be likely to be offended by the sounds issuing therefrom.

A. J. HICKMAN,
B.A., B.Mus., L.R.A.M.

Servicing Certificates

RESULTS of this year's examinations for the sound and television broadcast Servicing Certificates have now been announced by the Radio Trades Examination Board which, with the City and Guilds of London Institute, organizes them. Entries for both exams. showed an increase over the 1955 figures. Of the 822 entries for the sound radio exam., an increase of 55 per cent, 322 were successful and a further 185 have to retake the practical test. In the television exam. 60 of the 134 entries passed and a further 51 have to take the practical test again.

Next year's sound radio certificate exam. will be held on May 7th, 9th and 18th, and the television exam. on May 13th and 15th and June 22nd. Entry forms and further particulars are obtainable from the R.T.E.B., on which are representatives of the Radio Industry Council, Radio and Television Retailers' Association, Scottish Radio Retailers' Association, and Brit. I.R.E. The address is 9, Bedford Square, London, W.C.1.

Attendance at an approved course of instruction is not essential for these exams., but technicians who have attended are eligible to sit for the examination after a shorter period of full-time employment in radio. An intermediate examination in "radio service work" is conducted by C. and G.I. for which attendance at an approved course of instruction is essential.

The Great Transistor Chaos

By "CATHODE RAY"

2—Sorting Out the Mess

LAST month, after having taken a quick glance at the present state of ideas about the transistor as a circuit component (and having even more quickly backed away, shuddering violently), we reviewed the corresponding situation of the negative-grid valve, with the object of seeing (if we could) how transistors had got into the present mess and if there was a way out.

Let us try to summarize the summary I gave at the end. Nearly all valves as normally used have effectively three electrodes so far as signals are concerned. The input and output pairs of connections add up to four. So one electrode must be common to both. That makes three possible basic configurations: common cathode, common anode (or cathode follower) and common grid. Of these the common cathode is so much the most important that the valve characteristics or parameters are invariably measured in that condition. There are three possible two-terminal paths between the three electrodes, but of these only one—cathode to anode—normally passes current, so is the only one to appear in the "equivalent circuit" which for signal calculations can be substituted for the valve. It has two basic parameters: r_a, signifying its own resistance; and μ, the degree of control by the grid. (Other parameters, such as g_m and g_a, can be derived from these.) The equivalent circuit therefore consists of two things between cathode and anode terminals, and these two can be arranged in series or parallel: either a generator giving an e.m.f. $-\mu v_{kg}$ in series with a resistance r_a, or one giving a current $-g_m v_{kg}$ in parallel with a conductance g_a. These hold good regardless of the circuit in which the valve is used, but are directly useful only in the common-cathode configuration. For the other two, the corresponding parameters in terms of input e.m.f. are different; but rather than invent special symbols for them one usually expresses them in terms of the common-cathode parameters, r_a and μ.

Second-Best Symbols

Now let us turn to the transistor. It too has three electrodes, so there are three possible configurations: common emitter, common base and common collector. But at once a complication arises, because the first kind of transistor to be invented was the point-contact type. When used in the common-emitter configuration, which is the one analogous to the common-cathode, it tends to be unstable. The common-base arrangement is free from that difficulty, and even apart from that it seemed at first to be the more obvious way of using transistors. So the parameters were normally measured in that condition, and symbols for them became well established. Later, junction transistors appeared, which are stable in common-emitter circuits and offer more convenient input and output resistances than in common-base. But Jacob had by then grabbed the birthright, as it were, leaving the common-emitter Esau with the second best—the same symbols with the addition of a "′." At the present time there is every sign that junction transistors will oust point-contact types and that the common-emitter configuration will be the predominant one. In addition to the advantages already mentioned, it is the only one of the three that gives both current and voltage gain simultaneously, so its power gain is much the greatest. And it is the only one that does not necessitate some parameter being measured as a difference between two larger quantities, and therefore relatively inaccurately. So altogether its parameters ought to have first choice of symbols. It will be too bad if, because of an accident of birth, the commonly used parameters are condemned for evermore to bear the mark of subordination, while the exceptionally used ones (which in valve practice have not even been allocated symbols at all) have primary symbols such as α. The standardizing committees ought to look into it at once.

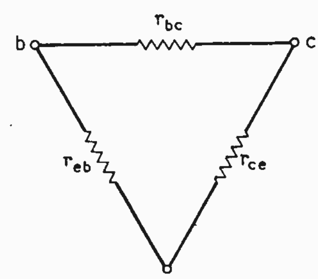


Fig. 1. The conducting paths between all three pairs of transistor terminals can most obviously be represented by this delta circuit.

The next complication comes from the fact that all three inter-electrode paths conduct. So in place of just r_a for the valve the transistor equivalent circuit must have at least three resistances. The obvious way to arrange these in an equivalent circuit is to put one between each pair of terminals, making a delta system, as in Fig. 1, which also suggests a logical nomenclature for the resistances. But what about the generator? Is one generator enough? I hasten to assure anxious readers who might have been envisaging the necessity for three generators that one *is* enough. But that very fact raises the invidious question as to which resistance shall have the generator. At the moment we are supposed to be keeping an open mind, unprejudiced by anything anyone else has done. We are aiming at a basic equivalent, independent of the circuit in which it may find itself. Does any one of the three paths qualify more than the others as the place for the internal generator?

Well, clearly the output part of the transistor is the most appropriate place. And this does make a distinction, for although theoretically one can connect the input circuit between (say) emitter and collector, and output between emitter and base, one wouldn't do so in practice because the transistor would merely act as an attenuator, and if that is what one wanted one wouldn't dream of using a transistor for it.

The snag is that although in two configurations the output is connected between collector and emitter, in the third it is connected between collector and base. So no one of the resistance paths has an exclusive claim to the generator. But we note that in all three cases the collector terminal is involved. So if we substitute (as we can*) a star formation for the delta, as in Fig. 2, we can put the generator in the collector branch without serious risk of complaints. This move simplifies the resistance nomenclature, too.

I haven't actually shown the generator in Fig. 2, because we still have a question to settle. Is it to be a voltage generator in series with r_c, or a current generator in parallel? As we saw with the valve, both are possible, but one of them can perhaps be regarded as the more fundamental. A valve is definitely a voltage-operated device at the input, and μ is the voltage amplification factor, so it is natural to think first of the output in terms of a voltage generator giving μ times the input volts. The alternative, the current generator giving g_m times the input volts, is then derived from it. That the transistor is a current-operated device is not quite so unquestionable, because the input signal voltage is by no means zero. But it can be accepted as current-operated for two reasons: its input resistance is low—lower even than the output—and the output is much more linear in relation to input current than to input voltage. So in place of the voltage amplification factor μ there is a current amplification factor α. It is natural, then, to regard the output as due to a current generator in parallel with r_c giving α times the input current. There can then, presumably, be an alternative voltage generator in series with r_c—and some sort of factor to give its voltage in terms of input current.

But immediately the question arises, *What* input current? For a start, which is the input terminal of the transistor? Until quite recently, the answer would have been the emitter. One has only to look at the standard symbol for a transistor! But nowadays the tide is flowing in favour of the base, and it certainly would be chosen if one went by analogy with the valve; but not all transistor authorities do. So what about it? Is there some decisive consideration?

Terminal Logic

We decided that the collector is *the* output terminal, on the reasonable ground that it is the only one used in the output in all three main configurations. In two of them, both base and emitter are input terminals, but in the third—common-collector—the emitter is not an input terminal while the base is. So clearly the base is entitled to be the input terminal of a transistor. And therefore the base current is *the* input current—*not* the emitter current, as in point-contact transistor circuits. Base and collector having by strict logic been appointed input and output terminals respectively, the only title left for the emitter is "common terminal," which clearly implies that the common-emitter configuration is the normal or basic one. On top of all the other arguments, this seems to clinch the matter. All the more unfortunate, then, that the symbol α was appropriated by the common-base. I do hope those committees will more than look into it.

*But not by the star-delta transformation we studied two months ago, since that applies only to passive networks and this is an active one (because of the generator).

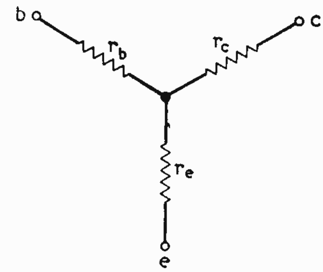


Fig. 2. The alternative star formation has the advantage of associating each resistance with one particular terminal.

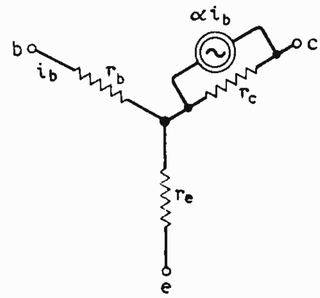


Fig. 3. Because the collector terminal is the one always used for the output, the equivalent generator is most appropriately located in that arm of the star. And because the transistor is primarily a current amplifier, the first choice is a current generator.

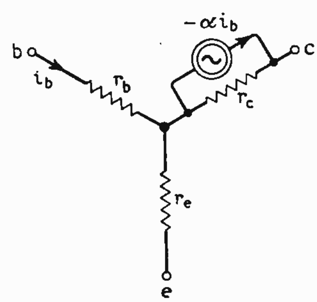


Fig. 4. Here the positive directions of the input and amplified currents are marked in agreement with the convention for valves. This, at last, is a basic transistor equivalent circuit. But note that here the symbols α and r mean what they ought to, not what they do in practice.

However, not waiting for them to act, let us pursue our ruthless logic regardless. According to it, Fig. 3 ought to be the basic equivalent for the transistor, equally valid in all circuits. Its α has no necessary connection with anybody else's α, but is defined strictly by the diagram. Nor, for the matter of that, are r_e, r_b and r_c necessarily the same as anybody else's r_e, r_b and r_c.

There remains the little question of sign. The positive directions of i_b and αi_b have to be decided by convention; that having been done, the sign of αi_b is decided for us by physical facts. The positive direction of the input voltage of a valve is conventionally regarded as being from cathode to grid. By analogy, the input voltage of a transistor would be from emitter to base, which would tend to drive current *into* the base. So we can regard that as the positive direction. If we continue to be guided by analogy with the valve we must take the positive direction of the generator as that which tends to make current flow out from the collector. That being so, the physical nature of a transistor obliges us to use a minus sign. So the complete result of our labours is as in Fig. 4.

Please remember again that this has been arrived at logically, without reference to past or present practice, and so the symbols do not necessarily have the same meanings as anyone else's. As a matter of fact, this transistor equivalent circuit is one of the recognized forms, and the symbols agree with current practice except for r_c and α, which are generally understood to be applicable to the common-base configuration. Even then there is a discrepancy (usually quite negligible) between α as officially defined and the multiplier in the current generator.

Published Data

As recently as last year a well-known exponent based his recommendations with regard to transistor parameters on the fact that all readily-available published data assumed the common-base configuration. But already that situation has almost completely reversed, as the transistor section in the 5th edition of *Wireless World* "Radio Valve Data" shows. Personally, I am for founding recommendations on the logic we have just been exercising, rather than on such shifting sand as published data. It is for published data to fall into line with requirements—as they can do quite quickly when the need arises. I would even go so far as to say it is not too late to appoint α and r_c as the symbols for the parameters shown in Fig. 4. Better the necessity, for a year or two, of having to declare clearly every time that the "new" convention is being used, than be handicapped for ever by a clearly transitory and illogical convention. After all, for many years "C" was the standard symbol for "current," and yet it was found possible to transfer it to "capacitance" without causing complete chaos in electrical engineering circles. And the older readers will remember that "Ω" used to stand for "megohm," "ω" being the symbol for "ohm." So please, committees, don't put it off!

At this stage, filled with pride at having achieved the one and only true basic transistor equivalent circuit, we may suppose that the only thing remaining to be done is to derive the parameters for the two other configurations, just as we did last month with the valve. There is, in fact, no great difficulty in doing that. It is even simpler than one might expect; for instance, in the common-base circuit r_e and r_b are unchanged, and r_c is not very much changed. But if long experience and disillusion have built up in us a strong ingredient of caution we will be feeling rather uneasy about all those pages and pages of transistor equivalent circuits and all those sets and sets of parameters for which somehow we don't seem to have felt the need. The authors of the books containing them—were they really just wasting their time, and everyone else's? Or is what we have done too easy to be true, and are we the ones who have been wasting time?

No, I don't think we have been wasting time by striking out from scratch, disregarding everyone else, and achieving a single basic equivalent. But the caution is right, too, because when we examine our achievement from the practical point of view we find it has distinct disadvantages. To begin with, we can't directly measure our four basic parameters. Therefore it is necessary to have some other parameters that can be measured, and devise our basic parameters from them if we want. But will we want? After all, they are means to an end, and the end is usually the calculation of such things as input and output resistances, optimum load, and amplification. Given r_a and μ for a valve, these things can be found with the greatest of ease. But not so with the transistor and its corresponding r_e, r_b, r_c and α.

For one thing, as we can see from Fig. 4, connecting a load to *c* and *e* alters the input resistance as seen between *b* and *e*. Similarly, altering the resistance of the signal source attached to *b* and *e* affects the output resistance seen between *c* and *e*. (I really ought to say "impedance" every time, but for simplicity we are working at low frequencies and neglecting reactances.) And the internal generator not only drives signal current into the output circuit but also to some extent back through the input. So the equations for the things we want to know are considerably more complicated than they are in valve circuits. As it happens, they are especially complicated when given in terms of our chosen parameters.

Cause of the Chaos

So there are two good reasons for choosing other parameters, such as can be directly measured and yield simple design equations. And that, in brief, is the cause of the chaos at which we took a fleeting glance last month. Mind you, I don't consider it is a complete justification of it. What has happened is that the bright boys who were turned loose on transistor development said to themselves that it took their forerunners many years to evolve valve circuit theory, and their little fingers were jolly well going to be thicker than their fathers' loins. And so they went wild and invented far more varieties of equivalent circuit than anyone found a use for in a generation of valve work. Admittedly the transistor problem is more complicated and no doubt justifies the

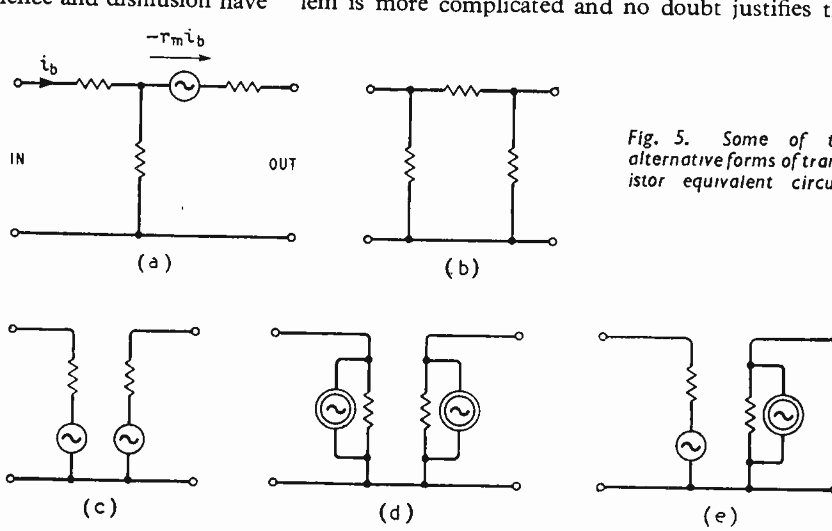


Fig. 5. Some of the alternative forms of transistor equivalent circuit.

use of a larger number of alternatives. But let not the beginner be intimidated by the idea that all those that have been published are essential to him. It is better to have a few that are understood, even if some of the calculations may be a little longer and less elegant than they need be, rather than get confused by a multiplicity of alternatives. I am sure that in time the really useful ones will survive and the others will be forgotten except perhaps by academic types.

But since it would be rash to prophesy which ways these cats will jump, let us review them generally and see why they were invented.

Equivalent Circuit Forms

First, the alternative *forms* of the equivalent circuit. Fig. 4, as I said, is one of the recognized ones. The series voltage generator variation is even better known. Like the current generator type, it is always drawn in T form, as in Fig. 5(a). Just as the valve parallel generator necessitated a derived parameter g_m to relate generator current to input voltage, so this transistor series generator necessitates a derived parameter r_m to relate generator voltage to input current. (Readers familiar with duality will note it here.) Fig. 5(a) illustrates the common practice of basing the form on the input and output terminals, rather than on the transistor electrodes. As a result, the generator comes in the collector arm for two configurations but in the emitter arm for the third (common-collector). Our Fig. 4, on the contrary, is the same for all configurations, and thereby seems to me less likely to confuse.

The Fig. 1 form is also known, but in view of what I have just said you will be prepared to find it drawn as in Fig. 5(b). There are actually six varieties of this alone, according to where the generator is placed, and whether it is current or voltage—and that doesn't count the differences in parameter values according to configuration! Because they are not often used I haven't bothered to draw them all, but leave you to fill in the generator according to taste.

Then new vistas are opened up when one realizes that it is not compulsory for only one of the four necessary circuit elements to be a generator. There can be two generators and two resistances. Indeed, the two-generator equivalent shown in Fig. 5(c) was highly recommended by W. T. Cocking in the series I mentioned last month. And if one gets tired of voltage generators one can always change to Fig. 5(d). And there is a school of thought that considers that the transistor is best represented by one of each, as at (e). And so we could go on.

Then for each of these forms there are many varieties according to the system of parameters favoured. And then the whole lot has to be done twice again to cover the other two configurations!

As regards the forms, I'm not going to try to argue the advantages and disadvantages of each. But the sort of argument that comes in can be seen by thinking back to the two alternatives for the valve—the series voltage generator and the parallel current generator. Either *can* be used for any valve, but for low-resistance triodes the series arrangement is more convenient because a low resistance has least effect when it is in series. The very high resistance of a pentode matters least when it is in parallel, and it is more sensible to work with it that way than to have to assume a very high-voltage generator to overcome the very high series resistance, even though the other way does give the same answer. Similarly one can argue in favour of any of the innumerable transistor forms for particular purposes, but I do feel that the thing has been overdone. Too wide a choice defeats its object.

The other question was the different systems of parameters. The reason for them, you remember, was the need for something that can be measured. Even if the parameters marked on the equivalent circuit cannot themselves be measured—those in Fig. 4 for instance—there have to be some measurable ones from which to calculate them. One system that has been used quite a lot consists of four resistances, r_{11}, r_{22}, r_{12} and r_{21}. The first of these is the input resistance, measured with the output open-circuited. In practice this means the ratio of signal input voltage to signal input current, the signal output current being kept constant by using an external series resistance that is very large compared with the transistor's own output resistance, or in some other way. The second, r_{22}, is the output resistance measured with the input short-circuited. These are both true a.c. resistances, but the other two are "transfer" resistances, in the same way that the g_m of a valve is a mutual or transfer conductance or transconductance as the Americans call it: r_{12} is the ratio of input voltage to *output* current, the input current being kept constant; and r_{21} is the corresponding thing the other way through. This set of parameters can be used to calculate the r_e r_b r_c α set by simple formulae, or it can be inserted directly in Fig. 5(c)—which raises that form in the estimation of advocates of this set of parameters—or else they can be used directly in equations to calculate the gain, etc., of the transistor.

An obvious variation is to turn all these resistances upside down into conductances, in conjunction with Fig. 5(d). Another, recommended by Mr. Cocking, is to substitute forward and backward amplification factors, α and β, for r_{12} and r_{21}, α being r_{12}/r_{11} and β being r_{21}/r_{22}. All these varieties, by the way, are measured in the common-base configuration. According to the present silly symbolism one has to add one tick to each for the common-emitter values and two to each for the common-collector values. In the book already mentioned, the need for r_c' in the common-emitter circuit is avoided by calling it r_d, but that seems rather a makeshift.

Pros and Cons

One snag about the r_{11} r_{22} r_{12} r_{21} system and its variants is that modern transistors tend to have such high output resistances that for the purposes of measuring r_{11} it is hardly practicable to use an external resistance which by comparison is vastly greater. This is a point urged in favour of the hybrid or h system, in which the parameters are h_{11}, h_{22}, h_{12} and h_{21}. As Mr. Cocking pointed out, however, the fact that these are not (as the first glance would lead one to think) all quantities of the same kind—the same dimensions—but comprise one resistance, one conductance and two numerical ratios, is a point against the system.

A disadvantage possessed in varying degrees by

(*Continued on page 605*)

all the systems mentioned so far—and not least, I am afraid, by our r_e r_b r_c α—is that the equations giving the transistor gain, etc., in terms of them are quite inconveniently complicated. For this reason the Mullard people have introduced yet another modification of the r_{11} r_{22} r_{12} r_{21} system, in which the r_{12} and r_{21} are displaced by r_{in} and r_{out}, which are measured in the same way as r_{11} and r_{22} respectively, except that the far end is short-circuited instead of open-circuited to signals.* The relationships are:

$$r_{in} = r_{11}(1-\alpha\beta) = r_{11} - r_{12}\,r_{21}/r_{22}$$
$$r_{out} = r_{22}(1-\alpha\beta) = r_{22} - r_{12}\,r_{21}/r_{11}$$

By making these substitutions, the design equations are reduced to something resembling the simple ones used with valves, and at the same time the effects of varying the signal source and load resistances are made easier to see.

Although we seem to have looked at quite a lot of things this time, they can be summarized quite simply. Working on the same successful lines as we did last month with the valve, we evolved an analogous equivalent for the transistor, with its parameters in terms of the common-emitter configuration, but valid for all. As a result of the transistor having three conducting paths in place of the valve's one, this single theoretically definitive equivalent circuit turns out to be awkward for practical measurements and calculations. So a considerable number of alternative forms of circuit and sets of parameters have been devised by divers persons. And because no one of these is unquestionably the best, search for the ideal is likely to result in the marketing of yet more. Even without these there are too many. I am not going to risk predicting which will survive as the best general-purpose system, but there seems to be quite a lot to be said for Mullard's. However, the theoretically and practically predominant common-emitter configuration must have its symbols rid of all those nasty little ticks. How about it, standardizing committees?

*"An Improved System for Calculating the A.F. Performance of Junction Transistors," by L. B. Johnson. *Mullard Technical Communications*, Vol. 1, No. 8 (July 1954), p. 187.

EUROPEAN TELEVISION

AT the end of July, when this map was prepared by the European Broadcasting Union, there were well over one hundred television stations operating in Europe and the number has increased considerably since then. In Italy, alone, a further seven stations have come into service. In the table we give, in addition to the number of stations operating in July, the standards employed (number of lines and bandwidth in Mc/s).

Austria (625/7)	4
Belgium (625/7: 819/7)... ...	2
Denmark (625/7)	1
France (819/14)	14
Germany, Western (625/7) ...	31
Italy (625/7)	29
Luxembourg (819/7)	1
Monaco (819/14)	1
Netherlands (625/7)	2
Norway (625/7)...	1
Saar (819/14)	1
Spain (625/7)	1
Sweden (625/7)	1
Switzerland (625/7)	4
United Kingdom (405/5) ...	18
	113

Transistor Super-Regenerative

WORKING CONDITIONS FOR OPTIMUM PERFORMANCE

WHERE it is necessary to obtain high gain from a receiver with a minimum of components, the super-regenerative principle has been widely used, and the theory for valve super-regenerative circuits is well developed. In essence, a super-regenerator is a high-frequency oscillator, at carrier frequency f_o, which is periodically quenched at a quench frequency f_q. If a modulated carrier signal is injected into the oscillator tuned circuit, the resulting pulses of oscillation contain the original modulation amplified by the super-regenerative gain factor; this modulation is then extracted by straightforward detection of the oscillation pulses. Typical gain figures for super-regenerative stages are in the order of 80 dB.

A transistor can be made to oscillate up to about its cut-off frequency, f_α, and usually somewhat higher; the idea, therefore, suggests itself to make use of this ability to oscillate to obtain super-regenerative gain at these high frequencies where linear r.f. or i.f. gain using the same transistor is difficult, if at all possible, to obtain.

The development of superheterodyne receivers using transistors has so far been limited largely to the medium- and the long-wave bands because of the difficulty of designing r.f. and i.f. transistor amplifiers. Such amplifiers can now be made with

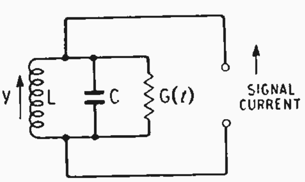


Fig. 1. Basic equivalent super-regenerative circuit.

stage gains of about 30 dB at frequencies up to the order of half the transistor cut-off frequency f_α. They are, however, difficult to design as they must be very carefully neutralized to avoid oscillation. The advantage is, therefore, evident of employing, where possible, the super-regenerative principle in transistor high-frequency circuits.

It should be noted that, with normal quench arrangements, super-regenerative receiver circuits are limited to frequencies above about 10 Mc/s. This is because the quench frequency f_q must be at least twice the highest modulation frequency to be detected (from information theory), yet must be lower than the carrier frequency by a factor of about 10^3 to assure adequate quenching of each pulse of oscillation. The Philco surface barrier transistor was chosen for these studies as it can be made to oscillate readily to frequencies above 50 Mc/s.

A short review of the theory of super-regeneration is given first to underline the difference between the two basic modes of operation. Some transistor self-quench circuits have appeared in the literature[1,2]; the advantage of linear mode operation for speech and music is pointed out and a linear super-regenerative detector circuit is given using two transistors.

Theory of Super-regeneration.—The quenched high-frequency oscillator, or super-regenerator, can be regarded as a parallel-tuned circuit damped by a periodically varying conductance and into which is injected the signal (see Fig. 1).

The conductance will vary over the quench cycle from negative (during oscillation) to positive (during quench), as shown in Fig. 2(a).

At time t_1, as the damping factor G decreases to zero and becomes negative, oscillations begin in the tuned circuit, building up from the level of the signal (or noise, whichever is dominant) existing in the tuned circuit at that time. Oscillations continue to build up until G becomes positive again, thus damping them out. The total positive G area must be several times the total negative G area to ensure adequate quenching, so that oscillations build up from signal or noise and not from remnants of previous pulses of oscillation.

Two modes of receiver operation are possible. If, as in Fig. 2(b), the oscillations are quenched before they begin to be limited by the circuit supply voltages, the pulses of oscillation then have amplitudes linearly proportional to the signal levels from which they began. This is the "linear mode" of super-regenerative operation, and is the useful mode for speech and music modulation. Fig. 3 shows a photograph of a series of linear mode pulses of oscillation from a super-regenerator responding to a sinusoidally modulated carrier. Linear mode super-regenerators require a quench signal to be applied from another circuit stage (some form of low-frequency oscillator). The modulation is obtained by diode rectification of the r.f. pulses, and filtering

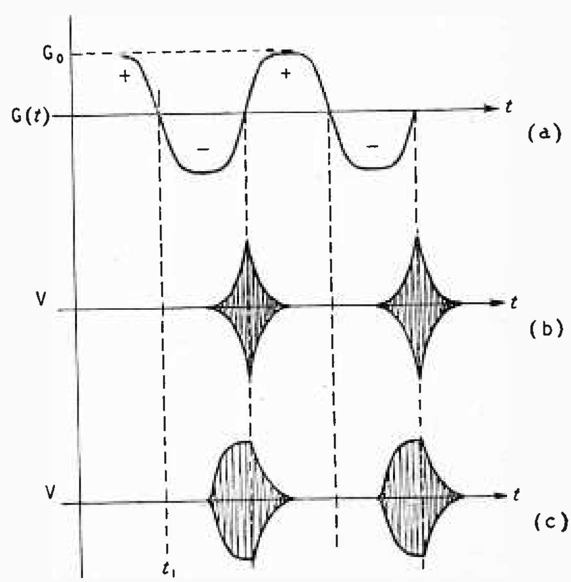


Fig. 2. Behaviour of quenched oscillator; conductance changes over cycle shown at (a) with pulse shapes for linear (b) and logarithmic (c) modes of operation.

Circuits

By D. F. PAGE

out the audio envelope components (envelope detection).

If, however, as in Fig. 2(c), oscillations are allowed to limit before being quenched, the pulse lengths are then logarithmically proportional to the signal levels from which they began, and operation is said to be in the "logarithmic mode." The distortion in this mode is undesirable for speech and music reception, although acceptable for code reception.

Self-quenching or "squegging" super-regenerators operate in the logarithmic mode and no external quench voltage is required. In this case oscillations quench themselves when they reach a fixed level. Thus, since successive pulses of oscillation grow from different signal levels (for a modulated input carrier signal), there will be more pulses for a high instantaneous signal level than for a low one. In the self-quenching circuit there is a "built-in" quench which varies in frequency according to the signal modulation. Detection for all logarithmic mode super-regenerators is accomplished by measuring changes in the total area of oscillation pulses, i.e., by averaging, over audio time intervals, the super-regenerator current.

Self-quenched Transistor Super-regenerator Circuit.—The literature on the subject of transistor super-regenerators has so far been confined to this type of circuit, which is the simplest to construct and operate. Several "squegging" arrangements are possible; Fig. 4 shows the one used by the author.

The circuit is a conventional collector-tuned r.f. oscillator with feedback applied in the base circuit *via* a step-down transformer; C_2 is an r.f. bypass capacitor. As oscillations grow, the fed-back voltage is rectified at the emitter diode, charging C_1 through R_2. As C_1 charges negatively the emitter diode is cut off and oscillations die down, not to begin again until C_1 has discharged through R_2 and R_1 in shunt with the back emitter resistance. The quench frequency is therefore determined largely by the value of R_1, although R_2 contributes somewhat; the amount of feedback (determined by the transformer turns ratio) is also important in determining the quench frequency.

The tuning frequency of the circuit is determined by C and by the inductance presented by the transformer. The table gives the circuit details for two amateur bands.

TABLE

For operation on	20 metres	15 metres
N_1	24 turns	12 turns
N_2	14 turns	8 turns
C	30 pF	30 pF
R_1	100 kΩ	100 kΩ
R_2	1 kΩ	1 kΩ
C_1	0.01 μF	0.02 μF

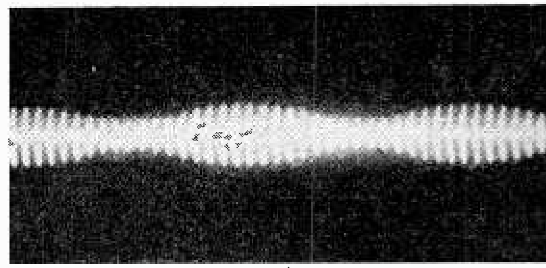


Fig. 3. Linear mode pulses produced by a sinusoidally modulated carrier.

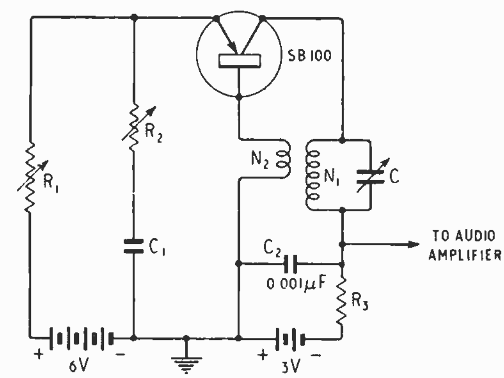


Fig. 4. Self-quenched super-regenerator using a high-frequency junction, or surface barrier, transistor.

The transformer is close-wound on ¼-in diameter plastic rod with N_2 wound on top of N_1. The aerial may be coupled by means of two or three separate turns wound on the transformer rod. No. 30 s.w.g. enamelled wire was used for all windings.

The collector current is averaged at the bypassed resistor R_3, the voltage across which is the required audio modulation output. A convenient value for R_3 is approximately 1 kΩ; this matches very well into a succeeding common-emitter audio stage, yet is not high enough to drop the collector voltage seriously. It is emphasized again here that the modulation output bears a logarithmic relationship to the original modulation and is thus severely distorted. In addition, there is a strong quench frequency component in this low-frequency output, but this can be filtered out in the audio amplifier.

Linear Mode Transistor Super-regenerative Circuits.—For undistorted reproduction of speech or music we require linear mode operation of the super-regenerator, with a separate low-frequency oscillator to supply the quench voltage. A complication arises in obtaining the audio output as the r.f. oscillation pulses must be rectified and envelope detected.

The r.f. oscillator must have a variable feedback element which can be used to control the build-up of oscillations so that super-regeneration can be kept linear. Several of the conventional feedback-type oscillator circuits can be adapted for this purpose, but for simplicity and economy of components a less conventional arrangement, which we will call the "Q-current" circuit, is chosen for this discussion. This is drawn in Fig. 5(a) where it will be noted that no direct feedback is used. The circuit is, in fact, similar to that of the familiar base-tuned negative-resistance oscillator using point contact transistors. The surface barrier transistor, behaving as it does as a junction transistor, will not oscillate in this circuit at low frequencies. It can, however, be shown that at higher frequencies approaching the transistor cut-off frequency f_α, a junction transistor in the circuit of Fig. 5(a) will exhibit a negative base input resistance and will oscillate.

The mechanism of this oscillation is indicated in Fig. 5 (b) where the transistor equivalent circuit has been drawn in. For oscillation, a current multiplication mechanism is required to make that component of emitter current i_d in phase with the current generator αi_d at least twice the value of αi_d. In low-frequency oscillators a transformer is used for this multiplication. At these high frequencies, however, we make the emitter resistance r_d a part of a branch of the parallel tuned circuit, so that i_d becomes part of the "Q-current" of the tank circuit and is amplified by the approximate factor

$$\frac{C_1}{C + C_1 + C_c} \cdot Q$$

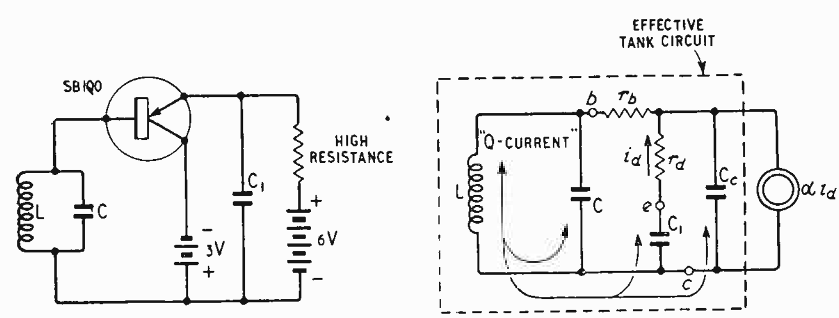
over the tank circuit input current αi_d. This factor assumes r_d and r_b are small; at the highest frequencies these resistances limit the Q and thus limit oscillations. It must also be noted that i_d is predominantly capacitive, and to give a magnified component in phase with αi_d, α must have a lagging phase shift; this is so only at frequencies approaching the order of magnitude of the transistor cut-off frequency. In practice, a surface barrier transistor can be made to oscillate in this circuit over a frequency range of about 5 Mc/s to 50 Mc/s.

Oscillations are controlled by C_1, which in the author's circuits is usually a 30-pF trimmer; C_1 is adjusted to a low value at which super-regenerative oscillations do not limit so that linear mode operation is ensured. Reception frequency is determined by C which should be kept high (by using a low L/C ratio) to minimize the effects of changes in C_1 and the collector capacity C_c.

Quenching may be accomplished in one of two ways:—
(1) by switching the transistor itself, as for example in Fig. 6(a) where the emitter is switched at quench frequency, or (2) by switching an element external to the transistor, as for example in Fig. 6(b) where a diode shunt on the tuned circuit is switched at quench frequency.

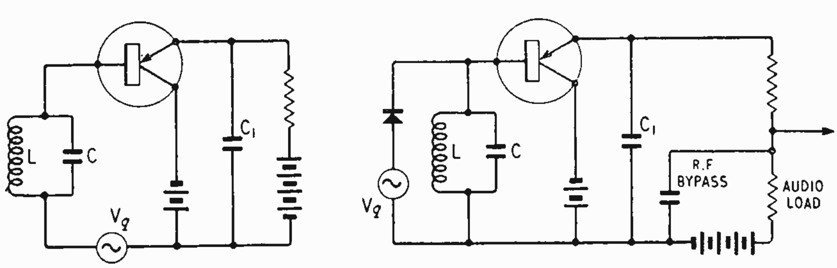
This second alternative has several advantages. It allows the transistor to operate at a fixed operating point, and so eases the problem of applying the existing theory of super-regeneration to the design of transistor super-regenerators. A further advantage arises because, during the damping part of the quench cycle, the tuned circuit is shunted by the forward conducting diode, while in Fig. 6(a) the tuned circuit is shunted by the back emitter resistance. The more effective damping by the external diode of Fig. 6(b) results in less danger of "coherence" between oscillation pulses at higher quench frequencies. Finally, quenching *via* an external diode greatly eases the problem of detecting the modulation. Since the transistor does not "see" the quench voltage (the tuned circuit is a short-circuit for low frequencies) we may make use of the "built-in" diode at the emitter to rectify the super-regenerative pulses. The mechanism is as follows:—

As oscillations grow, the emitter resistance acts as a diode, and the r.f. component of emitter current assumes the shape of pulses in the forward direction. Thus the r.f. current entering the tank circuit is in the form of pulses, and the oscillator operates in a manner analogous to class C, with the tuned circuit smoothing out the effect of these current pulses. The pulses of emitter current carry the quench and audio amplitude modulation, which can be extracted, as indicated in Fig. 6(b), from an audio load in the emitter after the r.f. component has been bypassed. This low-frequency output consists of a series of pulses at quench frequency, amplitude modulated with the audio signal. Maximum undistorted audio voltage available here is about 10 millivolts across 1,000 ohms. Fig. 7 is an oscillogram of such a series of detected pulses which have been passed through two stages of audio amplification using OC71 transistors in the common-emitter connection.



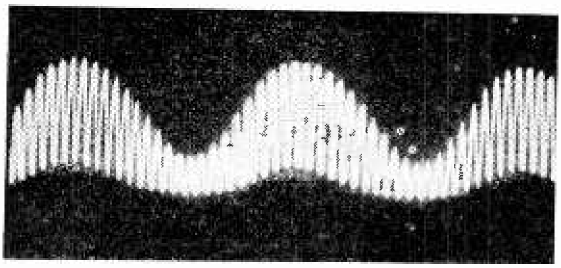
(a) (b)

Fig. 5. Transistor r.f. oscillator shown at (a) with its equivalent circuit (b) showing "Q-current" paths.



(a) (b)

Fig. 6. Methods of quenching, (a) via the emitter, (b) via an external diode.



L may be 25 turns of No. 30 s.w.g. enamelled wire, close-wound on a ¼-in diameter plastic rod; the aerial may be coupled with two turns wound on L. C may be a 30-pF trimmer.

The question of radiation interference should be mentioned. It has been common practice with valve super-regenerators to use an r.f. buffer stage between the aerial and the super-regenerative stage to prevent radiation of the oscillations. Transistor r.f. stages are not easily designed, and indeed the use of such a stage would seriously reduce the super-regenerator's advantage of simplicity. It has been found, moreover, that with the small amplitude levels of transistor oscillators, the radiation problem does not appear to be serious.

Fig. 7. Oscillogram of audio output.

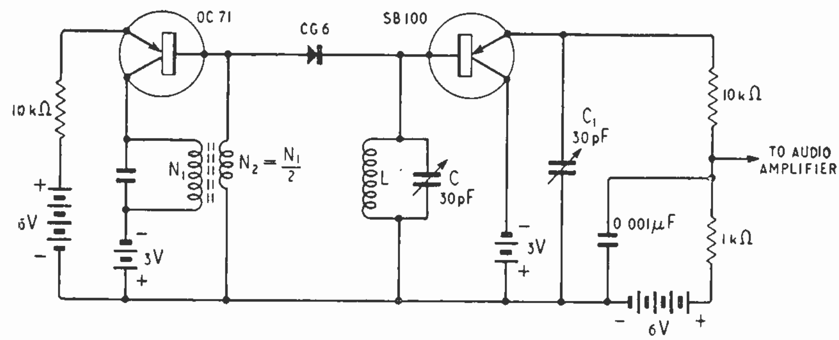


Fig. 8. Linear mode super-regenerator.

The quench frequency components may be removed by suitably restricting the bandwidth of the audio stages.

Fig. 8 shows a complete linear super-regenerator circuit using this method of quench. The quench oscillator is a conventional low-frequency type; the transformer in the circuit was wound for convenience in a Mullard Ferroxcube pot core. A quench frequency of 15 kc/s is generally suitable. The tuned signal circuit is designed for the carrier frequency employed. For operation at 13 metres,

References

[1] W. A. Wadsworth "A Transistor Super-Regenerative Receiver for 10 and 6 Metres," *QST*, November 1954, p.17.

[2] Kircher and Kaminow "Super-regenerative Transistor Oscillator," *Electronics*, July 1956.

BRIT. I.R.E. AWARDS

THE Clerk Maxwell Premium, the premier award of the British Institution of Radio Engineers for papers published in the institution's journal during the year, has been received by E. M. Bradley and Dr. D. H. Pringle for "The theory and design of gas-discharge microwave attenuators." Dr. Pringle is in Ferranti's electronics research laboratory, where Mr. Bradley was until recently. The value of the premium is 20 guineas.

Dr. R. Filipowsky, who was head of the electronics department of Madras Institute of Technology and is at present with the Westinghouse Electric Corporation, Baltimore, U.S.A., is awarded the Heinrich Hertz Premium (20 gns.) for "Electrical pulse communication systems." The premium is awarded for the most outstanding paper dealing with the mathematical or physical aspects of radio.

The Louis Sterling Premium (15 gns.), awarded for the most outstanding paper on television technique, is received by D. R. Coleman, D. Allanson and B. A. Horlock for their paper "The development and design of an underwater television camera." The first two authors are with Pye Limited but Mr. Horlock, who was formerly with that company, is now in Plessey's radio research department.

Dr. Sin-Pih Fan, who was formerly with the Burroughs Research Centre, Paoli, Pennsylvania, and has now returned to China, receives the 10-guinea Marconi Premium (for the most outstanding engineering paper) for "The magnetron beam switching tube."

For their paper "A survey of tuner designs for multi-channel television reception" D. J. Fewings (Marconi's) and S. L. Fife (English Electric) receive the Leslie McMichael Premium (10 gns.) which is awarded for a paper on improvements in the technique of broadcast and television reception.

LOUDSPEAKERS with moulded ellipsoidal baffles, to be known as the "Unicorn" series, have been added to the range of units made by the Trix Electrical Co. Ltd., 1-5, Maple Place, London, W.1. The radiation pattern is virtually a 45° beam with minimum back radiation, a feature which can be exploited to reduce microphone feedback in public address systems.

Audio-Frequency Response Measurements

DEVELOPMENT OF SPECIAL GEAR FOR ROUTINE TESTING

By O. E. DZIERZYNSKI

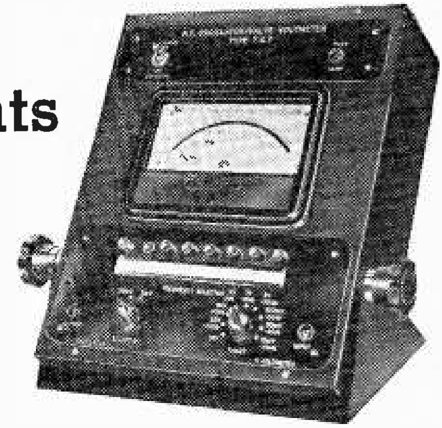


Fig. 1. Combined a.f. oscillator and output meter for routine testing of amplifiers and tape recorders.

GENERALLY speaking the performance of a.f. amplifiers and tape recorders is defined by: (1) non-linearity distortion (for a given maximum output); (2) frequency response; (3) sensitivity (and associated with it hum and noise level); (4) wow and flutter (applied only to recorders).

Conventionally, the routine test equipment required for measuring the above would comprise at least four separate units, namely: (1) audio-frequency oscillator; (2) valve voltmeter; (3) distortion meter; (4) wow/flutter meter. Some of these instruments can be used separately (for example, the flutter meter); others have to be used in pairs. For instance, the frequency response characteristic requires the use of both oscillator and valve voltmeter.

A special self-contained instrument has been developed for this purpose, and although this unit has been used chiefly in the factory production line, it is felt that the circuit details may be of general interest.

Basically, the frequency response test is a simple operation. To the input of the audio equipment is injected a constant a.f. voltage, at various frequencies in turn. The output of the audio equipment is then measured by means of an output meter (usually a valve voltmeter having a response independent of frequency over the operating range). It is obvious that while testing an ordinary amplifier, both operations can be made simultaneously, but with a tape recorder, two operations have to be carried out in turn. First, a recording of the test frequencies has to be made, then these frequencies are played back and corresponding outputs noted by the valve voltmeter.

The chief requirement for an oscillator is constant output throughout the range of test frequencies; additional requirements are fairly good waveform, low hum level and good frequency stability. Frequency selection has been achieved by employing an eight-way push-button unit, selecting the following frequencies: 60 c/s, 300 c/s, 1,000 c/s, 4 kc/s, 8 kc/s, 10 kc/s, 12 kc/s, 13 kc/s. There is no hard and fast rule about the choice of frequencies and different combinations could be arranged if necessary. Push-button control has the advantage of speed where mass routine testing is concerned. The use of a press-button unit in place of a rotary switch also confers some benefits in construction and wiring.

Output Meter. There are numerous types of valve voltmeters, but not all will satisfy users and constructors alike and at the same time be reasonable in cost and reliable in service. Chief requirements for this sort of instrument are: (1) gain independent of frequency (within the limits 15 c/s-20 kc/s); (2) fairly high input impedance, constant on all ranges (not less than, say, 2 MΩ); (3) properly damped movement of meter needle; (4) well-designed sub-ranges and associated scale calibration. Additional important requirements would be calibration independent of mains voltage variations and low power consumption (to reduce heat and prevent deterioration of components—an important point if equipment is working continuously all day).

The photograph (Fig. 1) shows that the combined instrument is mounted on a special base which enables it to be tilted to any convenient angle. The operating panel is small and is situated at the bottom of the case, so that the operator can work with minimum effort. The middle part of the instrument is occupied by a standard 4½-in moving-coil meter. On the top of the front panel are located the mains switch and indicator lamp. The right-hand bottom side of the operating panel is occupied by the valve-voltmeter controls (input socket and range switch), while the oscillator controls are located on the left (output socket and two-way switch providing outputs of 20 mV and 2 mV). The frequency selector buttons are situated just under the meter.

The circuit of the valve voltmeter is given in Fig. 2. One section (V1a) of the first double triode works as an input cathode follower, while V1b and the first section of the second ECC83 (V2a) form a two-stage R-C amplifier. V2b functions as an output cathode follower which feeds a full-wave bridge rectifier and 0-1 mA meter (100 μA movement shunted by 150 ohms).

Point X which feeds the meter rectifiers is also connected to the negative feedback line (25 μF, P_2 and 0.5 MΩ) reducing the total gain from approximately 5,000 to 1,000 (60 dB). Consequently the standard sensitivity of this voltmeter is 10 mV for full scale deflection (10V is obtained at point X, which is large enough for the bridge rectifier to give a linear scale from 1/10 of f.s.d. corresponding to the minimum measurable input, 1 mV).

The next things to consider are the input attenuator and how particular voltmeter ranges have been designed. The attenuator is connected in the output of the first cathode follower. This gives the great advantage that the attenuator network is associated with the fairly low impedance of the cathode follower output circuit (of the order of 500-1,000 ohms in the case of the ECC83). Consequently hum pick-up and instability effects are greatly reduced and only moderate screening arrangements have to be made, relating to this part of the circuit. At the same time the input impedance of the instrument (grid circuit of the cathode follower) is very high (in the range 10-30 MΩ) and independent of the range being used. Components associated with the input circuit (0.05 μF, 1 MΩ, 27 kΩ) must be well screened.

There are eight ranges in this instrument, covering the following voltages: (1) 1-10 mV, (2) 3-30 mV, (3) 10-100 mV, (4) 30-300 mV, (5) 0.1-1 V, (6) 0.3-3 V, (7) 1-10 V, (8) 3-30 V.

Groups of ranges with odd and even numbers have been provided with separate meter scales (Fig. 3). The maximum reading on the middle scale (3, 30, etc.) does not quite correspond to maximum readings for the upper scale (10, 100, etc.) which are related to f.s.d. This has been arranged to give a correct reading for every range on the lower decibel scale. The latter has zero level at division marked 3.16 on top scale and -10 dB, $+10$ dB correspond to 1 and 10 (f.s.d.) respectively.

On the middle scale 1 corresponds with 0 dB and 3.16 would correspond with 10 dB. By changing range by one step (irrespectively of what range is being used) the reading indication is always

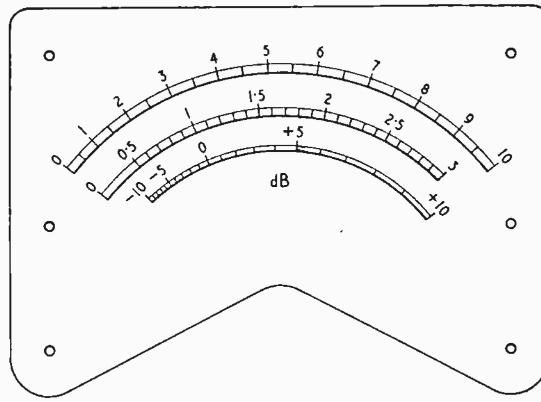
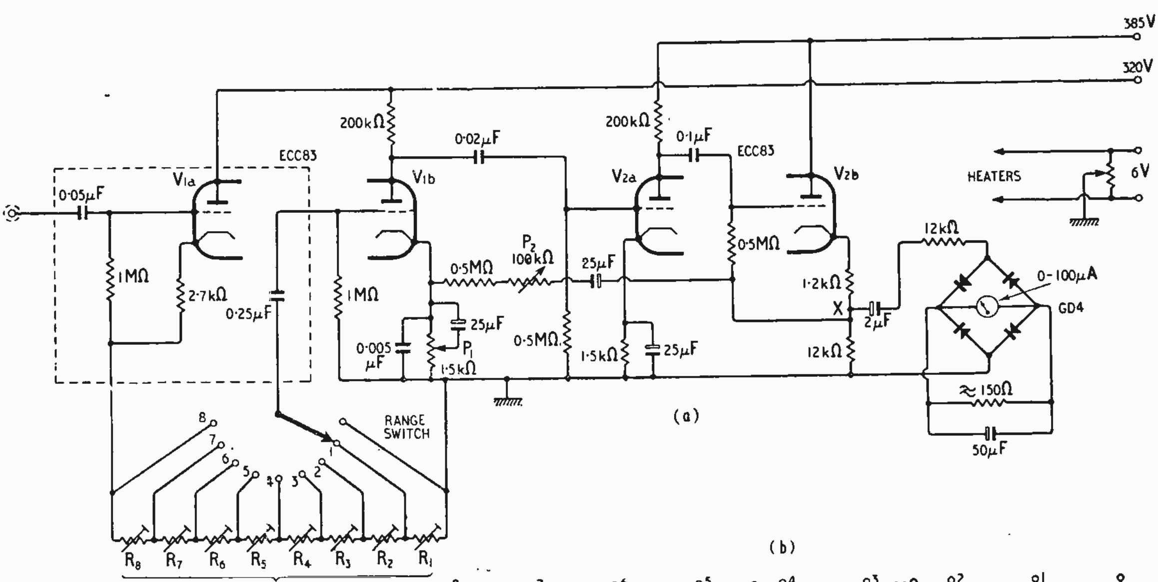


Fig. 3. Meter scales are calibrated on the basis of a 10 dB change of level between contacts on the range switch.

stepped up or down by 10 dB. This sort of arrangement is very helpful when making a quick calculation of the gain difference in decibels of two readings. For instance, if the first reading was +7 dB on range (2) and the second reading -5 dB on range (1), the gain difference would be $+7-(-5)+10=$ 22 dB.

The attenuator itself is a simple voltage divider across the cathode load resistor of the input cathode follower. The total resistance is 70 kΩ and as the first valve takes approximately 1 mA, more than 80 volts d.c. is developed across this load, and the maximum measured a.c. voltage, which is 30 V r.m.s., will be well below the minimum undistorted signal passed through the cathode-follower stage. Values of the resistors R_1 . . . . . . R_8 are calculated on the basis that the resistance to chassis of, say, contact 3 has to be 3.16 times larger than the resistance to the previous contact 2, and this would apply to con-



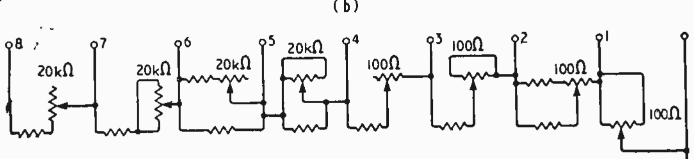


Fig. 2. (a) Complete circuit of valve-voltmeter section. (b) The range potential divider is adjusted by various series-parallel connections of preferred-value fixed resistors and potentiometers.

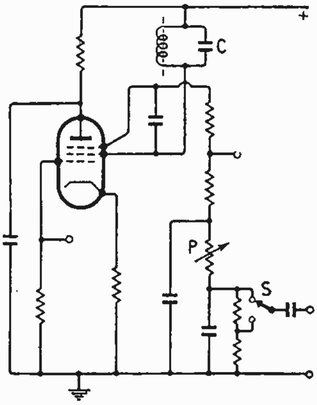


Fig. 4. Basic transitron oscillator circuit.

secutive contacts. R_1 . . . . . . R_8 are mostly of non-standard values and if accuracy of calibration is to be maintained to within, say, ±2 per cent, then resistors must be of corresponding close tolerance. The problem has been solved by using ordinary preferred-value resistors ±20 per cent, combined with pre-set potentiometers in each section. To simplify the supply of components, only two values of variable resistor have been selected, namely, 20 kΩ and 100 Ω, connected in various ways as shown in Fig. 2 (b).

The next important feature of the valve-voltmeter circuit is the negative feedback line, by means of which stability of gain is ensured in spite of ageing of valves, mains voltage variation and change of signal frequency. Potentiometers P_1 and P_2 are pre-set controls for negative feedback and the reason that there are two of these controls is as follows. At the higher audio-frequencies (above 10 kc/s) the gain of triodes starts to drop gradually, but negative feedback by virtue of the presence of the 0.005 μF bypass condenser would decrease as well, compensating loss of gain and maintaining frequency response to well over 20 kc/s. From the circuit it will be seen that there could be several combinations of the settings of P_1 and P_2 to maintain gain up to, say, 10 kc/s, but these would not hold for higher frequencies when the slider of P_1 is set near to the earth end of the potentiometer. Consequently there is some optimum combination of P_1 and P_2 when the gain over the frequency range 15 c/s to 40 kc/s is maintained constant within ±5 per cent (below 20 kc/s it can be maintained with ±1 per cent).

To allow for an adequate degree of feedback an initial overall gain of the order of 5,000 is required, and to achieve this an h.t. line voltage of 385 was necessary, giving a gain of about 75 per stage with each half ECC83. The h.t. supply to the first double triode is through a 30 kΩ resistor decoupled by 100 μF; otherwise the circuit had a tendency to be unstable.

The total h.t. current does not exceed 5 mA. This is quite a low figure, which satisfies our requirements for low power dissipation in this equipment.

The cathode-follower output stage is conventional, but it should be noted that the values of bias resistor and cathode load have to be chosen carefully to secure at least 20 V across the latter. Otherwise the cathode follower would not handle the maximum value of signal applied to the grid of V2b (approximately 10 V to give full scale deflection).

Oscillator Circuit.—The chief requirements of a stepped frequency oscillator working in this sort of equipment are good stability of amplitude (independent of mains voltage variations), low power consumption, and fairly good waveform.

For simplicity and reliability a single-valve pentode oscillator was developed based chiefly on the transitron circuit. The basic circuit is shown in Fig. 4. The valve used is an EF86 with the suppressor grid driven from the screen, which is connected as the anode of the oscillator. An a.f. voltage of the order of 40 is developed across the tuned cir-

(Continued on page 613)

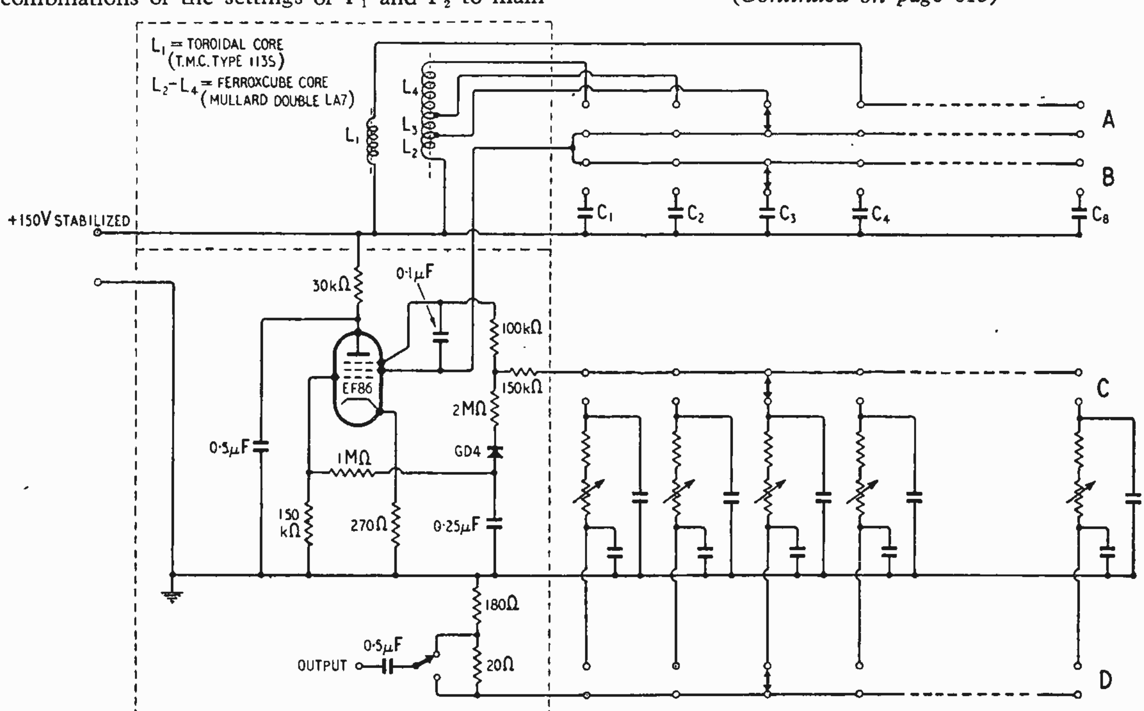


Fig. 5. Complete circuit diagram of oscillator section.

cuit LC, which determines the oscillator frequency. The waveform across LC is not good enough to be fed directly to the output voltage divider and a R-C filter plus attenuating network is inserted between the tuned circuit and the output terminal. Outputs of either 20 or 2 mV are available by using the two-position switch S, and their value is accurately adjusted by means of potentiometer P.

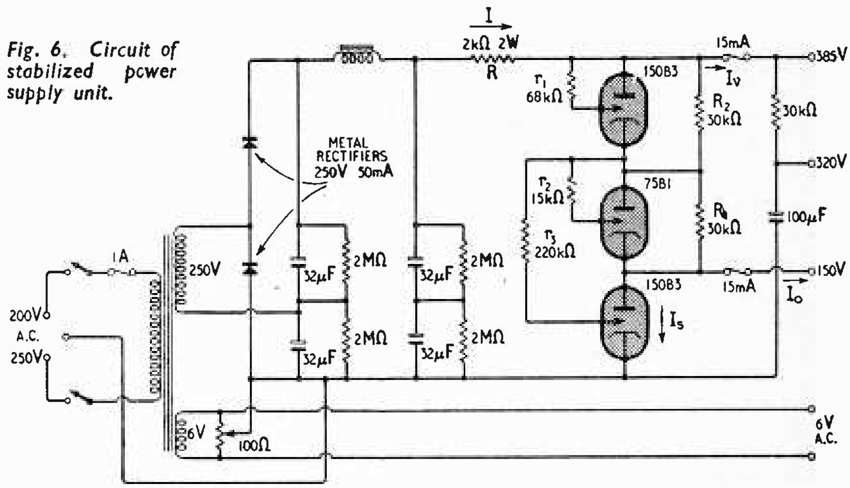


Fig. 6. Circuit of stabilized power supply unit.

Regarding the transitron circuit itself, it is a rather interesting fact that anode and grid are not "live" as far as a.f. is concerned, but their d.c. potentials have to be carefully chosen for oscillator performance. For instance, it is essential that the anode voltage should be substantially lower than that of the screen. It will be seen from Fig. 5 that the value of bias resistor is fairly low to help to start oscillations, which after building up drive the grid more negative (by diode GD4 action), improving the waveform across LC and introducing a certain amount of negative feedback to stabilize the output. This detail is important as we must bear in mind that the oscillator is frequently being switched over from one frequency to another, and while doing so it might happen that no button is depressed and oscillations would be interrupted.

To cover the full audio range at least four different inductances are necessary. In our case the five highest frequencies, 4-13 kc/s, are covered by a toroidal coil of 25 mH consisting of somewhat fewer than 50 turns of enamelled and s.s.c. 24 s.w.g. wire on a T.M.C. Type 113S high-Q moulded core. The three lower frequencies, i.e., 60, 300 and 1,000 c/s, have circuit inductances of 12, 5 and 1 H respectively. A double LA7 "Ferroxcube" core has been used here with 4,000 turns of 46 s.w.g enamelled, tapped at 2,400 and 1,700 for L_3 and L_2 respectively.

Switching arrangements are shown in Fig. 5. The two top banks of press-button units (A, B) control actual frequencies (switching over coils and condensers) while the two bottom banks (C, D) are associated with individual R-C output filter units. The two-stages filters reduce harmonic content to approximately 1 per cent which is quite satisfactory for the frequency response test.

Power consumption of the oscillator circuit is low; as the total h.t. current does not exceed 4.5 mA and the h.t. power dissipated is well below 1 watt.

Power Supply Unit.—Special attention has been given to the design of the power supply unit as much depends upon its performance. The circuit of Fig. 6 gives all essential electrical data. Three stabilizers are connected in series, one having a working voltage of 150 and the other two of 85 volts. Some of these stabilizers are shunted by additional resistors and there is a common feed resistor R, the value of which is quite important. Also, there are additional resistors, r_1, r_2, r_3, for feeding the auxiliary ignition anodes.

Calculation of the stabilizing chain should be carried out in the following way:

(1) First determine the lowest h.t. voltage at the output of the smoothing filter—depending on the lowest expected mains voltage. This voltage V is approximately 410 (equivalent to a mains supply of 200 volts).

(2) Calculate total current consumption I (in resistor R). As can be seen from the diagram, curent I is equal to the sum of currents supplied to the valve voltmeter (I_v), oscillator (I_o) and I_s in bottom stabilizer (150B3):

$$I = I_v + I_o + I_s$$

Values for I_v and I_o are 5.5 and 4.5 mA respectively and I_s from 150B3 data as lowest permissible current, is 2 mA.

Therefore total current will be: 5.5+4.5+2= 12 mA.

(3) Now it is possible to calculate the value of R which is $\frac{410-385}{12} \approx 2\,k\Omega$.

(4) Values for shunting resistors R_1 and R_2 are easily calculated from the known current which has to bypass each stabilizer. As the minimum working current for stabilizer 75B1 is 2 mA, R_1 has to bypass 2+4.5−2 mA across voltage drop 85 V, hence: $R_1 = \frac{85}{4.5} \approx 20\,k\Omega$. Similarly $R_2 = \frac{150}{4.5} = 33\,k\Omega$. The degree of stabilization depends largely upon the value of R, which has to be as large as possible; this can be achieved by making the available unstabilized voltage as high as possible and total current consumption as low as possible. Now it becomes clear why it is so important to reduce h.t. current in the instrument and to choose types of stabilizers with minimum permissible working current. When the mains voltage rises the currents in the stabilizers increase rather rapidly, but the working voltage (total 385 V) and bypass currents in R_1, R_2 remain practically unchanged.

For mains voltage fluctuations of ±10 per cent the oscillator output does not vary by more than ±0.5 per cent and the valve voltmeter gain is stable within ±1 per cent.

To reduce hum the heater supply is earthed through a 100-ohm potentiometer (humdinger). This is important particularly with regard to hum induced in the input circuit of the first cathode-follower valve. Without this humdinger, and with one side of the heaters earthed, the hum level would be of the order of 5-10 mV which would upset readings on the first two ranges of the valve voltmeter. When the humdinger is properly adjusted the hum is reduced to 50 μV.

Constructional Details.—Sections of the instrument are built as self-contained units with separate plugs and sockets for power supply. The power supply unit is at the top with an open-mesh cover for good ventilation.

Screening for the input circuit, as indicated in Fig. 2(a), is essential and it is important that wiring to the "top" part of the attenuator should be short and carefully spaced. Resistors and potentiometers of small physical size are desirable in this circuit. Otherwise the layout and wiring of the instrument are not critical.

Acknowledgment.—The author would like to express gratitude to J. Roast and R. Dean for help in the development of this equipment.

Wave Propagation: An International Symposium

REPRESENTATIVES from fifteen countries attended an International-Symposium on Wave Propagation held in Paris in September. The meeting was under the joint auspices of the Comité National Français de Radioélectricité Scientifique and the Societé des Radioélectriciens. A large number of papers were presented within the two separate groups covering ionospheric and tropospheric radio wave propagation. The papers, which covered many aspects of the two subjects, are to be published in a special number of *L'Onde Electrique*. What follows is a summary of the outstanding points arising from the discussions, which were of considerable interest.

Ionospheric.—It is now evident that our past conception of wave propagation *via* the ionosphere, based as it is upon geometric-optics, was far too simplified, and that the subject is much more complex than was envisaged. The geometric-optical theory is not fully adequate to explain what happens to a wave within the ionosphere because of the effects of inhomogenities, due to various causes, in the ionization. There are, for example, movements and undulations of different kinds, concentrations or "clouds" within the layers, ionospheric turbulences and meteoric trails. All these give rise to propagation effects outside the realm of geometric-optics, such as the forward-scattering of radio energy, and these scattering processes, which occur at the ground as well as within the ionospheric layers, modify the mechanism of propagation. In engineering practice this means that the m.u.f.s, which are calculated on the basis of the optical theory and applied to long-distance propagation by empirical methods, are generally too low. The calculated circuit m.u.f.s may therefore now be regarded merely as good approximations to the "actual" m.u.f.s: they have, in fact, long been observed to be nothing more. The question of how to deal with these complexities, so as to obtain more precise circuit predictions, is a difficult one and is still a long way from solution, but we may be sure that the information presented at the Symposium, and the discussions which resulted, will contribute towards that end.

It was evident, also, that the use of ionospheric scatter systems for communication is becoming a matter of growing importance. Some interesting discussion took place concerning the question as to whether the scatter on which such systems depend is due to ionospheric turbulence or to the effects of meteoric ionization, but the matter was not resolved. It appears that both phenomena may play a part and that it may be possible to make particular use of either. The growing use of these systems (which remain fixed in frequency) in the point-to-point communication networks may, perhaps, lead to some relief from channel congestion, because of the decreasing need for multi-frequency operation and because the scatter range is limited.

Tropospheric.—Similarly, in the field of v.h.f. and u.h.f. propagation through the troposphere it was apparent that ideas are undergoing fundamental alteration. What was at first supposed to be a case of line-of-sight propagation has already been shown to suffer no such limitations, and to be useful for communication services to distances far beyond the horizon. But these distances, and the quality of the service achievable over them, are being rapidly advanced. Distances up to 750 miles were mentioned as being attainable for reliable communication when the phenomenon of tropospheric scatter is utilized. Experiments designed to gain more knowledge of the characteristics and uses of tropospheric scatter propagation are being pressed forward, and it is to be noted that this system is suitable for wide-band transmissions. A great deal of work in connection with the meteorological factors which affect all kinds of tropospheric propagation is being done, and it is evident that the successful development of systems utilizing this depends, to a large extent, upon a more complete understanding of the meteorological factors affecting the refractivity and other relevant parameters of the atmosphere. The equipment requirements for these services were also discussed, and in particular the design of the paraboloid aerials, whilst the great value of space diversity in preserving the coherence of the tropospherically scattered signal at long distances was stressed. T. W. B.

Switched-tuned F.M. Unit

An unfortunate error in arithmetic resulted in wrong values being given for capacitors C_n and C_p in the Appendix to this article on page 434 in the September issue. Capacitor C_n should be 12.3 pF and C_p 37.7 pF. Using nearest preferred values the 50-pF tuning capacitor becomes 12 pF N470 in parallel with 39 pF P100. The N470 type should have been the smaller value. In line eleven N740 should be N470.

DECEMBER MEETINGS

LONDON

3rd. I.E.E.—"Electronics and automation—the use of nucleonic devices" by Dr. Denis Taylor at 5.30 at Savoy Place, W.C.2.

7th. Television Society.—"90° Scanning" by R. H. C. Morgan and K. E. Martin at 7.0 at 164 Shaftesbury Avenue, W.C.2.

11th. Institution of Post Office Electrical Engineers.—"The Independent TV network—its operation and maintenance" by C. E. Clinch and J. B. Sewter at 5.0 at the I.E.E., Savoy Place, W.C.2.

12th. I.E.E.—"The B.B.C. sound broadcasting service on very-high frequencies" by E. W. Hayes and H. Page at 5.30 at Savoy Place, W.C.2.

12th. Brit.I.R.E.—"Principles of the light amplifier and allied devices" by Dr. T. B. Tomlinson at 6.30 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

13th. British Kinematograph Society.—"A magnetic-tape recording system for colour television signals" by Dr. H. R. L. Lamont at 7.15 at the R.S.A., John Adam Street, W.C.2.

18th. I.E.E.—Discussion on "Breakdown in dielectrics" opened by C. G. Garton and J. H. Mason at 5.30 at Savoy Place, W.C.2.

21st. B.S.R.A.—"Some applications of magnetic recording" by J. Cunningham-Sands at 7.15 at Royal Society of Arts, John Adam Street, W.C.2.

ABERDEEN

12th. I.E.E.—"Tridac—a large analogue computing machine" by Lt.-Cdr. F. R. J. Spearman, J. J. Gait, A. V. Hemingway and R. W. Hynes at 7.30 at the Caledonian Hotel.

BELFAST

11th. I.E.E.—"The Crystal Palace television transmitting station" by F. C. McLean, A. N. Thomas and R. A. Rowden at 6.30 at the Engineering Department, Queen's University.

BIRMINGHAM

3rd. I.E.E.—"The Crystal Palace television transmitting station" by F. C. McLean, A. N. Thomas and R. A. Rowden at 6.0 at James Watt Memorial Institute.

CAMBRIDGE

4th. I.E.E.—"Ultrasonics in industry" by C. F. Brocklesby at 6.0 at Cambridgeshire Technical College.

CARDIFF

5th. Brit.I.R.E.—"Voltage stabilization" by Dr. F. A. Benson at 6.30 at the Cardiff College of Technology.

12th. Society of Instrument Technology.—"Electronic computers in relation to process control" by A. J. Young at 6.45 at the Physics Lecture Theatre, Cardiff College of Technology.

CHELTENHAM

14th. Brit.I.R.E.—"Radio astronomy" by R. L. Adgie at 7.0 at the North Gloucestershire Technical College.

DUNDEE

13th. I.E.E.—"Tridac—a large analogue computing machine" by Lt.-Cdr. F. R. J. Spearman, J. J. Gait, A. V. Hemingway and R. W. Hynes at 7.0 in the Electrical Engineering Department, Queen's College.

GLASGOW

13th. Brit.I.R.E.—"The design and manufacture of modern capacitors" by J. H. Cozens at 7.0 at 39 Elmbank Crescent.

LEEDS

4th. I.E.E.—"Electronics and automation: some industrial applications" by Dr. H. A. Thomas at 6.30 at the Central Electricity Authority, 1 Whitehall Road.

LIVERPOOL

13th. Brit.I.R.E.—"An automatic system for electronic component assembly" by K. M. McKee at 7.0 in the Council Room, Chamber of Commerce, 1, Old Hall Street.

MANCHESTER

5th. I.E.E.—"A point-contact transistor scaling circuit with 0.4 microsec resolution" and "A junction-transistor scaling circuit with 2 microsec resolution" by Dr. G. B. B. Chaplin at 6.45 at the Engineers' Club, Albert Square.

6th. Brit.I.R.E.—"Electronic automation applied to the wind tunnel" by D. S. Wilde at 6.30 at the Reynolds Hall, College of Technology, Sackville Street.

11th. Society of Instrument Technology.—"Control of the radio telescope" by Dr. J. G. Davies at 7.30 at the College of Technology.

14th. Institute of Physics.—"Electroluminescence and light amplification by phosphors" by Professor G. F. J. Garlick at 6.45 in Bragg Building, The University.

NEWCASTLE-ON-TYNE

12th. Brit.I.R.E.—"The design and application of quartz" by R. A. Spears at 6.0 at Neville Hall, Westgate Road.

PORTSMOUTH

10th. I.E.E. Students.—"Television outside broadcasting units" by F. H. Steele and K. T. D. Hughes at 6.20 at the C.E.A., High Street.

14th. B.S.R.A.—"New B.B.C. disk reproducing equipment" by H. J. Houlgate at 7.30 in the Lecture Hall, Central Library, Portsmouth.

REDDITCH

10th. I.E.E.—"Ultrasonics in industry" by C. F. Brocklesby at 7.30 at the College of Further Education, Easemore Road.

RUGBY

11th. I.E.E.—"The application of digital computers" by R. L. Grimsdale at 6.30 at the Rugby College of Technology and Arts.

SWANSEA

13th. I.E.E.—"Germanium and silicon power rectifiers" by T. H. Kinman, G. A. Carrick, R. G. Hibberd and A. J. Blundell at 6.0 at the Electricity Board Showrooms, The Kingsway.

TORQUAY

4th. I.E.E.—"Digital computers" by A. C. D. Haley at 3.0 at the Electric Hall, Union Street, Torquay.

WOLVERHAMPTON

12th. Brit.I.R.E.—"Design of an experimental colour television receiver" by H. A. Fairhurst at 7.15 at Wolverhampton and Staffordshire Technical College, Wulfruna Street.

RANDOM RADIATIONS

By "DIALLIST"

Marine Radar

BEING very interested in all that concerns radar, I've attended whenever possible the hearing in court of cases connected with collisions at sea in which one or both of the ships involved carried that wonderful aid to navigation. I don't think it's much of an exaggeration to say that, in open waters at any rate, collisions couldn't occur (except deliberately) if proper plotting were done and full use made of the information provided by it. Yet again and again I've heard examination bring out either that there wasn't any plotting or that it was done too roughly to be of any use. The trouble is that the plan position indicator (P.P.I.) of the radar set shows your own ship as remaining stationary at the centre of the screen and any others as moving in relation to it. Only by plotting can you obtain a working picture of the true motion of your ship and another. You can't do it in your head, particularly when there are other things to think about. And even if careful plotting is done at regular intervals when another ship is close, there's always the possibility of human error.

True Motion Presentation

That's why I welcome the coming of the Decca "True Motion" radar. In the "picture" shown by this device your own ship does not remain a fixed point. It moves over the screen according to its actual course and speed and so does the "blip" corresponding to other moving vessels. Only things that really are stationary—anchored ships, buoys and so on—remain fixed in position. The navigator of a ship fitted with this device will thus be able to tell quickly and without possibility of error whether his ship and another are on collision courses. Curiously enough I'd been thinking of a device on rather different lines for some time before this new Decca was announced. My idea was for a kind of marine predictor on the lines of those used in A-A and naval gunnery. Into the A-A predictor are fed the height and the changing range and bearing of the target, obtained visually or by radar. It then predicts the actions necessary to make the shell hit the target. You wouldn't, of course, need the height at sea and this predictor would tell you what to do to *avoid* hitting the target.

Tropospheric Scatter

FOR many months Marconi's have been operating continuously a tropospheric scatter link between Great Bromley, Essex, and Sutton Bank, near Thirsk, Yorkshire, using a transmitter with an output of only 500 watts. This 200-mile link, described as a purely private venture, is to be supplemented by another, between London and Newcastle, equipped with a 10-kW transmitter and intended for handling up to 36 simultaneous telephone calls or a television transmission. If the system fulfils its early promise, it should be of enormous value to the G.P.O. as well as to the B.B.C. and the I.T.A. for it might well be used for a direct television link with Holland or Belgium.

More About Effects

I'M much obliged to a Wellingborough reader who sends me a cutting from *The Model Engineer*, in which a discussion has been taking place on the build-up of static charges in motor cars. One writer is of opinion that this is due to the Thompson Effect, which is the correct name for what has been dubbed the "Bournemouth" or "Nelson" effect in these notes. He maintains that this effect causes the build-up by the rush of air into carburettors of petrol-air mixture through inlet manifolds and valves and of exhaust gases through valves and pipes. He gives an interesting instance of what the Thompson Effect can do. The manager of a workshop reported that there was a leakage of electricity from the shop's wiring into a steam hammer, from the stop-valve of which sparks could be drawn. On investigation it was found that steam was leaking from the gland of this valve. When the gland had been tightened up and the leakage stopped, there were no more sparks.

Troubles in the South-West

MY THANKS to J. S. Fielden for his letter referring to my note last month about the French 819-line Band I television transmitter near Caen. I said then that I hadn't heard of any interference with Rowridge by this station, which occupies a channel covering both Nos. 1 and 2 of our system. J. S. F. writes that any viewer on the South Coast, between Lyme Regis and Exmouth, who is served by Rowridge or North Hessary Tor, knows from bitter experience how well a 405-line receiver locks an 819-line picture, superimposing it on the B.B.C.'s. Others have told me of interference yet farther away near the Cornish coast. A peculiar point is that both Rowridge and North Hessary Tor use vertical polarization and the Caen station horizontal. I suppose that it's all connected with the freak reception which is being reported just now from many parts of the world. But this is a rather special sort of freak. Not only is sunspot activity causing the French signal to span unusual distances, but it's also apparently turning the polarization through ninety degrees from horizontal to vertical and so delivering a locked picture to vertical aerials. Once we're well past the sunspot maximum I don't imagine that the trouble will continue. Let's hope not, anyhow!

A Tidier Skyline

EVEN the most confirmed television addict could hardly maintain that the Hs, Ks, Xs, Band III "toast racks" and what not, which now rear themselves above our roofs, are things of beauty. Dr. R. C. G. Williams, chief engineer of Philips Electrical, who is this year's chairman of the I.E.E. Radio Section, coined a neat phrase when speaking at the recent convention on ferrites organized by the Institution. "The use of these materials for built-in aerials in television receivers," he said, "will allow a considerable tidying up of the skyline." It certainly should in places where signal strength is good; but in other areas we're likely to see the ubiquitous roof-top aerial for a good while yet. Thank goodness our arrays are neither so hideous nor so complicated as those widely used in the United States in places where several services are available on different channels in Bands I and III. These monstrosities are designed to bring in anything that's going and can be turned in any direction from the room in which the TV receiver is. As their efficiency must be of a low order on any given channel they have to contain a large number of elements. These are arranged in many different ways and the pictures in advertisements of them show some weird, wonderful and far-from-sightly contraptions. Ferrites are Europe's contribution to electronics. If ferrites help to tidy up American skylines, this application alone will be a graceful return to Americans for their gift to electronics of the transistor!

UNBIASED

By FREE GRID

Power by Radio

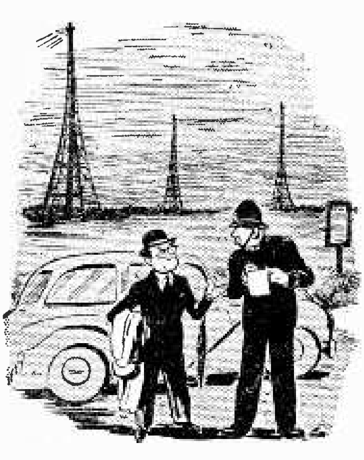
I WAS very intrigued, as the ladies say, by the Editor's remarks last month about Dr. Hollmann's ideas for using radio-transmitted power for operating transistorized receivers. The idea of transmitting power by radio is very old but up till now nobody seems to have made any practical suggestions about it.

If, however, we are eventually going to use the carrier waves of the B.B.C. to supply power to our receivers it is, I feel, bound to lead to legal complications, possibly ending up with somebody finding himself charged with "stealing electricity, the property of the British Broadcasting Corporation."

I am very interested in the legal position and am more than willing to be a legal guinea pig in this matter. In the past few days, therefore, I have been parking my car on the Great North Road in the shadow of the Brookmans Park masts and endeavouring to light special neon parking lamps from the aerials.

Some readers may recall a demonstration which used to be given in 1925 when the London transmitter was on the roof of what used to be called a "well-known Oxford Street store." The radio department of that store was on the top floor and a special feature was made of lighting several neon lamps from the radiation and I recall that permission had to be obtained from the B.B.C. for the demonstration.

In those days the power of the London transmitter was but a modest 3 kW. Even if the Great North Road is not immediately under the aerial it is not far from it, and with its 120 kW I ought to get some results. But all I have done so far is to excite the suspicion of the local constabulary.



"Loitering with intent."

I am, in fact, not unlikely to face a charge of "loitering with intent to commit a felony." By the irony of fate this would be a charge for which I should have no answer as I *am* loitering for that purpose. I appeal to you, therefore, to help me turn the "intent" into an actual commission by letting me have some technical advice and a circuit diagram. Better still, if any of you care to come along in your cars to help me we could really force the Corporation to make a test case of us.

Statogenic Toys

IF in the spring a young man's fancy lightly turns to thoughts of love, the season of peace and goodwill is apt to nourish thoughts of hatred and rage in the hearts of everybody as they see and hear the storm of interference produced by model electric trains given to children.

These diabolical devices, which will soon be on us, seem to be the only electrical apparatus sold nowadays without being adequately suppressed. It is admitted that they are not easy things to suppress except, of course, by the crude and obvious method of using a hammer.

There is not much room for fitting suppressors to the smaller models, but a complete answer to the problem should be obtained by lining one room of the house with earthed wire netting and putting the child and his statogenic toys inside it. I wonder it hasn't been made compulsory for a roll of netting to be included with every sale of these Machiavellian machines; maybe the P.M.G. hasn't the necessary powers.

I have an idea that this wire-netting idea is used by the large departmental stores as their wireless departments don't seem to suffer from the nearby toy-train demonstrations. Perhaps the manager of one of them will let me know; he might avert a murder.

Milli-Methuselahs

ONE of the most interesting articles in the September issue was the one in which M. G. Scroggie gave a series of curves showing how the sensitivity of our ears to the higher frequencies of the audio spectrum falls off with advancing years. As I mentioned in these columns a few months ago, everything in life—including the cutting of a baby's teeth—are but steps along the road to senility, but I must say I was not a little shocked to learn how soon one's high-note response is dulled. I was, however, sorry to see that the learned author failed to point out what a merciful protection this presbyotic phenomenon gives to old dodderers like myself against the strident screeching of sopranos.

It reminded me that advantage was taken of this phenomenon by a well-known radio manufacturer who also wished to produce something unusual in wireless sets for the 1938 radio show. At that time similar curves to those given by Scroggie had been appearing in the medical press and this manufacturer therefore designed a set having what he called a "senile selector" knob which was calibrated in years. This knob controlled a series of high-note compensators and the idea was that the listener could turn the dial to the year corresponding to his age. I gave an account of it in the 10th February, 1938, issue.

Unfortunately the makers had forgotten that women form the bulk of the listening public. No woman will ever confess to being a day older than thirty until she is fifty. This meant that the people in the higher age groups fought shy of the set.

The manufacturer consulted me about it, and I suggested calibrating the dial in milli-methuselahs as it would be more scientific and no woman would have the faintest idea that a milli-methuselah was only another name for a year or, to be precise, 0.969 year. In fact, I doubt if many men will know this unless they look up the fifth chapter of Genesis.

This set could, I feel, have been an outstanding success but the following year was 1939 and you know what happened then.

Echoes of 1942

I SEE that it is now possible to buy insulated heating cable to wind around the water pipes in the loft to stop them freezing up. Although this has not the remotest connection with radio the basic idea certainly had its origin in the brain of a very prominent person in the world of wireless, as I related in April, 1942.

Many midget sets of that period used a resistive connecting cable instead of a built-in voltage-dropping resistor, and this radio V.I.P. installed several of these sets in his loft with their connecting cables wound around the pipes. The resultant racket of all these sets in full blast had to be heard to be believed.

Acoustic peace on the pundit's premises was not secured until I had pointed out to him that he could achieve the same thermal effect without the cacophonic accompaniment by chopping off the connecting leads and stringing them across the mains in a series-parallel network. As I explained to him, the exact details could be easily worked out from the data, that this type of cable had a resistance of 150 ohms per yard and a current-carrying capacity of 0.3 amp. It is strange how great minds like his so often overlook the most obvious facts.