Wireless World

ELECTRONICS, RADIO, TELEVISION

Managing Editor: HUGH S. POCOCK, M.I.E.E.

Editor: H. F. SMITH *Assistant Editor:* F. L. DEVEREUX, B.SC.

VOLUME 62

JANUARY - DECEMBER 1956

46th YEAR OF PUBLICATION

PUBLISHED MONTHLY (4th Tuesday of preceding month) by ILIFFE & SONS LTD., Dorset House, Stamford Street, London, S.E.1 *Telephone:* Waterloo 3333 (60 lines). *Telegrams:* " Ethaworld, Sedist, London." *Annual Subscription:* Home and Overseas, £1 12s. 6d. U.S.A. and Canada $5.00. BRANCH OFFICES: *BIRMINGHAM:* King Edward House, New Street, 2. *Telephone:* Midland 7191. *COVENTRY:* 8-10, Corporation Street. *Telephone:* Coventry 5210. *GLASGOW:* 26B, Renfield Street, C.2. *Telephone:* Central 1265. *MANCHESTER:* 260, Deansgate, 3. *Telephone:* Blackfriars 4412. OVERSEAS OFFICES: *U.S.A.:* 111, Broadway, New York, 6, N.Y. *Telephone:* Digby 9-1197. *CANADA:* 67 Yonge Street, Toronto, 2, Ontario. *Telephone:* Empire 6-0873.

Wireless World

ELECTRONICS, RADIO, TELEVISION

Managing Editor: HUGH S. POCOCK, M.I.E.E.
Editor: H. F. SMITH
Assistant Editor: F. L. DEVEREUX, B.SC.

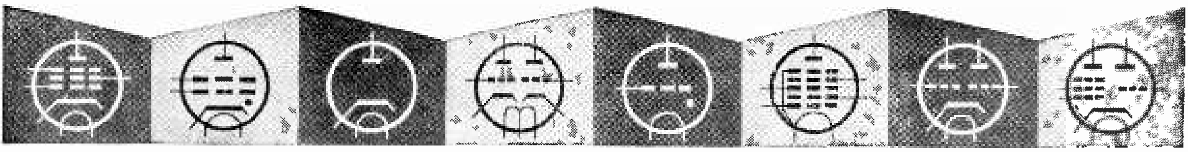
JANUARY 1956

In This Issue

VOLUME 62 NO. 1
PRICE: TWO SHILLINGS

FORTY-FIFTH YEAR OF PUBLICATION

PUBLISHED MONTHLY (4th Tuesday of preceding month) by ILIFFE & SONS LTD., Dorset House, Stamford Street, London, S.E.1 *Telephone:* Waterloo 3333 (60 lines). *Telegrams:* "Ethaworld, Sedist, London." *Annual Subscription:* Home and Overseas, £1 12s. 6d. U.S.A. and Canada $5.00. BRANCH OFFICES: *BIRMINGHAM:* King Edward House, New Street, 2. *Telephone:* Midland 7191. *COVENTRY:* 8-10 Corporation Street. *Telephone:* Coventry 5210. *GLASGOW:* 26B, Renfield Street, C.2. *Telephone:* Central 1265. *MANCHESTER:* 260, Deansgate, 3. *Telephone:* Blackfriars 4412. OVERSEAS OFFICES: *U.S.A.:* 111, Broadway, New York, 6, N.Y *Telephone:* Digby 9-1197. *CANADA:* 74, College Street, Toronto, 2, Ontario. *Telephone:* Walnut 4-5631.

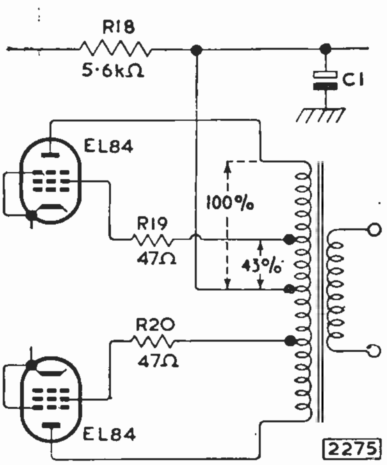


VALVES, TUBES & CIRCUITS

37. "DISTRIBUTED LOADING" FOR TWO MULLARD EL84's IN PUSH-PULL

A pentode push-pull output stage is conveniently operated with 'distributed loading' by connecting the two screen grids to tappings on the primary of the output transformer. The screen grid load is common with part of the anode load. Instead of being bypassed at a.f., as they are for normal pentode push-pull, the screen grids are fed with a voltage which varies during the a.c. cycle. In effect feedback is applied in the output stage itself, and the operation of the stage, in principle, is somewhere between that of a triode and a pentode. Connecting the output pentodes as triodes is equivalent to moving the screen grid taps to the anode ends of the primary. For the normal pentode connection, the screen grids would effectively be connected to the centre-tap. Power output is inevitably slightly less than can be obtained with conventional pentode operation, but distortion within the power range of the distributed load stage is very much lower than at the same levels in the normal push-pull pentode stage. In practice the distributed load stage results in a good compromise between the low distortion of a triode and the high output of a pentode, whilst retaining the high sensitivity of the pentode stage. Because of the voltage feedback via the screen grids, the output impedance of the stage is considerably less than with normal pentode operation, being about 8000Ω in this arrangement.

A distributed load output stage for two Mullard EL34's has already been described by *W. A. Ferguson* in his article in the May and June, 1955 issues of "Wireless World". A similar type of output stage can also be used for two Mullard EL84's in push-pull with an output transformer having the appropriate anode-to-anode loading and screen grid taps. The operating conditions are given in the table, the cathode current I_k being the sum of the anode and screen grid currents.



The circuit diagram shows the output stage of the Mullard '5-10' amplifier adapted for distributed loading. The screen grids are taken to the taps on the primary of the output transformer via the existing stopper resistors R19 and R20 of 47Ω. The centre-tap is fed from the reservoir capacitor C1. The dropper resistor R18 in the h.t. line must be increased from 1.2kΩ to 5.6kΩ to maintain the same d.c. conditions in the first two stages, as it no longer carries the screen grid current.

VALVE OPERATING CONDITIONS

Each screen grid tapped into anode load at 43% of turns from centre tap (h.t.)—

V_a	300V
V_{g2}	300V
$I_{k(0)}$	2×40mA
$I_{k(max.\ sig.)}$	2×45mA
R_k (per valve)	270Ω
$V_{in\,(g_1-g_1)\ r.m.s.}$	18V
R_{a-a}	8kΩ
P_{out}	11W
D_{tot}	0.7%

PERFORMANCE OF '5-10' CIRCUIT

A. Conventional pentode push-pull output stage

B. Distributed load output stage

	A	B
Rated power output	10W	10W
Overload point	÷14W	÷11W
Sensitivity across volume control	40mV	40mV
Harmonic distortion (10W, 400c/s)	0.3%	÷0.1%
Intermodulation distortion (at 10W, for 40c/s and 10kc/s in 4:1 amplitude ratio)	2.0%	÷1.0%
'Beat-note' distortion at 10W for:		
(i) 9kc/s and 10kc/s with equal amplitudes	÷0.25%	0.25%
(ii) 14kc/s and 15kc/s with equal amplitudes	0.4%	0.33%
Loop gain at 1000c/s	26dB	20.5dB

The anode-to-anode loading should be 8kΩ, corresponding to the normal loading published for the original circuit. Best results are obtained with each half of the output transformer primary tapped at about 43% of its number of turns, counting from the centre-tap. Suitable output transformers are the Parmeko P2642 and the Partridge P4014. In the feedback loop C12 will normally be 100pF for a 15Ω loudspeaker or 220pF for 3.75Ω.

The lower part of the table gives a comparison between the performance of the '5-10' circuit with the original pentode push-pull (A) and distributed load operation (B). The measurements were made on circuits modified according to the information given in the "High Quality Sound Reproduction" booklet. Distortion is very much reduced in the distributed load circuit whilst retaining the original design rating of 10 watts. The maximum power output of 11 watts at the overload point (onset of clipping with sine wave input) is somewhat less than for the original circuit. However, the rate at which distortion increases beyond the 11-watt point (that is, the slope of the P_{out}/D_{tot} curve) is very much less than for the basic circuit driven beyond 14 watts. There is virtually no change in the frequency response. Overall stability is considerably better than in the basic design, partly because the lower distortion is obtained with reduced loop gain.

Wireless World

JANUARY 1956

Vol. 62 No. 1

New Style Electronics Exhibition

IN last month's issue we deplored the proliferation of exhibitions catering for radio and all its electronic offshoots and pleaded for a new kind of show which, for want of a better word, we described as professional. This might embrace virtually everything within the electronic field except domestic broadcast receivers and their ancillaries, which are already well catered for each year at Earls Court.

Why suggest still another exhibition, when there are already so many? The fact is that some of the smaller private and semi-private shows have outgrown themselves and in the process have changed their character. A case in point is that of the Physical Society's annual exhibition, at which commercially made electronic equipment for measurement and research has been predominant for many years. Private and "institutional" non-commercial exhibitors, at one time prominent, have receded into the background. There is also some duplication of effort, as many of the commercial exhibits are shown elsewhere. The exhibition held by the Radio and Electronic Component Manufacturers' Association is another example of a show that has been too successful, in the sense that it has outgrown its present accommodation. All the products shown by R.E.C.M.F. members, and most of the apparatus presented at the Physical Society, would fit admirably into a comprehensive professional exhibition of the kind suggested.

In general, the proposal for an annual professional electronics exhibition has been well received. In particular, it has been pointed out that the manufacturers of transmitting equipment at present have no "shop window" in which their diverse products can be shown to the world in a suitably impressive manner.

The idea of two big exhibitions—domestic and professional—does not necessarily mean the end of all the small and highly specialized exhibitions, provided they retain their original character. They can serve a useful purpose, and have several advantages. The visitor knows what he is looking for, and can find it quickly. The exhibitor's costs are low and his time is seldom wasted by questions arising out of mere idle curiosity. The British Sound Recording Association's exhibition comes to mind as one that has filled a need for many years. However, the position here has been complicated by a proposal that has just been made to organize an Audio Fair in London next April. This is planned to be wider in scope and to appeal to a larger public than the B.S.R.A. show, but some overlapping seems inevitable. Anyway, this incident serves to point the moral that the organization of shows should be carefully considered and freely discussed.

Mobile Radio Economy

THE announcement that a "communal" mobile radio station had been set up in the Midlands caused something of a stir, for this seemed to indicate a change of heart on the part of the P.M.G. On investigation, however, it was found that the only thing communal about the station was that one mast was being used to support the aerials for a number of users of mobile radio. This, of course, is not new, for it has often been found that there is only one site in the neighbourhood suitable for the erection of an aerial. In such cases each user has his own remotely controlled transmitter, operating on a separate frequency, at the aerial site.

True communal operation of a mobile radio service by a number of small users in a locality would certainly mean a saving in money (only one fixed station would be needed), man-power (only one operator) and, of course, frequency space, as only one channel would be required to serve the half-dozen or so users. We were glad, therefore, to learn on enquiry that the P.M.G.'s mobile radio committee is actively considering whether licences should be granted to communal fixed stations.

In the United States they have what is known as the miscellaneous common carrier system under which a company sets up a fixed station for passing messages to an almost unlimited number of operators of radio-equipped vehicles. But over here, of course, such a scheme would run counter to the P.M.G.'s monopoly in radio communication.

Further Notes on the **Sensitive Three**

PERFORMANCE IMPROVED BY ADDING A DIODE TO THE R.F. STAGE

By ***H. E. STYLES,*** *B.Sc.*

THE description of the above receiver published in the December, 1955, issue of *Wireless World* made reference to various special features of the circuit for which advantages of one kind or another were claimed. Subsequent experience with the receiver has brought to light one further special characteristic, in this instance one which must be regarded as a drawback although its elimination can readily be accomplished. As this particular feature may give rise to somewhat mysterious effects, it seems desirable to describe its nature, cause and methods of elimination.

It has been found that, in some circumstances, the automatic gain control of the receiver fails to function properly when the receiver is first switched on. The symptoms of this are severe overloading on local signals and oscillation without the characteristic "motor-boating" when reaction is sufficiently increased. When such trouble occurs, it can be overcome either by momentarily switching off the receiver or by momentarily short-circuiting the suppressor of the r.f. valve to its cathode. Following such action, the trouble has not been observed to recur during subsequent operation of the receiver, but it reappears when the receiver is switched on again after a period of disuse.

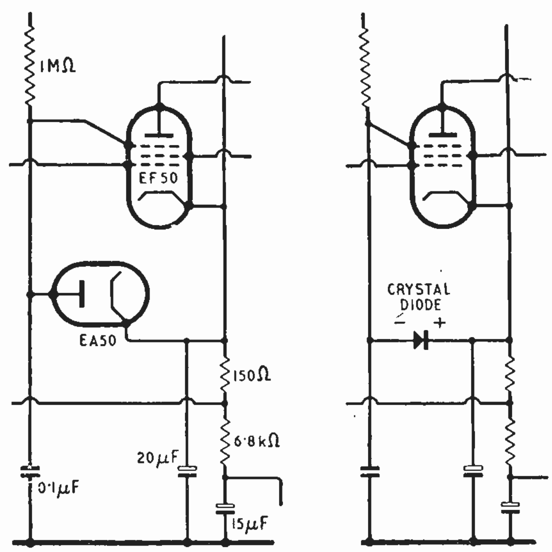
These facts leave no doubt that the abnormal behaviour can be attributed to the accumulation of a positive charge on the suppressor grid of the r.f. valve by the mechanism described in the letter from S. W. Amos on page 224 of the May, 1954, issue of *Wireless World.* That the trouble is not always encountered can probably be explained as follows:—

When the receiver is first switched on, all three valves are in a non-conducting state and, since the metal rectifier of the power supply functions without any time lag, the potential of the r.f. valve's suppressor grid becomes raised to the "no load" voltage of the power supply. If, then, the detector valve commences to draw current before the r.f. valve, the anode potential of the former drops to its normal working value as does the suppressor grid of the r.f. valve. In such case the circuit performs correctly and no difficulty arises.

If, on the other hand, the r.f. valve commences to conduct before the detector valve, it does so whilst its suppressor grid is still at a highly positive potential relative to its cathode. In such circumstances the suppressor grid readily loses electrons by secondary emission and, owing to the high resistance in series with the suppressor, this may suffice to maintain the electrode at a high positive potential despite the subsequent fall in the detector anode potential when the detector valve commences to conduct. In such case, the functioning of the automatic gain control system is completely upset with consequent production of the previously described symptoms of abnormal behaviour. Momentary interruption of the power supply, or short-circuiting of the r.f. valve's suppressor and cathode, will both result in the removal of the accumulated positive charge on the suppressor grid, which will not reappear so long as the detector valve remains conductive.

It follows that the trouble may be cured by interchanging the detector and r.f. valves if these happen to be sufficiently different in respect of warming-up characteristics, but such procedure cannot be regarded as particularly satisfactory as valve characteristics may well change at different rates during life. Moreover, a circuit which is sensitive to such variations in valve performance cannot be regarded as very suitable for general use.

The employment of a power supply having a time lag greater than the warming-up time of the detector valve would presumably overcome the difficulty, which might also be avoided by inserting a small amount of resistance in the heater wiring of the r.f. valve, sufficient to lengthen its warming-up period without seriously affecting its working characteristics. Undoubtedly, however, the most satisfactory solution of the problem is the one mentioned in S. W. Amos' letter, to which reference has been made; namely, the connection of a diode between the suppressor grid and cathode of the r.f. valve so as to preclude the possibility of the suppressor becoming



Left: Fig. 1. Method of wiring an EA50 or similar thermionic diode into the r.f. stage.

Right: Fig. 2. If a crystal diode is preferred it can be arranged as shown here.

Valve T.R.F. Receiver

appreciably more positive than the cathode. This addition is shown in Fig. 1.

This may be effected either by substituting a 6F33 for the EF50 r.f. valve as the former incorporates the required diode as an integral part of its construction, or by adding to the circuit a suitable diode with its anode connected to the suppressor grid of the r.f. valve, the cathode of which is connected to the cathode of the diode. The author has adopted the latter alternative using an EA50 which, with care, can be soldered directly into the wiring of the receiver thereby avoiding any major alteration in the layout. This modification has proved to be a complete cure for the trouble in question though the receiver can no longer strictly be described as a three-valve set. An even simpler solution would be to employ a crystal diode, in which case one suitable for a peak inverse voltage of something more than fifty should be used; see Fig. 2.

The introduction of the diode makes no difference to the normal performance of the receiver but, since it prevents the r.f. valve's suppressor grid from going positive, the gain control potentiometer can be set so as to obviate attenuation of relatively weak signals; in other words the gain control can be given any desired degree of delayed action. If, however, this is done, it will be found that automatic control of reaction becomes less satisfactory, there being a tendency for weak signals to cause increased regeneration instead of the greater stability which characterizes the circuit when no delay of gain control is present. Apart from this drawback, which can probably be disregarded for most purposes, a small degree of delay is advantageous as a means of rendering the receiver less susceptible to changes in supply voltage and, in particular, as a means of ensuring that the receiver will function without trouble during initial stages of warming up.

East-West Hemisphere V.H.F. Link

THE first long-distance v.h.f. radio station in Europe utilizing the ionospheric scatter mode of propagation is nearing completion on a north-western slope of the Chiltern Hills. It is being erected by the United States Air Force and forms part of a comprehensive v.h.f. chain linking the U.S.A. and U.S.A.F. bases in the far north, and when the new station comes into operation, with bases in Europe also.

Since the Atlantic cannot be bridged in a single hop, 1,400 miles being about the maximum by this mode of propagation, the English station will transmit to and receive from an ionospheric scatter station in Iceland, which is integrated in the U.S.A.F. American continental chain of long-distance v.h.f. stations.

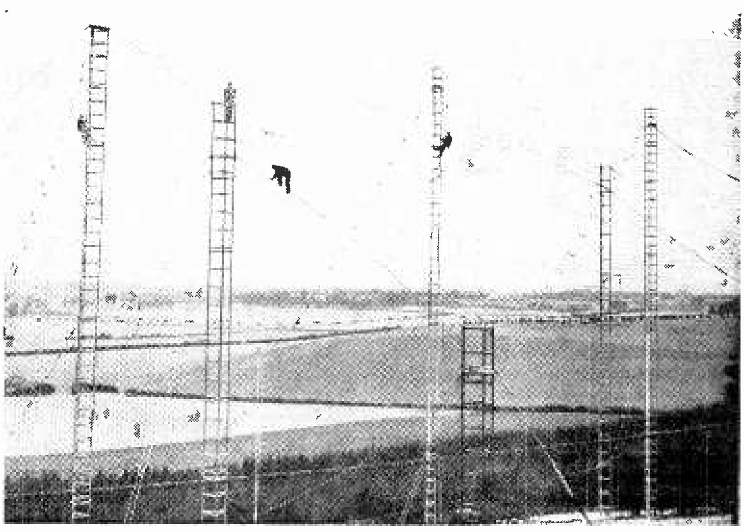
As the radio frequencies involved are no higher than our Band I television nothing unusual is required in the way of transmitters or receivers and the main interest lies with the aerial system.

As shown by an illustration in an article on scatter propagation elsewhere in this issue a comparatively small stack of yagis will suffice for reception of ionospheric scattered signals; at the new U.S.A.F. station broadside arrays of four-in-line horizontal dipoles are used backed by a V-shaped reflecting curtain of wires. Each aerial system is about 160ft wide, 90ft deep and about 120ft high; one will be used for transmitting and two in space diversity for reception. Each dipole element is a cage-like construction of wires resembling two cones base to base.

Unfortunately no details of the design gain, beam angle or bandwidth are available, but it is understood that the system is expected to provide facilities for simultaneous operation or at least eight communication channels. One or more may be speech channels and the remainder teleprinter or its equivalent.

Nothing definite can be gleaned as to the likelihood of exchanging television programmes with the U.S.A. over a link of this kind, but some of the technical personnel on the site were quite optimistic over its ultimate practicability. There is a lot yet to be learned of this newest mode of v.h.f. propagation, and it is interesting to record that reception on this site of the Icelandic transmitter is now being effected on a long-wire aerial and quite frequently on a single folded dipole. However, its location ensures a good signal-to-noise ratio.

This system of propagation is subject to variations in signal amplitude, but it is said there is a usable signal for about 98 per cent of the year.



Some of the towers supporting one of the v.h.f. aerial arrays used for direct communication with Iceland, a distance of some 1,100 miles or so, using frequencies adjacent to Band I television. Some idea of the great size of the array can be gained from the appearance of the erectors working on it

WORLD OF WIRELESS

Organizational, Personal and Industrial Notes and News

I.T.A. Goes North

COMMERCIAL television extends to the Midlands on February 17th. Although initially opening with a reduced effective radiated power of 50 kW, the service area of the Lichfield I.T.A. transmitter will not differ very much from that shown in our October issue. It is planned to increase the e.r.p. to 200 kW within a few months.

The transmitting equipment is provided by Pye and the mast and aerial system by Marconi's. As already announced, the station will operate in Channel 8 (vision 189.75 Mc/s, sound 186.25 Mc/s).

The site finally chosen for the Yorkshire I.T.A. station is Emley Moor, which lies between Huddersfield and Barnsley, and planning permission has been given by the Denby Dale Urban Council. The I.T.A. hopes to issue very soon a map showing the anticipated combined service areas of the Lancashire and Yorkshire stations.

The first annual report of the I.T.A. (H.M.S.O. 2s) sheds some light on the controversy which arose on the co-siting of stations. It was apparently suggested by the B.B.C. that at the Crystal Palace site the Corporation should broadcast the I.T.A.'s programmes on a relay basis, but this was not considered satisfactory as "it would have meant complete engineering dependence on the B.B.C."

New B.B.C. Stations

TWO links in the B.B.C.'s proposed chain of v.h.f. sound broadcasting stations, Pontop Pike and Wenvoe, were brought into service on December 20th. Each of the three transmitters at Pontop Pike, near Newcastle—one for each service—has an effective radiated power of 60 kW. They radiate on 88.5, 90.7 and 92.9 Mc/s. The transmitter at Wenvoe, near Cardiff, is a temporary set-up to permit the early introduction of a v.h.f. service in South Wales where medium-wave reception is particularly bad. The transmitter, operating on 94.3 Mc/s, has an e.r.p. of 30 kW. Two more transmitters will be ready in the Spring.

The B.B.C. has announced that owing to delays in the delivery of equipment the completion of the permanent aerials at the North Hessary Tor and Rowridge television stations will be delayed. They will not be in service until April and May, respectively. Also the opening of the v.h.f. sound broadcasting stations at Meldrum and Divis will be delayed until March.

Not Transferable

ASKED in the House of Commons if he would make car radio licences transferable with a car, the P.M.G. stated that a car radio licence, like a car driving licence, is in law a personal authority to the licensee and is not transferable with the car to another person. If the holder of a car radio licence sells his car and gets another, the licence can be made to cover his new car.

Doyen of Technical Journals

HISTORICALLY speaking, the technical journal is quite a new thing. Specialist publications were rare until after the repeal in 1855 of the infamous newspaper tax—the so-called "tax on knowledge." One of the periodicals then launched was *The Engineer,* which is now celebrating its centenary.

During its long career *The Engineer* has missed little in the way of significant engineering developments in any field, and was quick to appreciate the possibilities of wireless telegraphy, a subject referred to several times in 1897. A leader on "ethereal telegraphy" described Marconi's apparatus as "extremely ingenious, having for its object the getting out of the Hertzian vibrations sufficient work for telegraphic purposes." The peroration displayed an appreciation of underlying principles that was often lacking in the literature of the period: "Finally, let us add that there is nothing in common between the ethereal telegraphy of which we have spoken and telegraphy by induction. The phenomena are wholly distinct."

Rolls-Royce Reproduction

A RECENT demonstration of sound reproduction in the best modern tradition was that arranged by Victor Buckland, of Derby, for the benefit of some 500 Rolls-Royce employees. It was more than a straightforward presentation of selected records for it opened with a brief history of sound recording, complete with working examples of early phonographs, progressing to the high-quality equipment made by several well-known companies, including G.E.C., Lowther and M.S.S.

The pattern for these lecture-demonstrations which are so fashionable to-day was undoubtedly set by G. A. Briggs at the Royal Festival Hall. Some readers will, however, recall the excellent demonstrations given by P. G. A. H. Voigt in pre-war days.

PERSONALITIES

On the resignation of **Sir Edward C. Bullard,** Sc.D., F.R.S., from the directorship of the National Physical Laboratory, **Dr. R. L. Smith-Rose,** C.B.E., D.Sc., M.I.E.E., who is director of radio research in the Department of Scientific and Industrial Research, has been appointed acting director pending the appointment of a successor. Sir Edward, a director since 1949, has accepted a fellowship at Caius College, Cambridge. Dr. Smith-Rose has been director of radio research since 1948 and was previously superintendent of N.P.L. radio division.

Dr. William Shockley, "father of the transistor," has left the Bell Telephone Laboratories, where he has been director of transistor physics research, and has joined Beckman Instruments, of Fullerton, California. It was whilst leading a team working on a programme of solid state physics research at the Bell Telephone Laboratories, which he joined in 1936, that the transistor was evolved. Dr. Shockley is to organize a research group for Beckman Instruments on the development of semiconductors.

When awarding **Professor H. S. W. Massey, F.R.S.,** the Hughes Medal of the Royal Society, the president stated that "He was the first to apply the theories of attachment and recombination to problems of the ionosphere and he led the way in reviewing the results of the radio experimenters and in trying to explain them." Dr. Massey, who was a member of the Radio Research Board of the Department of Scientific and Industrial Research from 1946 to 1950, is Quain professor of physics at University College, London.

Dr. Willis Jackson, F.R.S., director of research and education with Metrovick, was a member of the delegation sponsored by the Atomic Energy Authority which recently visited the Soviet Union.

R. E. Burnett, M.A. (Oxon.), A.M.I.E.E., A.Inst.P., who joined the Marconi Company in 1950 as manager of education and technical personnel and principal of the Marconi College, has been appointed deputy general manager of Marconi Instruments, Ltd., of St. Albans. A few months ago he relinquished his educational appointment to become assistant to Marconi's general manager and has recently visited the U.S.A. to study industrial management at Columbia University. Before going to Marconi's he dealt with the Technical and Scientific Register of the Ministry of Labour.

Ananta B. Sarkar, M.Sc., Grad.Inst.P., Grad. Brit. I.R.E., has joined H. J. Leak and Company for research on sound reproduction problems, particularly the development of the combined electrostatic loudspeaker and bass cone-speaker system for domestic use. Mr. Sarkar, who is 27, received his M.Sc. from London University for his thesis on measurement of acoustic impedance which he wrote following research in the physics department of Chelsea Polytechnic. He also has a M.Sc. degree from the University College of Science and Technology, Calcutta. Since 1953 he has been with Standard Telephones and Cables.

Three more appointments to its technical staff are announced by Granada TV Network, contractors responsible for the week-day programmes to be radiated by the Yorkshire and Lancashire I.T.A. stations. **D. J. Burton,** who was from 1941 to 1953 in the operation and maintenance division of the B.B.C., is appointed technical supervisor of outside broadcasts. **D. G. Thompson,** who was for two years also in the same division of the B.B.C., is appointed an assistant sound engineer. **R. W. Mills,** who during the war was with the Air Ministry's Aeronautical Inspection Directorate as a supervisor inspector in the radio communications division and for the past three years has been on the recording staff of E.M.I. Studios, is also appointed assistant sound engineer.

OUR AUTHORS

D. M. Leakey, who is one of the authors of the article on "ultra-linear" output transformers in this issue, joined the General Electric Company in 1953 on completing a three-year course at the City and Guilds College where he specialized in communications and electronics. After a two-year graduate apprenticeship with the G.E.C., he is now back at the City and Guilds College on a G.E.C. scholarship studying for a higher degree. During his apprenticeship he spent six months in the acoustics laboratory at the Research Laboratories, Wembley, under F. H. Brittain, who is well known to *W.W.* readers for his work on the metal-cone loudspeaker.

R. B. Gilson, co-author with D. M. Leakey, has for thirty years specialized in the design of small iron-cored transformers for the electrical and communications industries. He is interested in high-quality sound reproduction as a hobby and is a director of R. F. Gilson, Limited, manufacturers of transformers and chokes.

E. J. Jordan, who is in charge of loudspeaker enclosure development with Goodmans Industries, Limited, contributes in this issue the first of two articles on this subject. Mr. Jordan, who is 27, is also responsible for the design of some of the company's loudspeakers. He joined Goodmans in 1952, prior to which he was for six years in the radio service department of the G.E.C. at Westminster.

OBITUARY

A. A. Kift, who retired in 1945 from the Marconi Company, has died at the age of 74. He joined the company in 1902 and after a course at the Marconi College, which was then at Frinton, was appointed to the engineering staff and was at one time assistant engineer-in-chief.

WHAT THEY SAY

Silence Wasn't Golden.—"It appears that the magnetic field set up by the generators in an aircraft can completely erase a tape recording, but it is understood that wrapping each recording tape carefully in tin foil prevents erasure."—G.P.O. spokesman, commenting on a spool damaged during air transport.

The Amateur Spirit.—"Has anyone had a crack at amateur radar?"—Sir Noel Ashbridge, at the opening of the R.S.G.B. Exhibition.

IN BRIEF

October's increase of 194,413 **Television Licences** (the greatest in any one month) brought the total to 5,078,262. The number of sound only licences at the end of October was 9,130,223, including 286,755 for car radio. The overall total for broadcast receiving licences in the U.K. was 14,208,485.

Television Receiver Sales for October were the highest ever recorded—282,000. This was undoubtedly due to the pre-Budget spending spree. Just over 50 per cent of the purchases were credit transactions.

Purchase Tax on sound and television receivers in the first nine months of 1955 contributed £6.75M and £21M, respectively, to the National Exchequer.

Servicing Exams.—We would remind prospective candidates for the 1956 examinations in radio and television servicing (held jointly by the Radio Trades Examination Board and City and Guilds Institute) that the closing dates are January 15th (television) and February 1st (radio). Entry forms and regulations are obtainable from the R.T.E.B., 9 Bedford Square, London, W.C.1. Since the formation of the Board in 1942, the number of candidates taking the radio servicing examination totals 2,652 and 609 have sat for the television examination introduced in 1950.

Aerial Link.—For the first television relay from Havana, Cuba, to the United States recently an aircraft, flying at about 12,000 feet above the Florida Straits, was used for the relay station. Signals from Havana were picked up by the aircraft and relayed to Miami, Florida, where they were injected into the network of the National Broadcasting Company. The distance between the two cities is approximately 230 miles.

Marconi Memorial in U.S.—Signora Degna Marconi Paresce unveiled a bust of her father in the Hall of Fame of the Engineering Societies Building in New York in October. At the unveiling the president of the American I.E.E. recalled that when addressing the Institute in 1922 Marconi forecast what we now know as radar. In his short-wave experiments he had noted reflections from solid objects and expressed the opinion that this property might be utilized for the detection of ships or land in darkness or fog.

Membership of the **Radio Society of Great Britain** again showed a rather heavy drop during the year ended June 30th. This reduction of 1,576, bringing the total membership to 8,159, is attributed in the annual report to the decision reached at the end of 1953 to increase subscription rates. An analysis of the membership in the report reveals that 62 per cent are licensed amateurs.

If plans materialize the **British Forces Network** in Germany will this month cease broadcasting in the medium-wave band and go over entirely to v.h.f. Eight of the nine f.m. stations have been in use experimentally for some months.

S.I.M.A. Electronics Section.—The new chairman of the electrical and electronics section of the Scientific Instrument Manufacturers' Association is A. G. Peacock, director of Mervyn Instruments, Woking. He succeeds P. Goudime, the managing director of Electronic Instruments, of Richmond. The vice-chairmen of the section, which now has over forty members (nearly a third of the Association's total membership) are R. Y. Parry, of Ekco Electronics, and L. A. Woodhead, of Cossor Instruments.

QRP.—The winning entry in the QRP Society's contest for portable amateur equipment was a transmitter-receiver submitted by John J. Yeend (G3CGD), of Cheltenham. A miniature single-valve band-switch transmitter entered by V. E. Brand (G3JNB), of Surbiton, was second and a crystal check oscillator by G. B. Moser (G3HMR), of Windermere, was third. Sec.: John Whitehead, 92 Rydens Avenue, Walton-on-Thames, Surrey.

Two short courses on colour television and experimental servo-mechanisms begin at the **Southall Technical College**, Middlesex, in the next few weeks. The television course, at which the lectures will be given by members of the staff of E.M.I. Research Laboratories, is on Wednesdays at 7.0, beginning on January 25th (fee £1). The six lectures on servo-mechanisms open on February 2nd (fee 10s).

Among the papers to be read at the conference on **Cloud Physics** being held in the Department of Meteorology, Imperial College, London, S.W.7, on January 4th and 5th is one on radar studies of clouds and precipitation. The conference is being organized jointly by the Physical Society and the Royal Meteorological Society.

R. A. Cail (not Gail as stated last month) is the lecturer on January 19th at the Woolwich Polytechnic, London, S.E.18, in the series on **Automation.** His subject is automatic control of machine tools. On January 24th J. A. Sargrove will deal with automatic machine and process control. Lectures are free and seats can be reserved on application to the Polytechnic.

Lichfield Tests.—The aerial of Belling & Lee's Band III pilot transmitter at Lichfield has been raised to the 350-foot level on the permanent I.T.A. mast. Transmitting times are Monday to Friday 9.30 a.m.-12.30, 2.0-5.30, 7.30-8.30, Saturday 10 a.m.-1 p.m.

Design of Furniture for housing domestic sound-reproducing equipment is the subject of the leading article in the January issue of *Art in Industry.*

EXHIBITION NEWS

Television Show.—The annual exhibition of the Television Society, scheduled to be held this month, has been postponed until March owing to the difficulty of securing suitable accommodation. It will be held at the Royal Hotel, Woburn Place, London, W.C.1, from March 6th to 8th. The first day is reserved for members of the society; admission on subsequent days being by ticket obtainable from the Television Society, 164, Shaftesbury Avenue, London, W.C.2.

Audio Show.—The eighth exhibition of sound recording and reproducing equipment, organized by the British Sound Recording Association, will be held on May 26th and 27th in the recently completed new hall of the Waldorf Hotel, London, W.C.2. There will be accommodation for over 40 exhibitors (last year there were 24) and some 12 rooms for demonstrations.

The annual **P.A. Show,** organized by the Association of Public Address Engineers, will this year be open to the public each afternoon. It will be held at the Conway Hall, Red Lion Square, Holborn, London, W.C.1, on April 25th and 26th.

The biennial **Production Exhibition and Conference,** sponsored by the Institution of Production Engineers, will be held at Olympia, London, W.1, from May 23rd to 31st. Among the members of the organizing committee is R. Telford, general works manager, Marconi's W.T. Company.

Montreal and Toronto will again be the venues for this year's **Canadian Audio Shows,** which will be held from January 18th to 21st (Montreal) and February 1st to 4th (Toronto). They are being organized by Emery Justus who was responsible for last year's Audio Shows, the first to be held in these cities.

Atoms, Electrons and Industry, is the title of an exhibition which the electrical and electronics section of S.I.M.A. is organizing in Bristol from June 6th to 8th.

BUSINESS NOTES

A new record company, **Recordiscs (London), Limited,** with offices at 23 Great Pulteney Street, London, W.1, has been formed to produce extended-play 78 r.p.m. records. The company has taken over a part of the factory of Norton Plastics, at Heanor Road, Ilkeston, Derbyshire, for the pressings. Recordiscs are sole British licensees for the system developed by the North American company, M. E. Kopelman, Ltd. The playing time of the discs, which will cost 5s 6d, including purchase tax, will be 6½ minutes. The company is also producing 10-in long-playing records which will cost 13s 8d.

Automation Consultants and Associates, Limited, is the name of a new company which has been recently formed to advise on matters connected with automatic production—technical, managerial, economic, social and architectural. The address is 18 Berkeley Street, W.1, and the directors include Sir Walter Puckey and J. A. Sargrove.

A joint demonstration of mobile military radio equipment has been staged by **Mullard** and **Plessey.** The two Army-type vehicles, which have toured Western Europe, are equipped with h.f. transmitter and receiver and four v.h.f. transmitter-receivers, all of which are designed to specifications drawn up by the Signals Research and Development Establishment (M.o.S.) and conform to N.A.T.O. requirements.

C. G. Mayer, European technical representative of the Radio Corporation of America, informs us of the setting up of **Laboratories RCA, Limited,** at Hardturmstrasse 169, Zurich 5, Switzerland, to provide facilities in Europe for fundamental research by R.C.A. The laboratories, of which Mr. Mayer is managing director, will be under the direction of Dr. Albert Rose.

It is announced in the annual report of **Electric and Musical Industries** that the company will shortly start test transmissions with colour television equipment, operating in Bands 4 and 5. The tests will be radiated from the 200-foot mast at the company's laboratories.

The annual report of **Radio and Television Trust, Limited,** which now has only one operating subsidiary company (Airmec, Limited), records that Crompton Parkinson, Limited, well-known electrical manufacturers, have acquired the whole of the cumulative redeemable preference stock and also 82% of the sinking fund certificates.

An agreement providing for the integration of the study and development of electronic control equipment for machine tools has been concluded between the **E.M.I. Group** and the Cincinnati Milling Machine Company, of America. E.M.I. has recently installed in a Norwich factory what is believed to be the first electronic analogue machine tool control equipment to be put on routine production work in this country.

Electro Methods, Limited, instrument makers, of Caxton Way, Stevenage, Herts., have completed an arrangement with Winchester Electronics Incorporated, of U.S.A., whereby they will manufacture certain components including connectors for printed circuits. The connectors are intended for use between printed circuitry and conventional wiring.

Plessey Development Company has been formed to control the establishment and development of a number of new Plessey enterprises in this country. It will be mainly concerned with Anglo-American collaboration in design and production. In order to unify the control of the research units set up by Plessey in various parts of the country, another new company, **Plessey Research, Limited,** has been formed.

Continental Radio and Electronics, Limited, which, as announced last month, has been formed to market in this country equipment manufactured by Continental-Rundfunk G.m.b.H., of Germany, is now established at 3, Farringdon Road, London, E.C.1. (Tel.: Chancery 4131.) At the same address is Diktat Limited, set up to market the tape recorder of that name.

The London representative of the **A.R.F. Development Corporation,** a subsidiary of the Armour Research Foundation of Illinois Institute of Technology, Chicago, has notified us that **Collaro** have concluded licence agreements with the Corporation enabling them to use the many patents held by Armour in the field of magnetic recording. **E.M.I.** have also made licence agreements with the A.R.F. Development Corporation.

Electric Audio Reproducers, Limited, have moved their offices, service department, stores and development section from the factory at Worton Road, Isleworth, to The Square, Isleworth. (Tel.: Hounslow 6256)

The service sections of **Aerialite** have been centralized at Congleton, Cheshire, where a department to deal exclusively with trade technical problems has been set up.

Woollett Sound and Wireless Equipment, of Wells Park Road, London, S.E.26, have appointed John Lionnet and Company, of 62/63, Queen Street, London, E.C.4, as sole export agents for the Woollett transcription gramophone turntable.

The Ministry of Transport and Civil Aviation has approved the **Lustraphone** noise-cancelling microphone and headset attachment for use in aircraft.

The Patent Department of **Associated Electrical Industries,** which incorporates the B.T.-H., Metrovick and Siemens Patent Departments, is now at 64-66, Coleman Street, London, E.C.2. (Tel.: Monarch 1030.)

Deroy Sound Studios, of Little Place, Moss Delph Lane, Aughton, Ormskirk, Lancs., who specialize in vinylite pressings, have substituted the word "Service" for "Studios" in their name.

Goldring Manufacturing Company, Limited, have closed their north London and Woodford, Essex, works and have now centralized manufacture at 486/488, High Road, London, E.11. (Tel.: Leytonstone 1081 and 1252.)

The external video modulation frequency given in our note on the **Rohde and Schwarz** v.h.f. signal generator last month (page 620) should have been 6.5 Mc/s. In quoting the price, mention should have been made that nearly £150 was duty and that exemption from this is in some cases granted by the Treasury.

OVERSEAS TRADE

An order for a complete new broadcasting station near **Baghdad** has been received by Marconi's. Four 100-kW transmitters will be installed, two being for the m.f. service and two for h.f. operation. The contract also includes the provision of a four-channel s.h.f. radio link between the studios and the transmitter, a half-wave mast radiator and a short-wave aerial system. The station is scheduled for completion by next October.

Iraq.—A fully automatic multi-channel radio-telephone network between Makinah (the headquarters of the Basrah Petroleum Co.), the oil fields at Zubair, fifteen miles south-west, and the loading port of Fao, has been set up by Automatic Telephone and Electric Company. The f.m. equipment carries up to 36 speech channels in the 160-Mc/s band and the voice frequency dialling equipment operates at 2,520 c/s.

H. C. Willson, chairman and managing director of Reproducers and Amplifiers, Ltd., of Wolverhampton, is on a two months' business tour **of South Africa** and the **Rhodesias.**

A contract, valued at approximately £40,000, for the supply of radar for the Jan Smuts airport—the largest civil airport in the **Union of South Africa**—has been awarded to Marconi's. The S232, which is being installed together with four display consoles and ancillary gear, was described in our May, 1955, issue.

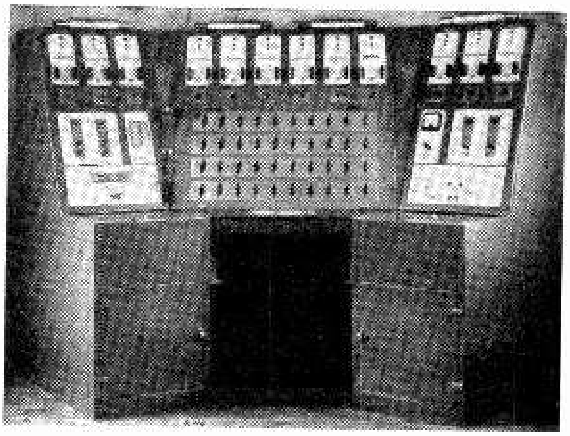
Among the British instrument makers who participated in the joint display at the Atomics Exposition at **Cleveland, Ohio,** in December were Automatic Coil Winder, Burndept, Edwards High Vacuum, Electronic Instruments, Ekco Electronics, E.M.I. Research, Fleming Radio and Labgear.

U.S.A.—Lafayette Radio, of 100, Sixth Avenue, New York 13, N.Y., are seeking a source of supply in the United Kingdom of miniature electrolytic and by-pass capacitors.

Also from the **U.S.A.** comes an agency enquiry for a British combined a.m./f.m. broadcast receiver to retail at about $85. Interested manufacturers should communicate direct with Alfred Blom-Cooper Co., Inc., 10927, West Pico Boulevard, Los Angeles, 64.

Uganda.—Electronics, Ltd., P.O. Box 1869, Kampala, who already represent a number of manufacturers of radio and electrical equipment, want to act as agents for manufacturers of tape recorders and tapes.

Denmark.—The Copenhagen importers, Ditz Schweitzer, have notified us that they have moved to Bredgade 37.



CONTROL CONSOLE for the sound reproduction system being fitted in the "Empress of Britain" by Pye Marine. It includes two 3-speed playing desks, tape recorder and an all-wave broadcast receiver.

LOUDSPEAKER ENCLOSURE DESIGN

By E. J. JORDAN*

I.—Alternative Methods: Their Advantages and Disadvantages

IN the first part of this article the theory underlying the principal types of loudspeaker enclosure is reviewed, and formulæ associated with the major design factors are given.

This will be followed later by a discussion of some recent developments in which an improved low-frequency performance has been achieved in cabinets of relatively small volume.

THE loudspeaker enclosure has the task of doing something (useful or otherwise) with the low-frequency radiation from the rear of the loudspeaker cone, which would otherwise cancel the radiation from the front of the cone.

Before examining various methods of overcoming this, let us establish the principles on which our future arguments will be based.

We shall regard the moving parts of a loudspeaker as a mechanical system which at low frequencies is analogous to an electrical circuit, as shown in its simplest form in Fig. 1.

The complete analogy is revealed by an examination of the electrical and mechanical equations viz.

$$\text{Force} = M\frac{d^2S}{dt^2} + R\frac{dS}{dt} + SK$$

$$\text{E.m.f.} = L\frac{d^2Q}{dt^2} + R\frac{dQ}{dt} + \frac{Q}{C}$$

where M = mass, L = inductance, S = displacement, Q = charge, C = capacitance, K = stiffness and R = resistance.

There are, of course, other analogies, but the above lends itself more readily to discussions of the proposed nature.

Assume for a moment that the loudspeaker is mounted on an infinite baffle. It will be seen, that the power developed in R_a (Fig. 1) is a function of the current through it. Comparing the above equations it will be seen that $i\left(=\frac{dQ}{dt}\right)$ is analogous to the cone velocity $v\left(=\frac{dS}{dt}\right)$. Hence it is the cone velocity, and not the displacement, that is responsible directly for the radiated output power, v^2R_a.

From this it would seem that, if the radiated power is to be independent of frequency, the resistive components of the circuit should be high relative to the reactive components. This is not so in practice, since at frequencies where the wavelength is longer than twice the cone diameter the value of R_a falls as the frequency is lowered. The reactance of M_c also falls, however, and the increasing velocity resulting from this may largely compensate for the fall in R_a to the extent that the radiation remains substantially constant, down to a frequency where $\omega M_c - \frac{1}{\omega C_c} \to 0$. Here the velocity of the cone rises sharply, and is limited only by R_d, R_c and R_a. This produces an increase in the radiated power and is the resonant frequency of the loudspeaker.

Below this frequency, the impedance of the circuit rises as the frequency falls, due to the reactance of C_c, consequently the radiation falls very sharply. The resonant frequency may thus set the limit to the low-frequency response of the loudspeaker.

The above may be shown by considering the expression for the radiated power at the frequencies being discussed:

$$P = v^2 R_a = \frac{\text{Force}^2}{Z^2_M} \cdot \frac{2\pi\rho f^2}{c} \cdot (\pi r^2)^2,$$ where r is the radius of the cone.

Above resonance if $R_M << X_M$ (mass)

$$P \propto \frac{\text{Force}^2}{X^2_M} \cdot f^2$$

This is the condition of mass control, and since $X_M^2 \propto f^2$, P is independent of f.

Above, at, or below resonance, if $R_M >> X_M$

$$P \propto \frac{\text{Force}^2}{R_M^2} \cdot f^2 \propto f^2$$

This is the condition of constant velocity, and P falls with f at the rate of 6dB/octave.

Below resonance if $R_M << X_M$ (stiffness),

$$P \propto \frac{\text{Force}^2}{X_M^2} \cdot f^2 \propto f^4$$

This is the condition of constant amplitude and P falls with f at the rate of 12dB/octave.

Above resonance if R_M is comparable to X_M

$$P \propto \frac{\text{Force}^2}{Z_M^2} \cdot f^2$$

and P falls with frequency at a rate determined by the ratio $\frac{f^2}{R_M^2 + X_M^2}$.

In all cases the radiation resistance is small

*Goodmans Industries Ltd.

relative to the total mechanical impedance of the system; its effect on the velocity has therefore been neglected.

So far, it has been assumed that the loudspeaker is mounted in an infinite baffle. The analogous circuit is similar to that of a loudspeaker mounted in free air, except that the baffle produces a large increase in R_a and a small increase in L_a.

It is very important to realize that any baffle or enclosure may be represented in the analogy by a series impedance Z_b which will tend to reduce the cone velocity, but, depending upon the nature of this additional impedance, partial compensation may be effected by resonant phenomena over at least part of the low-frequency range.

The effective mechanical impedance presented to the cone, due to any acoustical impedance Z_A is given by: $Z_M = Z_A(\pi r^2)^2$
where Z_A is the vector sum of Z_r and the acoustic impedance due to the mounting. At low frequencies

$$Z_r = R_r + j\omega L_r \approx \frac{2\pi\rho f^2}{c} + j\frac{0.85\rho\omega}{\pi r}$$

Impedance Curves.—A very convenient way of measuring the effects of the enclosure on the output of the loudspeaker, is to plot the impedance/frequency curve of the loudspeaker, when housed in the enclosure. If a base line is drawn at a value equal to the clamped impedance of the voice coil, then the impedance curve relative to this line is directly proportional to the velocity of the cone.

The relationships between the electrical impedance (Z_E) the mechanical impedance (Z_M) and the velocity (v) of a loudspeaker system, are as follows: where B = flux density in the magnet system, l = length of voice coil conductor enveloped by flux, i = current flowing in coil.

Back e.m.f. due to the motion of the coil:

$$E \propto Blv = \frac{B^2l^2i}{Z_M}$$

Motional impedance of the coil:

$$Z_m = \frac{E}{i} \propto \frac{B^2l^2}{Z_M}$$

Total electrical impedance:

$$Z_E = Z_{vc} + Z_m$$

where Z_{vc} is the clamped impedance of the voice coil.

From above $v \propto \dfrac{1}{Z_M} \propto Z_m$

If the component parts of Z_M are expressed in c.g.s. terms then Z_m will be in electro-magnetic units. Impedance curves often give a far more accurate assessment of the performance of an enclosure than pressure response curves, since the latter depend not only on the cone velocity but, in the case of vented enclosures, upon the port radiation as well. Pressure curves are also greatly affected by diffraction and while they are invaluable in demonstrating the overall radiation from a loudspeaker system, they do not show clearly the action of the various acoustic components due to the enclosure on the loudspeaker cone.

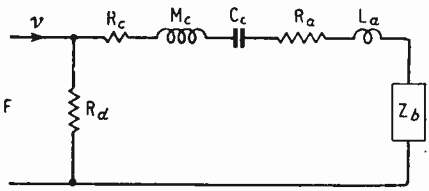


Fig. 1. Simplified electrical analogue of mechanical properties of a moving-coil loudspeaker.

Wall Mounting.—The nearest practicable approach to the infinite baffle condition is by mounting the loudspeaker in a wall e.g. a partition wall between two rooms.

This method of baffling a loudspeaker ensures complete separation between the front and rear radiation of the cone and imposes a relatively low mechanical impedance to the cone velocity. The extent of the low-frequency response is limited by the resonant frequency of the cone.

For wall mounting it is therefore desirable to use a loudspeaker having a low-frequency, highly-damped cone resonance. The damping in this case will be mainly electromagnetic, i.e. a high value of R_d in the analogy, tending to produce constant velocity conditions and resulting in a falling low-frequency response, as we have shown. Since under these conditions the cone displacement at resonance does not exceed the level required to maintain the velocity constant, a considerable amount of bass lift may be applied from the amplifier to compensate for this loss at low frequencies. The bass lift required commences at the frequency at which the wavelength is equal to twice the cone diameter, and has a slope which may be determined either aurally, or from the expressions previously given, the latter being possible only when the necessary loudspeaker parameters are known.

SYMBOLS

c = velocity of sound in air.
C_b = compliance of air in closed cabinet.
C_c = compliance of cone suspension.
F = force applied to cone.
k = ω/c = wave constant.
L_a = $L_r(\pi r^2)^2$.
L_r = acoustic radiation mass
M_c = mass of cone system
M_v = mass of air in vent.
P = radiated acoustic power.
R_a = $R_r(\pi r^2)^2$.
R_c = resistance due to friction in cone.
R_d = mechanical resistance due to voice coil damping.
R_M = total mechanical resistance.
R_r = radiation resistance.
R_s = viscous resistance of vent.
R_v = total resistance component of vent = $R_r + R_s$.
v = velocity of cone.
X_{cb} = reactance of air in closed cabinet.
X_M = total mechanical reactance.
Z_A = total acoustic impedance.
Z_r = acoustic radiation impedance.
Z_b = impedance due to loudspeaker mounting.
Z_M = total mechanical impedance.
Z_m = motional impedance of coil.
μ = coefficient of shear viscosity.
ρ = density of air.
ω = $2\pi f$.

C.g.s. units for mechanical and acoustical quantities, and e.m. units for electrical, have been assumed throughout.

A consideration which should be borne in mind, particularly in the case of wall mounting, is that the aperture in which the loudspeaker is mounted will behave as a tube of length equal to the thickness of the wall or baffle, and in so doing will exhibit a number of harmonically related resonances and anti-resonances, causing irregularities in the treble response. There are, of course, a number of obvious remedies for this, e.g. bevelling the edges of the aperture or mounting the loudspeaker on a sub-baffle.

Finite Baffles.—If the baffle is finite, at some low frequencies, depending on its size, back-to-front cancellation will occur, and the limiting baffle size for a given low-frequency extension is:

$$l = \frac{c}{2f}$$

if the baffle is rectangular and l is the length of the smallest side.

If the bass response is to extend down to a reasonably low frequency, the necessary baffle size will be relatively large, e.g. a square baffle suitable for reproduction down to 60 c/s will have a side of 9.42ft. A loudspeaker acting as a treble unit in a crossover system should be mounted on a baffle large enough to work down to half the crossover frequency.

For the sake of convenience, baffles often take the form of open-backed cabinets. In such cases, in addition to the normal baffle action, the cabinet will behave, more or less, according to its depth, as a tuned pipe, and will exhibit a number of harmonically related resonances, the lowest of which will approximate to:

$$f = \frac{c}{2\,(l + 0.85r)}$$

where l is the depth of the cabinet, $r = \sqrt{A/\pi}$ if A is the area of the open back.

It is these resonances that contribute to the unnatural "boomy" quality evident in many commercial reproducers.

Closed Cabinets.—Alternatively a method of preventing back-to-front cancellation, is to completely enclose the rear of the loudspeaker cone. Under these conditions, however, the enclosed air will apply a stiffness force to the rear face of the cone.

This may be represented by a mechanical reactance X_{cb} the value of which is given by:

$$\frac{\rho c^2\,(\pi r^2)^2}{\omega V}$$

where πr^2 = piston area of cone and V = volume of enclosure.

In the analogy, this reactance appears as a series capacitance as shown in Fig. 2.

In order not to raise the cone resonance unduly, the value of C_b must be large relative to C_c. Since, for a given loudspeaker system, C_b is the only variable, it must be large.

It has been found that, for a 12-in loudspeaker having a fundamental cone resonance at 35 c/s, the volume of an enclosing box would need to be of the order of 12 cu ft for its reactance to be sufficiently low not to impair the low-frequency performance of the speaker.

There are a number of factors in the design of loudspeaker enclosures which should be considered.

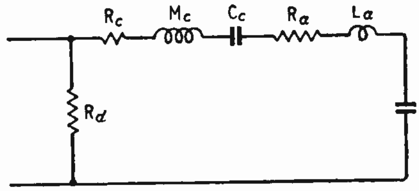


Fig. 2. Analogue circuit of m.c. loudspeaker in a closed cabinet.

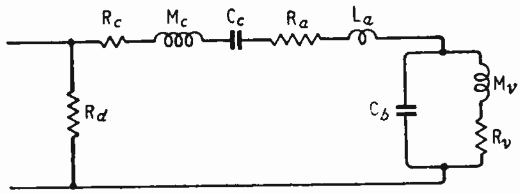


Fig 3. Analogue circuit of m.c. loudspeaker in a vented cabinet.

These are common to most types of enclosure and are:

Shape of the Enclosure.—As the frequency is lowered the radiated wavefront from the loudspeaker cone tends to become spherical, consequently the boundary edges of the loudspeaker enclosure constitute obstacles in the path of the wavefront. This results in (a) bending of the wavefront (diffraction), and (b) secondary radiation from these edges. This secondary radiation will produce interference patterns, causing irregularities in the frequency response of the system.

These effects are largely dependent on the shape of the enclosure, and will be smallest for a spherical enclosure, and greatest for a cube. Since the cabinet has to be a presentable piece of furniture, there are certain limitations on its shape. Fortunately, however, the effects of diffraction are not very serious, and it is not difficult to reach a compromise.

Corner Position.—Consider a source of sound that is small compared to a wavelength and situated in free space. The radiation from this source will be of equal intensity at a given distance in all directions, i.e. spherical.

If a large flat wall is placed near the sound source, then the total radiation will be concentrated into a hemisphere, and its intensity will then be doubled. Similarly, if a second wall is placed near the sound source at right angles to the first, the total radiation will be concentrated into one-quarter of a sphere and its intensity will be four times greater. A third wall at right angles to the other two will increase the intensity eight times.

A loudspeaker standing in the corner of the room may, at medium low frequencies, be regarded as similar to the second case, and approaching the third case as the frequency calls to a point where the wavelength is much greater than the height of the speaker above the floor.

Construction.—At frequencies where the wavelength is comparable to the internal dimensions of the enclosure, reflections between inside wall faces will occur, resulting in standing-wave patterns, which in turn will produce irregularities in the frequency response of the system.

These standing waves may be considerably reduced (a) by lining the enclosure walls with soft felt or wool thus providing absorption at points of maximum pressure, (b) by hanging curtains of the same material near the centre of the enclosure, thereby introducing resistance at points of maximum velocity.

A further point to be considered is that the material (usually wood) from which the enclosure is made, possessing both mass and compliance, will be capable of movement and will resonate at one or more frequencies and, in so doing, will (a) behave as a radiating diaphragm and (b) modify the air loading on the cone, both of which will produce unwanted coloration in the reproduction. The enclosure should, therefore, be made of as thick and dense a material as possible.

Vented Enclosures, Reflex Cabinets.—One method of overcoming the disadvantage of the closed cabinet, is to include in the cabinet wall an orifice or vent.

An enclosure, suitably vented, will apply to the rear of the loudspeaker cone an impedance which offers the cone a maximum degree of damping at, or near, its resonant frequency and the radiation from the vent around this frequency will be more or less in phase with the frontal radiation from the cone, i.e., the back radiation is inverted. Before we describe the nature of this impedance, we will describe the Helmholtz resonator, the principle on which the design of vented and reflex cabinets is based.

For the benefit of readers not familiar with this resonator, it consists simply of a partially enclosed air cavity having a communicating duct to the outside air.

An enclosed volume of air will have a stiffness reactance equal to $\rho c^2/\omega V$.

The air in the duct will move as a homogeneous mass, the reactance of which is given by:

$$\frac{\rho l' \omega}{\pi r_v^2}$$

where πr_v^2 is the cross-sectional area, and l' is the effective length of the duct.

This system will have a resonant frequency at which the mass of air in the duct will move most readily, bouncing, as it were, on the elasticity of the air in the enclosure. This occurs when the sum of the reactances, which are opposite in sign, is zero.

Equating the two expressions and transposing for f, we have

$$f = \frac{c}{2\pi}\sqrt{\frac{\pi r_v^2}{Vl'}}$$

which is the usual expression for the natural frequency of a Helmholtz resonator.

In actual fact, this is only an approximation, since the full expression for the mass reactance should contain a Bessel term for the load on the vent, due to the air outside the cabinet, but in practice this is small enough to be neglected.

Some of the air adjacent to the end of the duct moves with the air in the duct, and thus becomes added to it. The effective length of the duct, therefore, is greater than its actual length. Rayleigh shows that the increase at each end is:

$$\delta l = \frac{8}{3\pi} r_v$$

where r is the radius of the duct.

The total effective length is, therefore:

$$l' = l + \frac{16}{3\pi} r_v = l + 1.7 r_v$$

If the duct is not circular, $r_v = \sqrt{A/\pi}$, where A is the cross-sectional area of the duct.

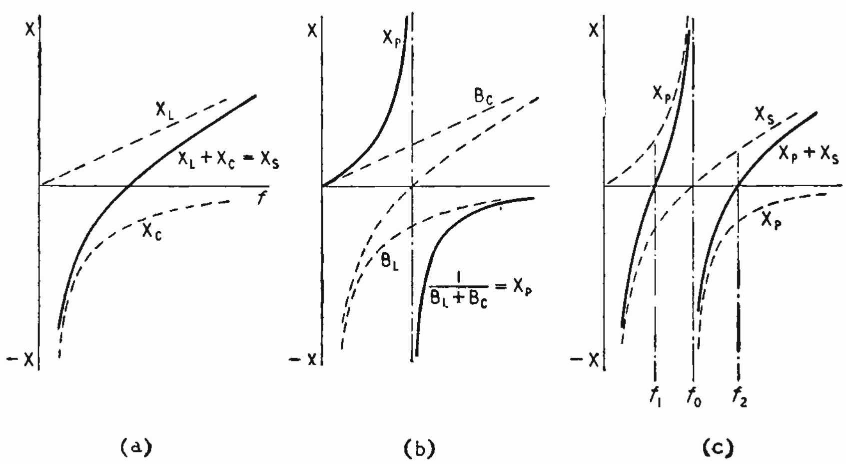
Returning now to the subject of loudspeaker enclosures, a vented cabinet containing a loudspeaker will exhibit a resonance in accordance with the above description, which will be reasonably independent of the loudspeaker cone resonance.

When the cabinet resonance is excited by the loudspeaker, the motion of the air in the vent will reach its maximum velocity and will be in phase with the motion of the cone. At this frequency, therefore, the air in the cabinet will come under the double compressive and rarefactive forces of both the cone and air in the vent; consequently, its effective stiffness rises, and the resulting impedance applied to the rear of the cone becomes much higher at this frequency than at any other.

If the resonant frequency of the enclosure is made to coincide with that of the cone, the latter receives maximum damping at its resonance and any peak in the radiated power at this frequency is removed.

In addition to this, the reduction in cone displacement results in a considerable increase in the power-handling capacity of the loudspeaker and

Fig. 4. Variation of reactance with frequency of the circuit elements of Fig. 3. X_L = total mass reactance of series section; X_C = total stiffness reactance of series section; B_L and B_C are the mass and compliance susceptances of parallel section, and X_S and X_P the total series and parallel reactances, respectively.



in a reduction of harmonic and intermodulation distortion. Although the velocity and therefore the power radiated from the cone is reduced around this frequency, the overall radiated power from the system is increased considerably, due to the very high air velocity at the vent. Unlike the cone there is no physical limitation to the displacement of the air in the vent.

Below the resonant frequency of the enclosure the stiffness reactance becomes high, and the system behaves as though the air mass in the vent were coupled directly to the mass of the cone. At some frequency the reactance of this combined mass will become equal to the stiffness reactance of the suspension system of the cone. A resonance will occur at this frequency, the amplitude of which will be considerably lower than that of the initial cone resonance, and the radiation from the vent will be in anti-phase with that from the cone.

Above the resonant frequency of the enclosure the mass reactance of the vent becomes high, and the cabinet behaves as though it were completely closed, presenting a purely stiffness reactance to the rear of the cone. At some frequency the combined stiffness reactance of the cone suspension system and the enclosure will become equal to the mass reactance of the cone. At this frequency a further resonance will occur, and again the amplitude will be considerably less than the cone resonance.

Now let us consider the nature of the impedance presented to the rear of the cone by a vented enclosure. Since this impedance rises to a maximum value, a parallel tuned circuit is indicated in the analogy Fig. 3, where R_v and M_v are the vent components.

By drawing the reactance sketches for the complete system, we are able to see clearly the derivation of

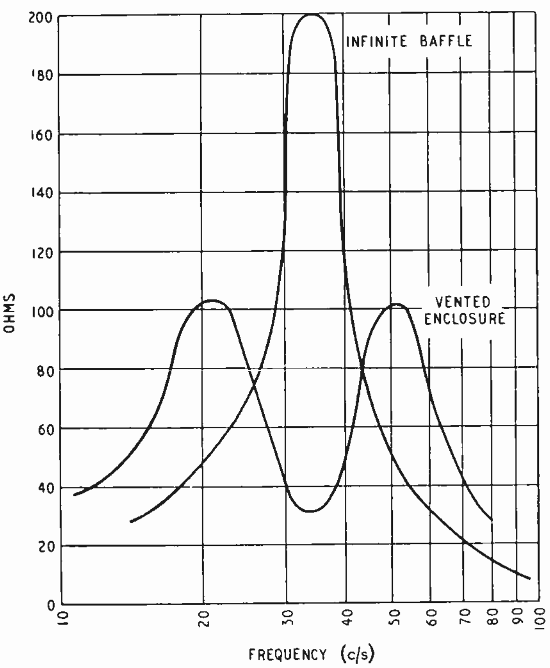


Fig. 5. Impedance/frequency response of a loudspeaker on an infinite baffle and in a vented enclosure.

the resonant frequencies described above Fig. 4.

Figs. 4(a) and 4(b) show the well-known reactance sketches for the series and parallel sections of the circuit respectively. When these are added, we have Fig. 4(c) which exhibits three critical frequencies f_1, f_o and f_2. It will be noticed that at f_1 and f_2 the reactance falls to zero, and at f_o rises to infinity. The corresponding impedance curve, together with the impedance curve, taken with a loudspeaker mounted on an infinite baffle is shown in Fig. 5.

Whilst a reflex (vented) enclosure is much smaller than a completely closed cabinet for a given bass extension, the reduction in size is limited by the mechanical impedance it imposes on the cone, at frequencies away from its resonance (f_o). In the design of these enclosures it is important, therefore, to calculate the impedance over a wide range of frequencies, to ensure that this does not become excessive.

To accomplish this, the various components of the enclosure are expressed as follows:
Referring to Fig. 3.

$$C_b = \frac{V}{\rho c^2}$$

$$R_v = R_s + R_r$$

$$M_v = \frac{\rho l}{\pi r_v^2}$$

R_s is resistance due to air viscosity in vent

$$= \frac{\sqrt{2\mu\rho\omega}}{\pi r_v^3}\, l$$

R_r is radiation resistance of port $= \dfrac{\rho c k^2}{2\pi}$

Having already met the first two expressions, the new symbols appearing in the second two expressions are: μ, the coefficient of shear viscosity and $k = \omega/c$, the so-called wave number or wave constant.

It is convenient to express all dimensions in c.g.s. terms.

The acoustical impedance of the enclosure Z_{ab} may be obtained from the usual expression for an L C R circuit of this type, i.e.

$$Z_{ab} = \frac{R_v - j\omega[C_b R_v^2 + M_v(\omega^2 M_v C_b - 1)]}{\omega^2 C_b^2 R_v^2 + (\omega M_v C_b - 1)^2}$$

where all terms are in acoustical units.

Expressing this as the modulus of the mechanical impedance, we have:—

$$|Z_b| = \left[\frac{R_v^2 + \omega^2 M_v^2}{\omega^2 C_b^2 R_v^2 + (\omega M_v C_b - 1)^2}\right](\pi r^2)^2$$

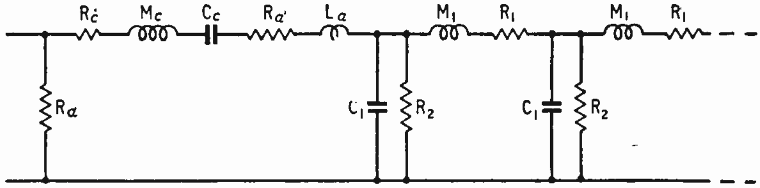
At the resonance of the enclosure, the right-hand expression in the denominator becomes zero, the

Z approximates to $\dfrac{M_v}{C_b R_v}(\pi r^2)^2$.

This is the dynamic impedance of the circuit and is the value of a purely resistive component which may replace the parallel circuit at a resonance in the analogy.

The "Q" of the enclosure is given by $\dfrac{\omega M_v}{R_v}$ and is normally much higher than that of the cone system and is therefore not critical. It has been found that an optimum performance is given by the reflex enclosure if the cross-sectional area of the vent

Fig. 6. Equivalent circuit of m.c. loudspeaker mounted in a labyrinth, M_1, C_1, distributed mass and compliance of labyrinth. R_1, R_2, viscous resistance and absorption resistance respectively.



is made approximately equal to the piston area of the cone.

The required enclosure volume for coincident resonance is then obtained from a derivation of the formula for a Helmholtz resonator, and is given by:

$$V=\pi r^2\left[\frac{c^2}{\omega^2}\cdot\frac{1}{l+1.7r}+l\right]$$

In this equation l is the length of the duct or tunnel, which usually extends into the enclosure, and the volume of the duct has therefore, been added to the expression. Broadly speaking, increasing the tunnel length decreases the overall volume until a point is reached where the increase in total volume, due to the increased tunnel length, is exceeding the reduction in the volume required to correctly tune the enclosure. The tunnel length for minimum volume is:

$$l=\frac{c}{\omega}-1.7r$$

Another limitation on the length of the tunnel is that it must not exceed 1/12th of a wavelength at the resonant frequency of the enclosure, otherwise the contained air would not behave purely as a mass.

We have seen that the reduction in size of a reflex cabinet is limited by the increase in mechanical impedance presented to the cone.

There are, however, marketed enclosure designs which are based on the foregoing principle. These are extremely small, yet appear to have a substantial bass response.

It is evident from the expression for the resonant frequency of a vented enclosure that the enclosed air volume may become as small as we like, and the resonant frequency made low by having a very small vent and tunnel area. Such an enclosure has a very high mechanical impedance, thereby limiting the cone velocity at very low frequencies. Also, owing to the very resistive nature of the vent, the two lower resonances shown for a loudspeaker in a vented enclosure are highly damped, and the upper resonance is prominent, resulting in an accentuated bass radiation around this frequency, hence, the apparent bass efficiency.

The amplitude and frequency of this upper resonance may both be reduced by facing the cone into a restricted aperture such as a slit, but this introduces serious irregularities in the response and will be discussed in a subsequent article.

The Tuned Pipe.—This is based on the well-known organ pipe principle. In order to exclude modes of resonance other than the air column resonance, the end of the pipe remote from the speaker should be either fully open or fully closed.

In the case of the open pipe, resonances will occur at frequencies corresponding to all even numbers of quarter wavelengths, and anti-resonances will occur at all odd numbers of quarter wavelengths. For the closed pipe, the reverse is true.

One method of applying these properties to loudspeaker mounting, is to use an open pipe with the loudspeaker mounted at one end, the length of the pipe being such that its fundamental anti-resonance coincides with the cone resonance thus securing some of the advantages of a reflex enclosure.

A closed pipe may also be used in the same manner, in which case the length of the pipe need only be about half that of the open pipe. However, the impedance presented to the cone by this method is high, and a serious reduction in cone velocity may result at low frequencies. The radiation from the open end of the open pipe increases the radiation efficiency of this system to some extent.

The length of an open pipe for a given frequency of anti-resonance f is:

$$l=\frac{c}{2f}-1.7\sqrt{\frac{A}{\pi}}$$

where A is the cross-sectional area of the pipe.

The length of a closed pipe for a given anti-resonance frequency f is:

$$l=\frac{c}{4f}-0.85\sqrt{\frac{A}{\pi}}$$

Whilst these pipes are a little more simple to construct than reflex enclosures, their overriding disadvantage is the presence of all resonances and anti-resonances occurring at every quarter wave length, and it is virtually impossible to damp the enclosure and to absorb all the resonances without severely attenuating the required fundamental. A way of partially overcoming this is described in a patent by Voigt. This is to mount the speaker in the wall of a pipe which is closed at one end and open at the other, the position of the loudspeaker being 1/3rd of the pipe length away from the closed end. By this means, the first resonance above the fundamental (3rd harmonic) will be cancelled.

The Labyrinth.—The labyrinth consists of a very long tube, usually folded and heavily lined with absorbing material, with the loudspeaker mounted at one end. The labyrinth is probably the cleanest way of disposing of unwanted back radiation, which, having left the rear of the loud speaker cone at one end of the tube does not re-appear at the other. It does not really matter therefore, whether this far end is open or closed.

The analogous circuit is that of a transmission line and is shown in Fig. 6. The sound energy, due to the back radiation from the cone, is largely dissipated in the resistive components R_1 and R_2, where R_1 is due to the viscous losses between the air in motion and the lining on the internal surfaces of the labyrinth, and R_2 is due to the absorption of sound energy at these surfaces.

As the frequency is increased, R_1 increases and R_2 decreases. Therefore, if the labyrinth is to be effective at the lower frequencies, the lining must be fairly thick. If, however, this begins to take

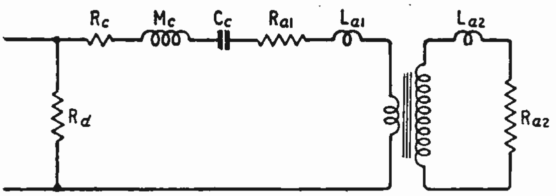


Fig. 7. Electrical analogue of m.c. loudspeaker with horn loading. R_{a1} and L_{a1} represent the air load on the side of the diaphragm not coupled to the horn. R_{a2} and L_{a2} constitute the air load at the mouth of the horn.

up an appreciable part of the cross-sectional area of the labyrinth, the air loading on the rear of the cone, which is normally quite high in this type of enclosure, will become excessive, resulting in a severe reduction in the radiated power at these frequencies. The cross-sectional area should, therefore, be at least equal to the piston area of the cone, and, to achieve the necessary dissipation of sound energy from the rear of the cone, the effective path length of the labyrinth should be as great as possible, the minimum length being set empirically at a quarter wavelength equivalent to the lowest frequency to be reproduced.

Under these conditions, the impedance presented to the rear of the cone is quite high and mainly resistive, so that the cone approaches constant-velocity operation and behaves in the manner previously described for this condition.

The Horn.—Horn loading is the most efficient form of loudspeaker mounting and, if the horn were large enough, it would give a performance superior in every respect to any other form of loudspeaker mounting.

The action of the horn can be most readily grasped by consideration of the analogous circuit.

The major problem in all the systems so far discussed has been to compensate for the fall in R_a at low frequencies. The use of a transformer would be an obvious answer if this problem were an electrical one, and, applying this to the analogy, we have Fig. 7. Acoustically, such a transformer is analogous to the horn, which may be used to match the relatively high mechanical impedance of the loudspeaker cone to the radiation resistance, and, by making the mouth of the horn large, this resistance does not become so low at low frequencies.

From the analogy, since the effective radiation resistance reflected back to the primary of the transformer is very high, the cone operates under constant velocity conditions and no resonance is evident.

Below a certain frequency the acoustic resistance of a horn falls sharply and its reactance (mass) rises. This cut-off frequency is determined by the dimensions of the horn and, since size-for-size an exponential horn maintains its efficiency to a lower frequency than a conical horn, the former is more often used. The cross-sectional area (A_x) of the exponential horn at any distance x from the throat is given by:

$$A_x = A_0 \epsilon^{mx}$$

where A_0 is the throat area and m the flair constant.

The cut-off frequency is given by: $f_c = \dfrac{mc}{4\pi}$

The diameter of the mouth should not be less than a quarter wavelength at f_c, otherwise the horn will tend to exhibit the resonances similar to a tuned pipe.

Most text books on electro-acoustics deal very fully with the horn, and there is little point in our doing so here, especially since, due to its size, an adequately large horn is rarely encountered. Although many small folded horn designs are capable of impressive (if not accurate) reproduction, let it suffice to say that a horn capable of presenting a constant radiation resistance down to 30 c/s to the cone of a 12-in loudspeaker would be over 12ft long and have a mouth diameter of about 9½ft.

Conclusion.—The different types of loudspeaker enclosures number as many as the possible combinations of L C R in series with the analogous cone circuit.

Some time ago, the thought arose that an excellent method of designing a loudspeaker enclosure would be to state the ideal velocity characteristics, and then determine an electrical impedance which, when placed in series with the analogous cone circuit, would produce these characteristics. It would then remain to transpose this impedance into acoustical terms and to evolve an enclosure having the required component values.

This line of development has been followed to a successful conclusion and will be described in the second part of this article.

COMMERCIAL LITERATURE

Unit Radio Masts, built up from 10-ft triangular-section units in mild steel, with a maximum height of 150ft. Stays at 20-ft or 30-ft intervals. Weight: 7lb per foot of length. A light alloy derrick pole is used for erection. Descriptive leaflet from British Insulated Callender's Construction Company, 30 Leicester Square, London, W.C.2.

Miniature R.F. Cables, Polythene and Teflon insulated, with outside diameters from 0.12in to 0.255in and impedances from 50Ω to 115Ω. Also miniature r.f. screened connectors to fit. Leaflets from Transradio, 138a Cromwell Road, London, S.W.7.

High Quality Amplifier and pre-amplifier. Output (main amplifier) 10 watts with less than 0.1% distortion at 400 c/s. Frequency response 30 c/s-30 kc/s within ±0.5 dB. Feedback 26 dB in main loop. Pre-amplifier has tone controls, etc., and switch for selecting various input characteristics. Specification on a leaflet from Phillips and Bonson, Pond Works, 8 Millfields Road, London, E.5.

Precision Oscilloscope, for observing pulses and transient phenomena, with high beam-current c.r.t., maximum sweep speed of 0.05 μsec per centimetre, calibrated time and voltage scales, trigger with calibrated delay, and pulse generator for triggering external equipment. Specification from Newport Instruments (Scientific and Mobile), Newport Pagnell, Bucks.

Coils and Transformers for f.m. receivers, high-quality amplifiers and other equipments. Also two 12-watt high-quality amplifiers with different input sensitivities; distortion claimed to be less than 0.02% and frequency response of 10 c/s-25 kc/s ±1 dB. Leaflets from Stanley Sound and Vision Products, Stanley Works, The Green, Pirbright, Surrey.

Noise-Cancelling Microphone, for close talking in noisy surroundings, giving steep decline of output with increased distance from speaker's mouth. Output about 1 mV; impedance 25Ω; frequency response peaked at 1.7 kc/s and flat to 3.5 kc/s. Also microphone floor stands, table stands and table bases. Leaflets from Lustraphone, St. George's Works, Regents Park Road, London, N.W.1.

Long-duration Tape Monitor for logging of messages, instructions, reports, etc. Simultaneous recording of any number of channels and many other facilities. Brochure from Simon Equipment, 46-50 George Street, Portman Square, London, W.1.

The R.S.G.B. official station, GB3RS, operated throughout the period of the exhibition

Ninth R.S.G.B. Exhibition

THE LATEST AMATEUR EQUIPMENT; HOME BUILT AND COMMERCIAL

AN innovation at this year's amateur radio exhibition held by the Radio Society of Great Britain was the presentation of an appropriately worded plaque for the most outstanding piece of amateur-built equipment in the show. The award went to D. Deacon (G3BCM) for a very compact transmitter-receiver measuring 16in high, 12in wide and 7in deep, and which can be used as a fixed, a portable, or a mobile station. It covers all amateur wavebands from 10 to 160 metres either by crystal control or by v.f.o. Plug-in coils or crystals are used and the rated power is 10 to 12 watts.

The receiver, mounted below the transmitter, is a 7-valve superhet covering the medium waveband, as well as all amateur bands down to 10 metres. The coils are in a detachable unit which slides into a recess in the panel.

No important changes were apparent in single-sideband technique this year although the stand devoted to it was well equipped with a variety of units, including a receiver designed primarily for s.s.b. work.

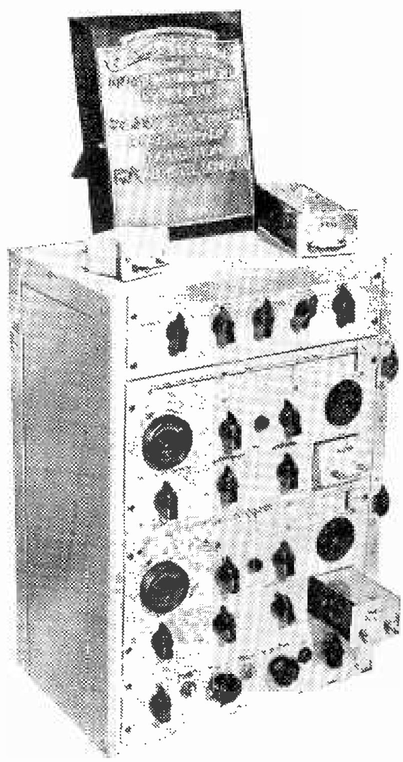
The u.h.f./v.h.f. section yielded some interesting items; one was a 24-cm transmitter, or rather the final 72- to 24-cm tripler cavities and aerial system. The latter consisted of a spun aluminium paraboloid reflector with dipole and dummy aerials fed by 24ft of 50-ohm coaxial cable. Careful matching by coaxial tuning stubs enables this length of feeder to be used without appreciable loss. The aerial is said to give a power gain of 8 to 10. Motor rotation with remote control is employed.

From coherers to transistors is a long stride and there cannot be many active amateurs now who can claim to have used both. This thought was provoked by a 70-cm field-strength meter comprising a small trough line, silicon detector and transistor d.c. amplifier shown by H. W. Pope (G3HT), one of the shrinking band of pre-1914 amateurs. It was built into a 2oz tobacco tin and is said to be most useful for exploring around 70-cm aerial systems and measuring front-to-back ratios.

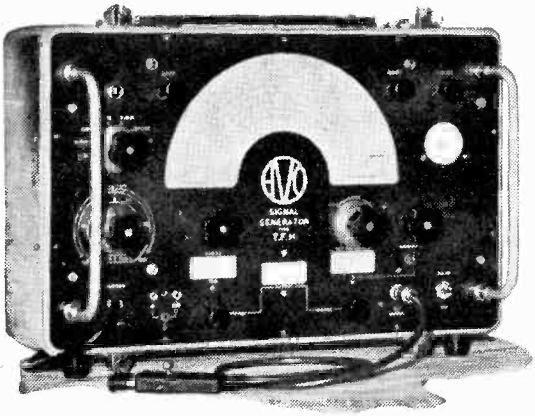
Amateur television was represented by two most interesting outfits. One was a 405-line 50-frame interlaced system using B.B.C. standards throughout shown by Ivan B. Howard (G2DUS/T). It used a Staticon camera for "live" transmissions, an impressive feature was the excellent "pictures" obtained in the hall with the minimum of lighting. The whole outfit costs about £250, but as an example of what can be done for, say, £25, M. Cox showed a 200-line 50-frame home-built television transmitter operating on a closed circuit using "surplus" parts throughout.

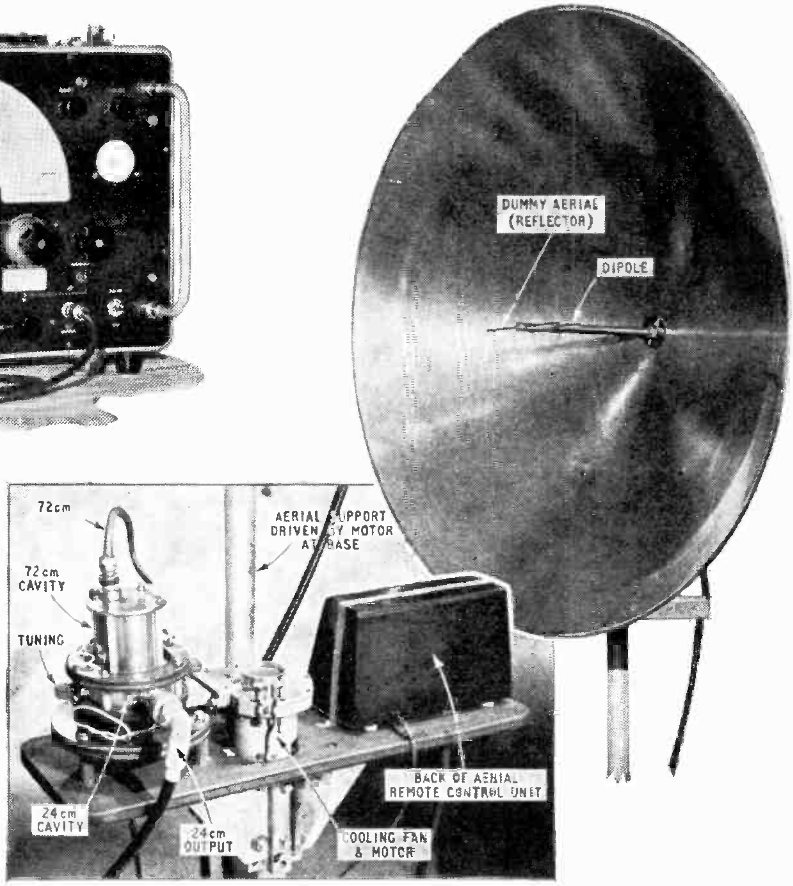
The "camera," for stills only, works on the flying-spot principle and utilizes an ex-radar c.r. tube.

The commercial section mustered some 13 firms,



Compact all-band transmitter-receiver shown by D. Deacon, adjudicated the most meritorious amateur exhibit.





Above: Avo Model TFM a.m./f.m. signal generator covering 5 to 225 Mc/s.

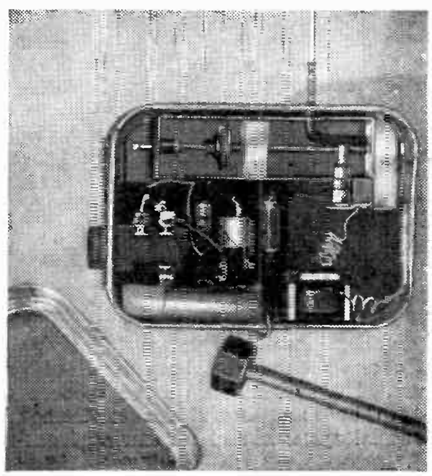
Right: Forty-inch paraboloid reflector with close-up view of double-cavity resonator tripling from 72 to 24 cms (S. C. Tucker G5DT).

not counting the Royal Air Force display and publishers of technical journals. Four exhibitors showed transmitters complete or in unit or kit form. The modern style of self-contained band-switched "table top" set was exemplified by the Panda PR120V, covering 10 to 80 metres and operating at 150 watts input, telephony and telegraphy. It was accompanied by the Panda "Cub," a 25/40-watt version covering 10 to 170 metres (amateur bands only, of course). The former costs £150 and the latter £65.

Since many amateurs have power supplies and modulators available, the transmitter shown by Labgear (Model LG300 Mk II) is of special interest as it comprises only the r.f. portion. It is band-switched for 10 to 80 metres, has a variable master oscillator, operates at 150 watts input and is fully screened and protected against spurious radiation on all bands. A very recent addition is a power and modulator unit assembled in a matching style cabinet. The transmitter, less 813 output valve, costs £57 15s and the companion power/modulator unit £80 complete.

The transmitter "foundation" units developed by the Minimitter Company have now been extended to cover the two-metre band and further two-metre equipment was shown by P.C.A. Radio. This firm had a most compact transmitter-receiver designed primarily for mobile use, but also applicable as a fixed station. It is crystal controlled, can be operated from a 12-V battery or mains, is rated at 12W and complete with all accessories costs £75 for battery operation. A mains unit costs £10 10s. This equipment is now available as a kit, which with drilled chassis and all parts, except valves and crystals, costs £25.

The latest in skeleton slots was seen on the J-Beam stand; known as the slot-beam, models were shown with from 2 to 24 parasitic elements. A typical 2-metre model, comprising three stacked slots with 6 reflectors, gives a gain of 14 dB (over dipole), has a horizontal beam width of 70 deg and



A 70-cm field-strength meter using silicon crystal and transistor d.c. amplifier assembled in a 2-oz tobacco tin (A. W. Pope).

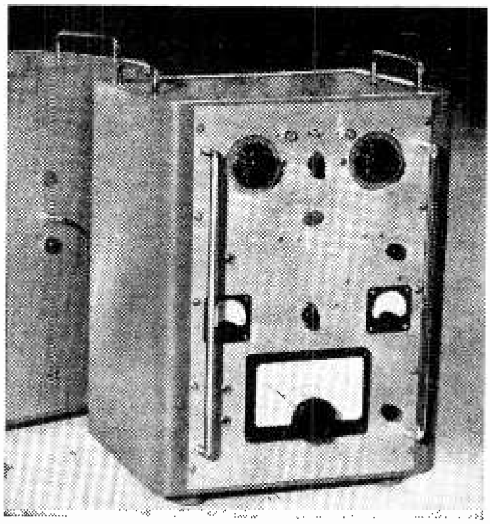
LIST OF COMMERCIAL EXHIBITORS

Automatic Coil Winder & Electrical Equipment Co. Ltd., Douglas Street, London, S.W.1.
Cleminson's Agencies Ltd., 36 Clifton Gardens, London, N.W.11.
General Electric Co. Ltd., Kingsway, London, W.C.2.
Harwin Engineers Ltd., 101-105 Nibthwaite Road, Harrow, Middlesex.
J-Beam Aerials Ltd., Cleveland Works, Weedon Road Industrial Estate, Northampton.
Labgear Ltd., Willow Place, Cambridge.
Measuring Instruments (Pullin) Ltd., Winchester Street, Acton, London, W.3.
Minimitter Co., 37 Dollis Hill Avenue, Cricklewood, London, N.W.2.
Multicore Solders Ltd., Hemel Hempstead, Herts.
Panda Radio Co. Ltd., 58 School Lane, Rochdale, Lancs.
P.C.A. Radio, Beavor Lane, Hammersmith, London, W.6.
E. J. Philpotts Metalworks Ltd., Chapman Street, Loughborough.
Standard Telephones & Cables Ltd. (Brimar), Footscray, Sidcup, Kent.

costs £7 10s (less mast). Models were shown for Band III television and 70 cm.

Single and multi-range test meters were shown by Pullin; Avo had their customary display of Avometers supported this year by a new a.m./f.m. signal generator covering 5 to 225 Mc/s on fundamentals. A.M. is available over the whole range, but f.m. over the 60- to 120-Mc/s portion only. F.M. is by means of a ferrite-type reactance unit giving up to ± 150 kc/s deviation, continuously variable from zero. Provision is made for external modulation.

Since soldering plays a vital part in amateur-built equipment the newest in soldering techniques was most appropriately displayed by Multicore Solders. There were wire strippers, all kinds of flux-cored solder and for portable and outdoor use a low-melting-point solder-tape with which perfectly good joints can be made with an ordinary match.



Labgear LG300 MKII 10- to 80-metre transmitter with new power/modulator unit behind.

BOOKS RECEIVED

Noise by Aldert van der Ziel. Analysis of the origins of fluctuation noise in electronic circuits, methods of measurement and the design of circuits for minimum noise level. Includes chapters on semiconductor and electron beam devices. Pp. 450+X1; Figs. 97. Price 60s. Chapman and Hall, 37, Essex Street, London, W.C.2.

The Visibility of Noise in Television by R. D. A. Maurice, Ing. Dr., Ing. E.S.E, A.M.I.E.E., M. Gilbert, Ph.D., B.Sc., D.I.C., G. F. Newell, A.M.I.E.E. and J. G. Spencer. B.B.C. Engineering Monograph No. 3. Discussion of the effects of noise in transmission circuits using cameras with high- and low-velocity beams, visibility of noise as a function of frequency, and the subjective comparison of photographic records of different signal/noise ratios with the original picture. Pp. 23; Figs. 20. Price 5s. B.B.C. Publications, 35, Marylebone High St, London, W.1.

Proceedings of the XIth General Assembly of the International Scientific Radio Union—The Hague, 1954. Vol. X, No. 3. Reports and papers submitted to Commission III on ionospheric radio. Pp. 194; Figs. 23. Price 29s. General Secretariat of the U.R.S.I., 42, Rue des Minimes, Brussels.

R.S.G.B. Amateur Radio Call Book. 1956 edition, giving call signs of amateur transmitters in Great Britain, Northern Ireland, the Isle of Man, the Channel Islands and Eire. Includes call prefixes of foreign countries. Pp. 54. Price 2s 6d (2s 9d by post). Radio Society of Great Britain, New Ruskin House, Little Russell Street, London, W.C.1.

Hi-Fi for Pleasure by Burnett James. Guide for gramophone enthusiasts to the choice of high-quality reproducing equipment, with a chapter on the playing of old records and advice on the problems of recording characteristics. Pp. 134; Figs. 14. Price 9s 6d. Phœnix House, Ltd., 38, William IV Street, London, W.C.2.

Repairing Record Changers by Eugene Ecklund, Serviceman's guide to the basic principles of record-changer operation with special reference to American practice. Includes a chapter on magnetic tape recorder mechanisms. Pp. 278; Figs. 222. Price 44s 6d. McGraw-Hill Publishing Company, Ltd., 95, Farringdon Street, London, E.C.4.

CLUB NEWS

Cleckheaton.—The first meeting of the year of the Spen Valley and District Radio and Television Society will be held on January 11th, when a selection of films will be shown. On the 25th, A. Thompson (G2FCL) will speak about 2-metre transmitters. Meetings are held at 7.30 at the Temperance Hall, Cleckheaton. Sec.: N. Pride, 100, Raikes Lane, Birstall, near Leeds.

Coventry.—January meetings of the Coventry Amateur Radio Society will be held on the 2nd, 16th and 30th at 7.30 at 9, Queens Road. Demonstrations of 2-metre equipment will be given at the last meeing. Sec.: J. H. Whitby (G3HDB), 24, Thornby Avenue, Kenilworth, Warwicks.

Edinburgh.—A recorded lecture by C. H. L. Edwards (G8TL) on mobile operation (from the R.S.G.B. tape library) will be given to members of the Lothians Radio Society on January 12th. A fortnight later F. Tuck (GM3BBW) will deal with Band III convertors. The club meets at 7.30 at 25, Charlotte Square, Edinburgh. Sec.: John Good (GM3EWL), 24, Mansionhouse Road, Edinburgh, 9.

FUTURE OF EUROPEAN BROADCASTING

A Plea for a New Approach to Planning

By G. H. RUSSELL, Assoc. Brit. I.R.E.

THAT the Copenhagen Plan has been a failure, no one can deny. That the B.B.C. has recognized this fact is proved by its decision to launch a nation-wide v.h.f. service. This can be regarded as a technological advance or as an admission of failure depending upon one's point of view. Nevertheless, the fact remains that the use of v.h.f. for broadcasting is spreading. Western Germany already has complete coverage, Italy's three programmes are radiated over a v.h.f. network of 18 stations and many other countries have adopted this form of transmission on a small or experimental scale. It is then, fairly safe to assume that by the time the B.B.C. v.h.f. programme is completed, a large proportion of Europe will be using these frequencies too.

This poses a question. What use, if any, is to be made of the progressively redundant medium- and long-wave bands? It can, of course, be argued that it does not matter anyway; that v.h.f. broadcasting will bring us the joys of high-quality, interference-free reception, and that in consequence, medium-frequency (m.f.) broadcasting is obsolete. This may be true from a purely technological aspect but the reasons for the continued expansion of broadcasting are not technological but social and political.

"1984 and All That"

From a political point of view, the argument against the abandonment of m.f. broadcasting is very strong. Both television and v.h.f. sound broadcasting —the main media of the future—are of short range. This fact raises the same objection as that made against wire distribution many years ago; that in the hands of an unscrupulous government use could be made of the listener's lack of choice to impart one point of view only. Such a prospect conjures up George Orwell's bizarre world of the "telescreen" but is none the less a possibility on that account. However, this is not a plea for propaganda broadcasting as such; there is far too much of it cluttering up the wavebands already, and the value of it is, to say the least, highly suspect. Rather, this is an appeal for the retention of m.f. broadcasting so that the listener is given the opportunity to listen to other shades of opinion.

From the serious political aspect, let us now turn to the lighter side of the question; that is the entertainment (or social) angle. With m.f. broadcasting it is theoretically possible to receive, in Europe, programmes from something like thirty different countries. With an average of two different programmes per country, there should be, theoretically, a choice of some sixty programmes. Do we need this number of programmes? The answer must surely be an unequivocal "yes"! There really cannot be too many programmes.

There undoubtedly was far more foreign listening in this country before the last war than there is to-day and the decline is almost certainly due to poor reception conditions. Therefore, if it is accepted that the continuation of m.f. broadcasting is desirable, reception conditions must be improved. To do this an examination of the present position must be made. Past errors must be reviewed in order to illustrate the reasons for the present chaos on the medium- and long-wave bands. History does not teach us, as many believe, not to make the same mistakes again, but only how not to make the same mistakes in quite the same way—but even this might prove useful. Finally, politics cannot entirely be eschewed, for many past errors were due to this cause rather than to technical considerations, and if any criticisms are made in this connection which seem anachronistic in the present atmosphere of international *bonhomie*, the reader is assured that they are made quite dispassionately and with a complete disregard for the geographical position of hypothetical curtains—be they ferrous or non-ferrous metal.

Copenhagen and Its Aftermath

Out of a total of 136 channels in the long- and medium-wave bands, 60 were allocated at Copenhagen as nationally exclusive. These then, are the channels, above all others, from which one would expect to obtain clear reception. After five years only 13 remain exclusive. In order to assess the practical effects of this situation a listening test was conducted at the peak listening hours during an evening in mid-winter, 1954-5. Two receivers were used; one being a wide-band receiver with eight tuned circuits and a pass band in the region of ±7 kc/s, and the other a standard production domestic receiver with a pass band in the region of ±3 kc/s. The results obtained with a high outdoor aerial showed that only 18 stations could be classified as of entertainment value. In order to present as fair an assessment as possible a listening test was also conducted on stations operating on non-exclusive channels which gave a strong, intelligible signal. Of these, 12 could be classified as of entertainment value, giving a total of 30. However, this may be misleading as a number of stations carry the same programme, so the number of programmes that were received amounted to 20.

An analysis of the results obtained from the listening test shows that of the 60 exclusive channels 17 were "pirated," 10 suffered from heterodyne whistles which were less than 9 kc/s in frequency, 7 from sideband splash, 4 each from "Luxembourg effect" and severe continuous fading, and 3 each from interference from jamming and navigational stations. Of the "pirates," 47 per cent were

German, 29 per cent Spanish and 23 per cent A.F.N.-Germany. Spain was responsible for 70 per cent of the heterodyne whistles, some of which were due to stations with a power output of as low as 200 watts. Three stations were responsible for causing Luxembourg effect. The biggest nuisance of the trio was the "Voice of America" station situated near Munich and transmitting on 173 kc/s. The other two were Luxembourg 233 kc/s and Allouis on 164 kc/s. The severe fading occurred, as one would expect, on the channels above 1250 kc/s.

This, it should be noted, was the position in London which, geographically speaking, may be regarded as a suburb of Europe. The situation in the centre of Europe can well be imagined, where receivers with "knife edge" selectivity and rotating ferrite aerials are used in an attempt to harvest something of value from the existing chaos; but it is a battle against impossible odds. Hence the popularity of v.h.f. broadcasting in Germany and wire distribution in Switzerland.

Political Pressure

The position is being continually aggravated by the manœuvring of various transmitters endeavouring to give their listeners a better service; an activity which results in a vicious circle of ever-mounting powers coupled with a battle for the more desirable lower frequencies. It has been said that this chaos arose because the unavoidable demand for channels exceeded the supply. This, of course, is true but represents only part of the story. If only allocations had been made from purely technical and unbiased considerations things might have been very different! As it was, the Copenhagen allocations appear to have been made on the basis of politics, prestige, tradition and influence. Politics were responsible for the fact that neither Germany nor Spain were represented. Prestige and tradition were responsible for Denmark and ourselves retaining long-wave channels in the face of more deserving cases. Influence was responsible for Luxembourg and Monte Carlo being allotted high-power channels. The results were, to say the least, interesting. Germany was allowed a total radiated power of 560 kW and is at present radiating over 3,600 kW. Spain, for reasons of national pride, has shown great determination in using any frequencies but those allocated. A number of countries that *were* represented raised objections and were, in consequence, non-signatories to the Convention. These were Austria, Egypt, Iceland, Luxembourg, Sweden, Syria and Turkey.

Of these, the most interesting is probably that of Luxembourg; a country with an area of about 1,000 square miles and a population of around 300,000, which, for a number of years before the war, occupied a frequency in the long-wave band for commercial broadcasts to foreign countries. It thereby achieved the doubtful honour of revealing the phenomenon known as the "Luxembourg effect." As an inducement to vacate this valuable frequency, it was allocated an exclusive channel at the high-frequency end of the medium-wave band (1,439 kc/s) with a permitted power of 150 kW! Gratitude for this generosity was expressed by occupying this new channel as well as retaining the low-frequency one (233 kc/s). Even the courtesy of moving 3 kc/s to the new long-wave channel 10 (236 kc/s) to avoid a heterodyne of 6 kc/s on channel 9 has been refused.

There are a number of commercial broadcasting stations in Europe. They are usually situated in Duchies, Principalities, Free Territories and the like. There is nothing inherently wrong in commercial broadcasting except that these stations annex channels without any consideration for their neighbours and radiate powers out of all proportion to the needs of their population. Thus we find Luxembourg with two channels (one exclusive) radiating a total power of 300 kW, and Monte Carlo with an almost exclusive channel radiating 120 kW. More recently another commercial monster, situated in the Saar Territory and calling itself Europe No. 1, has appeared in the long-wave band. Having tried a frequency near that of Radio Luxembourg, thereby incurring the wrath of its rival, it has finally settled in channel 4 (182 kc/s). Andorra is another of these tiny States that have found commercial broadcasting a lucrative proposition. It seems to have lacked the influence of its bigger brother at Copenhagen and was only given a share of an International Common Frequency with a power limited to 2 kW. Ever since, the 60-kW Andorra station has been trying to find a home in the medium-wave band.

To complicate the issue still further there are the American Forces in Europe. For the purpose of entertaining their Forces, the Americans were allocated channel 115 (1,554 kc/s) with a permitted power of 70 kW. As an occupying power America was represented at Copenhagen but, because it is not a European country, was not a signatory to the Convention. The delegation, moreover, informed the conference that the U.S.A. was not prepared to implement any allocation plan which provided for only one shared frequency for its Forces programmes and only one programme per zone in Germany. The American Forces Network in Germany now occupies 13 channels (curiously, channel 115 is not among them) with a total power of 400 kW. This attitude towards the Plan set a pattern of behaviour that has regrettably been followed by many lesser lights.

The Last Straw

Finally, the "cold war" emerged and turned the remaining shreds of the Plan into pandemonium. Berlin, being the centre of the cold war, has also become the centre of lunatic broadcasting. It has no fewer than 11 transmitters radiating a total power of over 1,300 kW. The game there has been for one side to increase its power in an attempt to achieve a dominant position, whereupon the other side, anxious to maintain the *status quo,* raise theirs. At the time of writing East Berlin is winning by some 350 kW! There are also the propaganda stations. On our side of the "iron curtain" 7 channels are occupied, with a total power of 1,660 kW. It is rather difficult to assess the score on the other side but it is no doubt equally impressive. A side issue is the jamming stations—a development peculiar to Communist countries—which although occupying only channels used for propaganda, cause severe sideband interference. This sorry story can be closed with an idiotic tale. Long-wave channel 3 (173 kc/s) is occupied by Moscow, in accordance with the Copenhagen Plan, using a 500-kW transmitter. Some time ago "The Voice of America" commenced broadcasting on the same frequency with a power of 1,000 kW. The Russians replied with a high-power jamming station on this frequency with the result that they are jamming their own broadcasts!

So much for the past and present, but what of the future? The growth of v.h.f. broadcasting does give Europe a chance to approach the allocation of frequencies in the medium- and long-wave bands in an entirely new way. It is in the hope that Europe, having reached the heights of lunacy, is now willing to approach this subject in a saner mood that the following suggestions are made.

A New Frequency Plan

Three things seem to be desirable if Europe is to have an orderly broadcasting system. The first is a new plan; the second, an authority to implement it; and the third, powers to enforce it.

For any new plan to succeed, it must be based on fixed principles, however arbitrary. The only principles on which it seems possible to base such a plan are area, population and language. Area being used to define frequency and power; population and language, the number of channels. Such a plan is bound to satisfy no one; but it does have the merit of giving every country a fair proportion of the frequency cake.

Table 1, shows the *modus operandi* of the suggested plan. Countries within the European broadcasting zone are listed in alphabetical order together with their area taken to the nearest 1,000 square miles, and their population taken to the nearest million. The recommended total power is calculated on a power-to-area ratio of 10:1, or 10 kW per 1,000 square miles. For comparison purposes, the total power permitted under the Copenhagen Plan and the total power now in use are also given. The number of nationally exclusive channels is calculated on the basis of one high-power channel for every country entitled to a minimum of 100 kW total power; one medium-power channel for each country entitled to a maximum power of between 50 and

TABLE 1

	Approx. area (units of 1,000 sq. miles)	Approx. population (units of one million)	Total power permitted in Copenhagen Plan (kW)	Total power in use (kW)	Recommended maximum power (kW)	Exclusive Channels					M.W. (B) National Network Channels
						L.W.	M.W. (A)	M.W. (B)	M.W. (C)	M.W. (D)	
Albania	11	1	127	60	110	–	1	–	–	–	1
Algeria	80*†	9	320	256	800	–	2	–	–	–	–
Andorra	0.2	0.005	2	60	2	–	–	–	–	1	–
Austria	32	7	324	575	320	1¶	–	–	–	–	1
Belgium	12	9	344	320	120	–	–	2	–	–	–
Bulgaria	43	7	187	145	430	–	1	–	–	–	1
Cyprus	3.5	0.3	12	110	35	–	–	–	2	–	–
Czechoslovakia ...	49	13	1084	970	490	–	2	–	–	–	–
Denmark	17	4	294	290	170	–	1	–	–	–	1
Egypt	14*†	17‡	80	102	140	–	1	1	–	–	–
Eire	27	3	154	110	270	–	1	–	–	–	1
Finland	130	4	494	460	1300	1	–	–	–	–	1
France	213	41	2559	1970	2130	1	3	–	–	–	–
Germany	138	67	140	3611	1380	1	5	1	–	–	–
„ A.F.N. ...	–	–	70	390	100	–	1	–	–	–	–
„ B.F.N. ...	–	–	70	81	80	–	§	–	–	–	–
Greece	51	8	189	228	510	–	1	–	–	–	1
Hungary	36	10	320	548	360	–	1	–	–	–	1
Iceland	41	0.2	106	111	410	–	1	–	–	–	1
Israel	8	2	45	79	80	–	–	–	2	–	–
Italy	131	47	976	1000	1310	1	3	1	–	–	–
Jordan	7*†	0.5	–	20	70	–	–	1	–	–	–
Lebanon	4	1	40	20	40	–	–	–	1	–	–
Libya	15*†	1	52	–	150	–	1	–	–	–	1
Liechtenstein ...	0.06	0.01	–	–	1	–	–	–	–	1	–
Luxembourg	1	0.3	150	300	10	–	–	–	1	–	–
Malta	0.12	0.3	2	–	1	–	–	–	–	1	–
Monaco	0.008	0.02	120	120	1	–	–	–	–	1	–
Morocco	120†	9	362	281	1200	–	2	–	–	–	–
Sp. Morocco	5*	1	–	14	50	–	–	–	2	–	–
Netherlands	13	11	242	240	130	–	1	–	–	–	1
Norway	125	3	524	510	1250	1	–	–	–	–	1
Poland	121	25	648	500	1210	1	1	1	–	–	–
Portugal	34	9	269	185	340	–	1	–	–	–	1
Rumania	92	17	317	590	920	–	1	1	–	–	–
Saarland	1	1	20	420	10	–	–	–	1	–	–
San Marino	0.04	0.01	–	–	1	–	–	–	–	1	–
Spain	190	23	309	350	1900	1	1	1	–	–	–
Sweden	173	7	950	800	1730	1	–	–	–	–	1
Switzerland	16	5	357	350	250¶	1¶	1¶	1¶	–	–	–
Syria	20*†	3‡	74	74	200	–	1	–	–	–	1
Tangier	0.2	0.1	2	115	2	–	–	–	–	1	–
Tunisia	30†	3	252	140	300	–	2	–	–	–	–
Turkey	220†	18‡	370	270	2200	1	–	1	–	–	–
United Kingdom ...	94	51	2451	1900	940	–	5	–	–	–	–
U.S.S.R. Byelorussia...	81	11	240	100	810	–	1	–	–	–	1
„ Estonia	18	1	120	120	180	–	1	–	–	–	1
„ Finno-Karelia ...	70	1	120	120	700	–	1	–	–	–	1
„ Latvia	25	2	142	140	250	–	1	–	–	–	1
„ Lithuania ...	32	3	252	250	320	–	1	–	–	–	1
„ Moldavia ...	13	3	120	100	130	–	1	–	–	–	1
„ Russia	630†	40‡	1452	1430	6300	2	2	–	–	–	–
„ Ukraine	225	41	882	840	2250	2	2	–	–	–	–
Vatican City	0.17	0.0009	100	5	2	–	–	–	–	1	–
Yugoslavia	96	17	934	680	960	–	2	–	–	–	–

*Populated area. †Estimated area to longitude 40°E. or latitude 30°N. ‡Estimated population within estimated area. ¶Special allocations—see text. §One channel shared with U.K. to carry same programme after dusk.

100 kW, one low-power channel for each country with a maximum power rating of 10-50 kW, and so on.

The frequency range is divided into five bands, each with a power limit:

Long wave:		150-285 kc/s	(15 channels)	100 kW
Medium wave:	(A)	525-998 kc/s	(53 channels)	100 kW
	(B)	1,007-1,295 kc/s	(33 channels)	50-90 kW
	(C)	1,304-1,493 kc/s	(22 channels)	10-40 kW
	(D)	1,502-1,602 kc/s	(13 channels)	under 10 kW

In the plan the l.w. band is reserved for countries with an area greater than 100,000 square miles, with three exceptions. Morocco would normally qualify for a l.w. channel, but taking into account the susceptibility of that part of the world to frequent electrical storms, a medium-wave (A) channel would appear to be preferable. The other two exceptions are Austria and Switzerland which, because of their mountainous terrain, should be given a l.w. channel in preference to a m.w. one.

Extra exclusive medium-wave channels are allocated on a population and language basis; one (A) channel for every 10 million unit of population over 10 million and one (B) channel for every 5 million unit of population over 10 million. Countries where more than one language (not dialect) is spoken over a wide area are allocated one exclusive channel for each language group; the total permitted power being maintained. Thus, a bilingual country with a total permitted power of 100 kW would receive two (B) channels of 50 kW each instead of one (A) channel of 100 kW. Here again, Switzerland may be regarded as an exception for the reasons given above and it is recommended that in addition to one l.w. channel of 100 kW for the German language group, a further 100-kW m.w. (A) channel for the French language group be allocated, as well as a 50-kW m.w. (B) channel for the Italian language group. It should be noted, however, that language channels are normally not in addition to those based on population.

Power Limitations

Allocations within each band are made in ascending order of frequency according to descending area of territory, but a certain amount of rearrangement would be necessary to reduce adjacent channel interference to a minimum. The procedure for filling the bands is to allot each country one channel in the correct order, then the second channel for each country, then the third, and so on. Power in the l.w. band and m.w. (A) band is normally limited to 100 kW per channel except where the territory lies on the perimeter of the European area, when the maximum power may be raised to a limit of, say, 500 kW in the l.w. band, and 200 kW in the m.w. (A) band. The maximum permitted power shown in Table 1 is a "ceiling" which no country may exceed but does not necessarily entitle it to use that amount of power as a right. The amount of power a country may radiate will depend on the number of channels in each band available to it. This is reasonable since the largest countries receive the lowest frequency channels; a factor which tends to cancel the effects of power to some extent.

Channels may be used for national networks with certain obvious limitations as to power and geographical spacing in order to spread the power over a relatively wide area and to forestall any attempt to defeat the plan by concentrating a large number of transmitters within a small area.

As well as a power maximum, every band also has a power minimum to prevent wastage of channels. Any country that cannot fulfil the power requirement of any channel allocated to it by the time the plan came into force (or within a reasonable time after) would have to accept a channel in the band appropriate to the power it can use. In the event of this occurring all the remaining stations in that band would be moved to the next lower frequency channel. This would leave a vacant channel at the h.f. end of the band which could be taken up by a country in the next band able to fulfil the power requirements without exceeding its maximum permitted power.

When all the exclusive channels have been filled, 22 channels are left vacant in the m.w. (B) band, 13 channels in the (C) band and 8 channels in the (D) band. It will be found possible to give every country that has so far received only one channel, an exclusive national network channel in the (B) band. This is probably the best use that could be made of the vacant channels in this band and they should be distributed in order of area of territory. The vacant (C) channels could be shared by various countries, and these, in combination with the vacant channels in the (D) band, should be sufficient for the booster stations that are needed in various parts of Europe where there are local propagation difficulties. Low-power international common frequencies can be made use of, in the (D) band, as in the Copenhagen Plan.

Accommodating Commercial Stations

We now come to the question of the commercial broadcasting stations of which there are six at present. It is recommended that they are accommodated in the (D) band. The utmost discretion should be used when considering applications for frequencies for these stations as they also make use of short-wave broadcasting; Andorra uses one short-wave channel, Luxembourg one, Monaco two and Tangier as many as seven. All these territories, of course, would be entitled to the transmitter power and appropriate channel calculated on their area and population. Because the Vatican City uses ten short-wave channels to reach its audience, one medium-wave (D) channel should suffice to cover its own territory.

The effect of the recommended plan can be seen in Table 2 on the next page. It shows the whole of the long-wave band and the first 20 channels in the medium-wave band. The allocations are in their calculated order and some rearrangement would be necessary to reduce adjacent channel interference. With this plan in operation, it should be possible to obtain reasonably clear reception from over 100 stations in Europe. This represents an improvement of more than three to one over the present situation. There is, however, nothing utopian about it; indeed, some countries may feel they would be making a bad bargain with this plan. If so, they should reflect that what they would lose in quantity, they gain in quality; and if the lack of channels should encourage them to accelerate any contemplated change to v.h.f. broadcasting, that is not necessarily a bad thing.

Certain principles of the Copenhagen Plan have been accepted. These are, the extent of the long- and medium-wave bands (150—285 and 525—1,605 kc/s), 9-kc/s channel spacing and the boundaries of the European broadcasting area. This area is limited in the east by longitude 40°E, and in the south by latitude 30°N. These lines cut across Russia, Turkey, Syria, Jordan and N. Africa, and only the areas lying within these boundaries have been used as the basis of calculation. Further, large portions of some countries in the Middle East and N. Africa are virtually uninhabited and these areas too have been excluded. In the plan, Russia is regarded as a separate republic within the U.S.S.R. This is to some extent justified, owing to the different languages spoken in the different republics of the Union—Estonia, Byelorussia, Ukraine, etc. Regarding the question of languages, the following countries are regarded as having more than one language: Algeria, Belgium, Cyprus, Czechoslovakia, Israel, Morocco, Spanish Morocco, Tunisia and Yugoslavia, two each; Spain and Switzerland, three each. Whether all these countries normally broadcast in more than one language is a point that requires verification where it affects the number of channels allocated to them.

The most noticeable effect of the plan occurs in the long-wave band, where Austria, Germany, Italy, Spain and Switzerland take the places of Czechoslovakia, Denmark, Iceland, Rumania and the United Kingdom who occupied long-wave channels under the Copenhagen Plan. Of the countries which are eliminated from the band, only Iceland and Rumania have not yet started a v.h.f. service.

As this is intended as an interim plan to cover the period of the changeover to v.h.f., it is of interest to note the latest position as taken from the *Wireless World* "Guide to Broadcasting Stations." The number of v.h.f. transmitters in use in July, 1955, or planned to be brought into service shortly, were: Austria—11, Belgium—1, Czechoslovakia—1, Denmark—5, Finland—18, France—3, Germany—154, NATO Forces, Germany—8, Gt. Britain—33, Israel —7, Italy—35, French Morocco—8, Netherlands—6, Norway—2, Portugal—2, Saarland—1, Sweden—2, Switzerland—2, Ukraine—1, Vatican City—2, and Yugoslavia—1. From this it can be assumed that the pattern of medium-frequency broadcasting is changing from that of providing a primary national service, to that of providing a service to outlying or sparsely inhabited districts and, possibly, an international service. It is on this conception that the plan is based, and it is for this reason that the extended* medium-wave band and the 9-kc/s channel spacing of the Copenhagen Plan have been accepted. By about 1965, it may be possible to approach the problem in an entirely different light and listening in the medium-wave band may become a positive pleasure.

TABLE 2

Channel	kc/s	Country	kW
	LONG-WAVE BAND		
1	155	Russia	$\ngtr$500
2	164	Ukraine	$\ngtr$500
3	173	Turkey	$\ngtr$500
4	182	France	100
5	191	Spain	100
6	200	Sweden	100
7	209	Germany	100
8	218	Finland	100
9	227	Norway	100
10	236	Poland	100
11	245	Italy	100
12	254	Austria	100
13	263	Switzerland	100
14	272	Russia	$\ngtr$500
15	281	Ukraine	$\ngtr$500
	MEDIUM-WAVE BAND (A)		
1	529	Morocco	$\ngtr$200
2	539	Jugoslavia	100
3	548	United Kingdom	100
4	557	Rumania	100
5	566	Byelorussia	100
6	575	Algeria	100
7	584	Finno-Karelia	100
8	593	Greece	100
9	602	Czechoslovakia	100
10	611	Bulgaria	100
11	620	Iceland	$\ngtr$200
12	624	Hungary	100
13	638	Portugal	$\ngtr$200
14	647	Lithuania	100
15	656	Tunisia	$\ngtr$200
16	665	Eire	100
17	674	Latvia	100
18	683	Syria	$\ngtr$200
19	692	Estonia	100
20	701	Denmark	100

Frequency Planning Authority

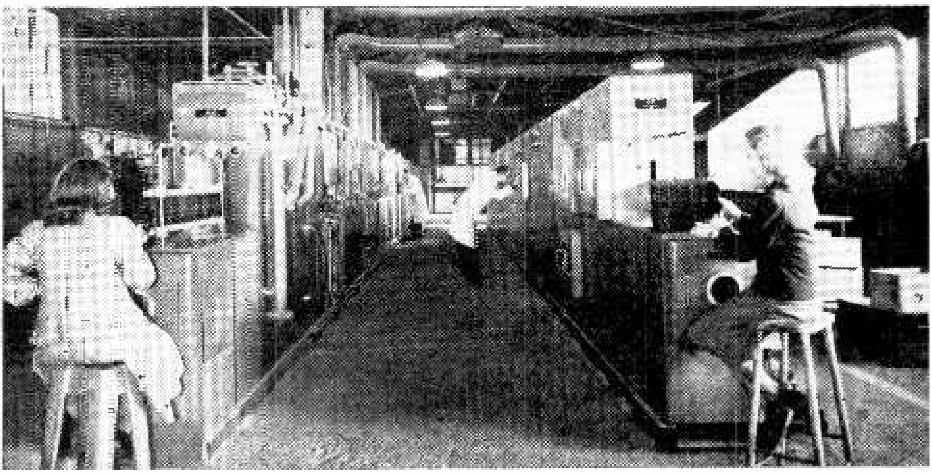
To launch this plan, or something similar, would require an international conference, but only agreement on principles would be necessary, the details being left to a European Frequency Planning Authority. An authority of this nature is a long overdue necessity for Europe. It should have complete power over the frequency range, 100 kc/s—2 Mc/s and should wield its authority from a permanent headquarters in a politically neutral country. From there, the new plan and any further plans would be implemented and it would deal with all fresh applications for channels, increases or decreases in power, monitoring and so on. Its executive staff should consist of physicists, engineers and geographers, and, it should be needless to add, no politician should be allowed within its doors.

The thought has no doubt crossed the reader's mind that no plan can possibly succeed in this wicked world without enforcement. This is an issue that has hitherto been shirked, possibly through the lack of a suitable instrument of enforcement. Fortunately, the "cold war" has suggested a suitable method—that of jamming stations. How effective these are can easily be verified by tuning round the medium-wave band during any evening. Two or three high-power jamming stations situated at strategic points in Europe should deter recalcitrant broadcasting authorities from kicking over the traces. With a couple of thousand jamming kilowatts at its disposal, the authority should have little dfficulty in keeping law and order. Needless to say, the sites of these transmitters should have extra-territorial rights.

It is not suggested that this is an ideal plan—no plan can ever be—and it can, no doubt, be improved upon. Whatever variations may be possible, the basis of working on fixed principles should be adhered to. It is this factor which makes the plan equable and therefore more likely to be accepted by the majority. In any event, a new plan is a necessity and should not be long delayed. It should be possible to put it into operation before 1960. Given a reasonable amount of good will it should further be possible to set up the Frequency Planning Authority by that date. The importance of the Authority cannot be over emphasized. Without it no plan can succeed, any more than law can be maintained without a police force. It is up to Europe to decide whether it wants law or anarchy.

Perhaps the European Broadcasting Union would care to take the matter up from here.

* At the Atlantic City Conference (1947) the medium-wave band was extended from 550-1,500 kc/s to 525-1,605 kc/s—Ed.



General view of ECME machine (two complete batteries) from the input end.

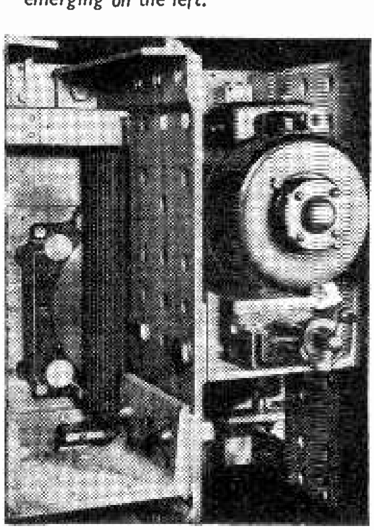
(Courtesy Central Office of Information).

Automatic Circuit Production

Plans for an Improved Version of the Sargrove ECME

SINCE 1947, when John Sargrove introduced his revolutionary new method of manufacturing complete electronic circuits*, there have been quite a few developments in the field of automatic circuit production. The printed circuit has become commonplace and various methods of automatic assembly have been designed around it. In spite of this, and the fact that the Sargrove system was never really put into full operation, certain organizations have expressed such interest in the scheme that Mr. Sargrove has been asked to consider a new version of the ECME† machine—a version more flexible than the original plant but still working on basically the same principle.

A high-speed surface milling unit in the machine, showing a circuit panel emerging on the left.



The purpose of the ECME machine, it will be recalled, was to reduce the cost of circuit production (notably in broadcast receivers) by eliminating the work of component assembly and wiring normally done by human operatives. It did this by turning out a "compound" circuit in the form of a moulded panel which had components as well as wiring as integral parts of the whole. The panel contained grooves and indentations of various shapes, which, when filled with conducting material, formed the connections, the inductors and the capacitors. The filling was done by spraying the whole panel with the conducting material and then milling off the surplus from the raised parts afterwards. Resistors were fabricated by spraying on graphitic material through suitable stencils.

All this was done automatically by the machine, which was arranged on the conveyor-belt principle, and at the end it was only necessary for accessories such as valves to be added by human hands. Electronic control was used extensively throughout the plant, and after each production process there was an automatic inspection device for controlling that process. There were also devices for automatically testing the circuit before and after the valves were inserted.

Unfortunately this early machine was really only suitable for large production runs on the same type of circuit. The cost of making the necessary new tools for a different circuit was quite large and could only be balanced by the savings obtained by automatic production on long runs. Improvements have now been worked out, however, which should make the second machine more versatile. The main one is a new design technique for the panel-moulding tools, based on the "Meccano" principle so that different indentation patterns can be more readily formed and altered. By this means it is expected that the normal preparatory period of 3 months before a production run will be reduced to something like one week-end. The Mk. II machine will be suitable for manufacturing television receiver circuits, among other things.

On the question of the saving in cost achieved by automatic assembly methods, it is interesting to note that where conventional components are used, as in one recent American system, there is actually no reduction in the cost of assembly pure and simple. The saving arises from the fact that the system produces a much tidier job, which enables it to be inspected and tested by automatic methods. With circuits assembled by hand, the construction generally appears more complicated and tends to vary from unit to unit, so that the inspection and testing can only be done conveniently by skilled human operatives. This, of course, is where expensive bottlenecks occur in normal factory production.

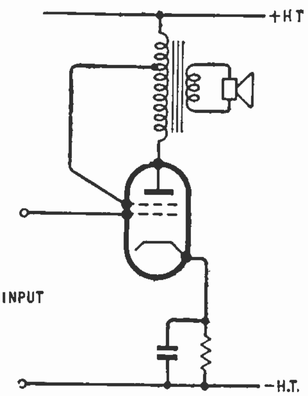
* See "Automatic Receiver Production," *Wireless World*, April 1947.
† Electronic Circuit Making Equipment.
See also note on Automation Consultants and Associates, p. 6.

Tetrodes with Screen Feedback

FURTHER LIGHT ON THE SO-CALLED "ULTRA-LINEAR" CIRCUIT

AFTER a period of caution, amounting in some quarters to undisguised scepticism, the "ultra-linear" output stage[1, 2, 3, 4] is undoubtedly here to stay. It was unfortunate, though, that Hafler and Keroes in popularizing this circuit for audio amplifiers should have chosen a term which, if it means anything, suggests that the transfer characteristic has been bent "beyond the straight" and is therefore still curved!

Several alternative descriptions have been suggested, the most plausible being "triode-tetrode" operation. This hardly does justice to the circuit, since, although at the extreme limits of the screen tapping (Fig. 1) the valve is undoubtedly operating either as a triode or a tetrode, the intermediate tapping points do not give a progressive transition, so far as distortion is concerned, from one set of characteristics to the other. When the screen tapping point is properly adjusted the transfer characteristic is more nearly linear and distortion is less than that of either the tetrode *or the triode* connection. Obviously some factor is at work which is not present in either of the limiting conditions and "triode-tetrode" is misleadingly simple. If it is called the "UL" circuit the special nature of its performance is underlined, and we do not have to grit our teeth over that "beyond the linear."



TAPPING POINT (Measured from +h.t.)	
Impedance (%)	Turns (%)
0	0
5	22.4
10	31.6
15	38.8
20	44.7
25	50
30	54.8
50	70.8
100	100

Left: Fig. 1. Basic connections of UL output valve.

The UL nomenclature is, incidentally, adopted by F. Langford-Smith and A. R. Chesterman who have recently[5] carried out an exhaustive experimental investigation of the push-pull circuit (Fig. 2). The results of their measurements with KT66s are given in Fig. 3 and it will be noted that they have taken the trouble to adjust the load resistance and bias for the best performance at each tapping point. This ensures that the effects of screen feedback will not be modified or obscured by unfavourable operating conditions.

The curve for maximum power shows a clear minimum for a screen tapping of about 15%, and a similar though less pronounced minimum occurs at about 20% under minimum distortion conditions. Both these minima are of lower value than the distortion present under optimum triode conditions.

Any reduction in inherent distortion in the output stage reduces the degree of overall feedback required for a given amplifier performance and so increases the stability margin, but the improvement over triode performance by itself would seldom justify the expense of the extra primary tappings. The real advantage of UL operation is that triode performance in the matter of low inherent distortion is achieved with a power efficiency performance approaching that of a pentode. For a given audio-frequency power output and distortion level, smaller output valves and a less expensive power supply unit can be used with the UL circuit than would be necessary with triodes in the output stage.

For a given anode and screen supply voltage the available power output from a pair of valves in the UL circuit is always less than that given by the same valves operated as pentodes (tetrodes) (see Fig. 3), and the voltage gain is also less. It is sometimes argued that, provided the amplifier has a stability margin

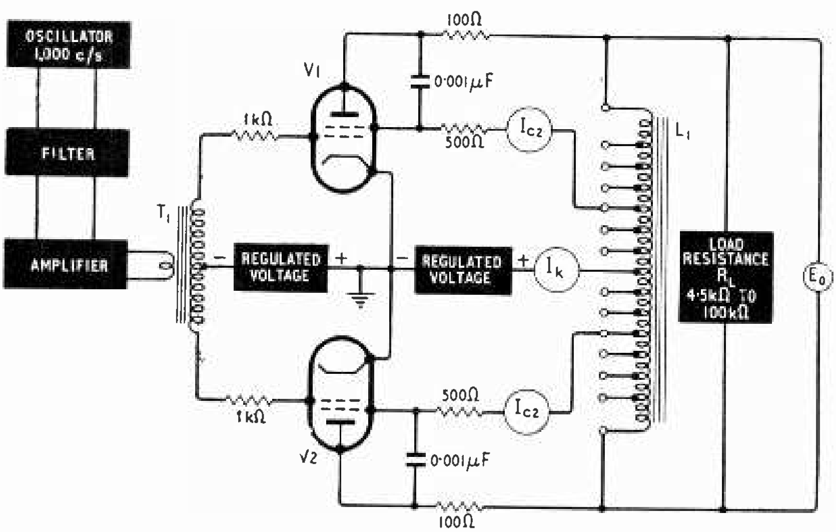


Fig. 2. Circuit used by Langford-Smith and Chesterman as a basis for measurements of power output and distortion given in Fig. 3.

capable of accepting the higher overall feedback necessary to reduce distortion, the same results will be obtained by using normal pentode operation. Langford-Smith points out[3] that the voltage gain characteristic of a pentode stage (Fig. 4 (a)) is far from linear compared with the UL circuit, and that with pentodes the feed back near full power output will be reduced—just where it is most wanted. It is also stated that since the maximum-signal cathode current is less with UL than with pentode operation and the cathode current efficiencies are approximately the same, it should be possible to increase the anode voltage to bring the UL power output up to the pentode level.

In the test circuit (Fig. 2) used by Langford-Smith and Chesterman it will be seen that anti-parasitic measures have been liberally applied and the authors mention a tendency towards instability which is attributed to the multiplicity of tappings and their associated switches. This tendency to instability in the UL circuit must not be overlooked. It is closely related to the design of the output transformer and is discussed in detail elsewhere in this issue.

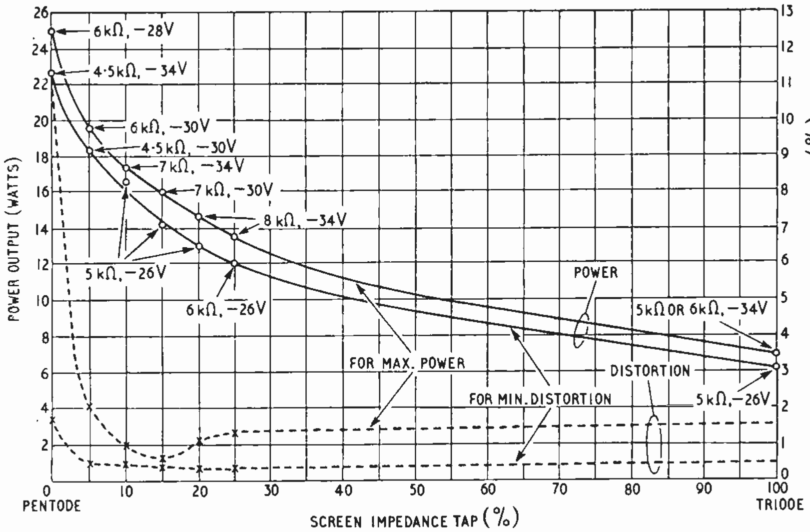


Fig. 3. Variation of total harmonic distortion and maximum power (peak input=grid bias) with screen tapping. Load and bias adjusted for optimum performance at each measured point using a pair of KT66 valves with 300V anode and screen supply.

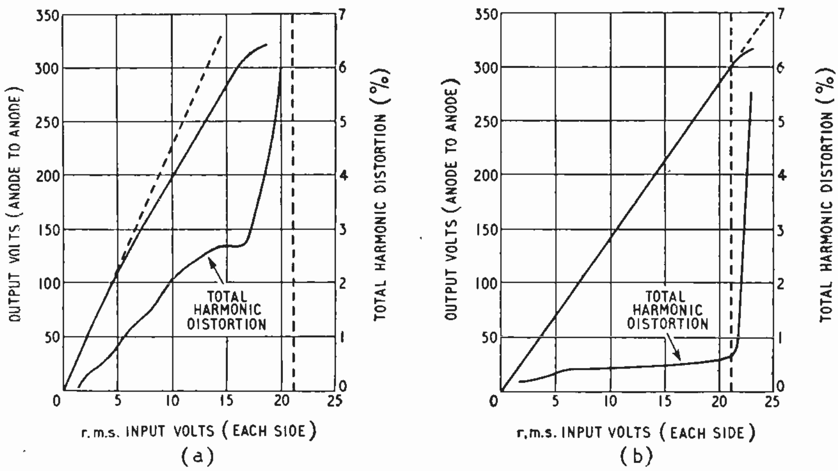


Fig. 4. Voltage transfer characteristics of KT66s, (a) as tetrodes, (b) under 20% tap UL conditions. The vertical dotted line indicates the level at which peak input equals the grid bias.

"Mechanism" of the UL Circuit.—Although the circuit behaves, so far as reduction of gain and output impedance are concerned[3], according to the known laws of feedback circuits and shows a smooth transition from the pentode to the triode condition, the conventional feedback formulæ fail to account for the dip in the distortion curve at a critical screen tapping point (which varies from valve to valve).

It has been suggested that non-linearity in the screen/anode characteristic may offset curvature of the control grid characteristic, but this cannot be easily checked as the screen characteristics of power output valves are not usually included in the makers' literature. But is this basically the right explanation? If the screen curvature is sufficient to cancel the grid curvature at comparatively low levels of feedback (5% in the case of the 6V6) why does it not predominate and cause more than the observed distortion as the screen feedback approaches 100% (triode)?

An alternative and more plausible hypothesis recently published[6], takes into account the non-linearity resulting from multiplicative mixing when feedback is applied to an electrode other than the input grid. It is known that non-linearity can be introduced into an otherwise linear valve characteristic by applying feedback to the suppressor grid. This form of distortion will be present also when the screen characteristic is itself linear. It is shown mathematically that feedback can be critically adjusted to cancel a particular harmonic (in practice the third) and that as all even harmonics are already cancelled by push-pull operation the residue must consist of higher-order odd harmonics. The analysis has not been extended to these higher harmonics, and although individually they are of amplitudes approaching the experimental threshold of measurement, it is by no means certain that they may not have been increased by the same process which reduced the much stronger third harmonic. In practice, judging from the subjective quality from UL amplifiers we have heard, this effect, if present, is negligibly small; but it would repay investigation (assuming that distortion measurements of sufficient precision are forthcoming) if only to throw more light on the fundamental processes of UL operation.

Acknowledgment. Figs. 2, 3 and 4 are based on Figs. 6, 2 and 5 respectively of *Radiotronics* (Australia), Vol. 20, No. 5, May, 1955.

References

[1] A. D. Blumlein. British patent No. 496,883 (1937).
[2] "An Ultra-linear Amplifier," by D. Hafler and H. I. Keroes; *Audio Engineering*, November 1951.
[3] "Amplifiers and Superlatives," by D. T. N. Williamson and P. J. Walker, *Wireless World*, September 1952.
[4] Correspondence: Graham Woodville, *Wireless World*, November 1954; P. J. Walker, N. F. Butler, *Wireless World*, December 1954.
[5] "Ultra linear Amplifiers," by F. Langford-Smith and A. R. Chesterman, *Radiotronics*, May, June, July, 1955.
[6] Editorial (W.T.C.), *Wireless Engineer*, August 1955.

"D.C. Stability of Transistor Circuits"

THE author of this article in the April, 1955, issue asks us to point out that the base current in the example (left-hand column, p. 167) should be calculated from equation (3) on p. 164 and not from equation (8) as shown. The numerical error is, however, small and the value of R_B is increased from 12,500 to 13,000 ohms and the stability factor S from 17 to 17.5.

Dates for Your *Wireless World* Diary

INDIVIDUAL announcements have already been made of the dates of some of this year's exhibitions, but for the convenience of readers we give below a list of the principal shows in 1956.

Television Society Exhibition — **March 6-8**
Royal Hotel, Woburn Place, London, W.C.1.

Components Show (R.E.C.M.F.) — **April 10-12**
Grosvenor House, Park Lane, London, W.1.

British Industries Fair — **April 23-May 4**
(Electrical Section), Olympia, London, W.14.

Association of Public Address Engineers Exhibition — **April 25 & 26**
Conway Hall, Red Lion Square, Holborn, London, W.C.1.

Mechanical Handling Exhibition — **May 9-19**
Earls Court, London, S.W.5.

Physical Society Exhibition — **May 14-17**
Royal Horticultural Society Halls, Westminster, London, S.W.1.

British Sound Recording Association Exhibition — **May 26 & 27**
Waldorf Hotel, Aldwych, London, W.C.2.

Institution of Electronics Exhibition — **July 12-18**
College of Technology, Manchester.

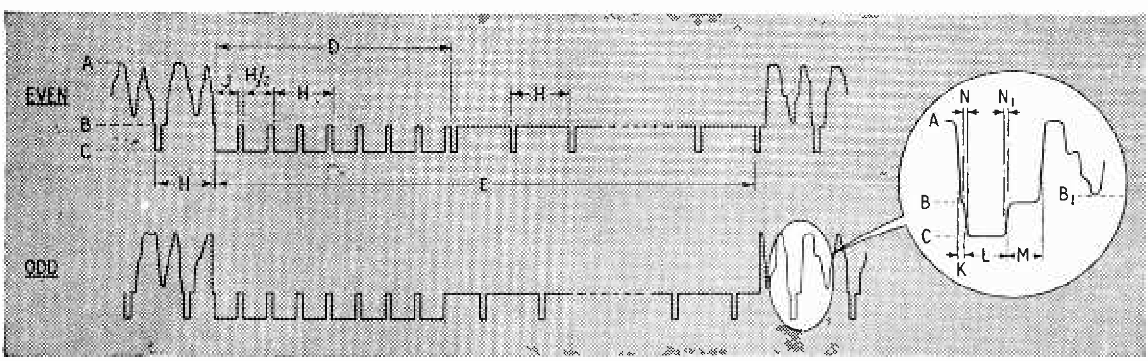
National Radio Show — **Aug. 22-Sept.1**
Earls Court, London, S.W.5.

Farnborough Air Show (S.B.A.C.) — **Sept. 3-10**
Farnborough, Hants.

Television Waveform

ONE or two minor changes have been introduced in the British television waveform since the publication three years ago (August, 1952, issue) of the operating details of the various world systems (405, 525, 625 and 819 lines). To bring up to date the published information, the amended drawing of the 405-line waveform and the relevant tabular matter are reproduced below.

The first change is in the black level (B_1) which has been lifted by 5 per cent of peak white amplitude. What was previously known as black level (30% of peak carrier) is now called the suppression level (B). The second change, made a few months ago, was the lengthening of the pre-sync. suppression period, or front porch, (K) by 0.5 μsec.



A	(peak white)	100%	H	(line period [μ sec.])	98.7
B	(suppression level)	30%±3%	J	(frame pulse duration [μ sec.])	40±2
B_1	(black level)	35%±3%	K	(front porch [μ sec.])	1.5−2
C	(sync. level)	0−3%	L	(line pulse duration [μ sec.])	8−10
D	(vert. sync. pulses)	4 lines	M	(back porch [μ sec.])	6−9
E	(frame suppression period)	14 lines (1.4 msec.)	N	(rise time [μ sec.])	$\not>$0.25
			N_1	[μ sec.]	$\not>$0.25

LETTERS TO THE EDITOR

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

"*Radio Navaids*"

"RADIOPHARE," writing in your December, 1955, issue, compares hyperbolic rho-theta air navigational systems. There are many points on which I should like to take issue with him but to do so would make considerable claims on your space; I shall therefore restrict my comment to those portions of his article in which I feel he has done hyperbolic systems considerably less than justice.

Although "Radiophare" rightly emphasizes the accuracy of the hyperbolic aid, he glosses rather lightly over the other side of the story. He does not, in fact, explain how inaccurate rho-theta—or rather, theta—devices are. On this point I need do no more than commend him to an editorial in the American *Aviation Week* of August last, which complains, amongst other things, that aircraft on VOR radials 15 degrees apart frequently find themselves on collision courses.

We believe that the finest presentation is a pictorial display actuated by information derived from a highly accurate system. Obviously, of course, we have a vested interest in such devices and anything I say in this regard could be considered special pleading. Instead, I summarize a statement issued on 15th November, 1955, by British European Airways which gives their reactions to Decca after more than 30,000 flying hours with our pictorial display—the Decca Flight Log.

B.E.A. found the Flight Log presentation of great value because it enabled predetermined tracks to be maintained precisely and "estimated times of arrival" calculated easily "with an accuracy we do not believe capable of achievement by any other contemporary system." Further, they found it invaluable in detecting sudden wind changes, frequently encountered at high altitudes, and in the ease and accuracy with which it enabled holding patterns to be maintained and a smooth and rapid transition to be effected from holding pattern to the final feed-in point. B.E.A. also stated that pilots were enthusiastic about the Flight Log display and consider that it eased the cockpit workload considerably.

"Radiophare" does not mention a major problem now facing aviation. This is the problem of air traffic congestion which is being caused by the wide separation standards imposed by Air Traffic Control. These separation standards are necessary because the majority of aircraft have no accurate navigational facility. They therefore have to be protected, as it were, from the possibility of their own errors. Separations can only be narrowed if each aircraft in a traffic complex knows exactly where it is at any moment. The Decca Navigator system provides this facility and it allows the maximum utilization to be made of the air space. We do not believe that this "lateral track separation," as it is known, will be possible with a rho-theta system because of the intrinsic inaccuracies of such systems. In support of this point I would quote General Arnold, who was Chairman of the late VORTAC Committee, who said that he "held out little hope at this time of the idea of lateral separation with VOR and DME" nor, he added, "would lateral separation be practicable even with TACAN."

One final point. Radiophare talks about the ambiguity of hyperbolic systems as though this were a major disadvantage. He appears to overlook the fact that long base lines and hence ambiguities are essential to high accuracy, but that, even so, the ambiguities are then resolved to the point where they are no longer operationally significant. Further, it is by resolving these ambiguities in stages that Decca is able to offer a "fail safe" facility which is not, of course, available with the rho-theta type of aid.

With a high-accuracy hyperbolic system it is always possible to keep a check on the functioning of the system itself and if anything goes wrong it is immediately discernible. This is not so with a rho-theta device, which may give erroneous information without any indication that it is in fact in error.

E. R. BONNER
(Manager, Air Division, The Decca Navigator Company).

Art or Science?

IT is distressing to observe that *Wireless World*, the acme of correct terminology, has again described the science of electronics as an art (December Editorial).

Art implies intuition and whereas some experimenters may consider their work the result of imagination, they cannot then claim the title of engineer because the true engineer should be able to deduce why or why not a circuit is good by scientific reasoning, whereas the artist (musician, painter or otherwise) does not necessarily so judge his work.

Scanning your "Situations Vacant" advertisements one observes a marked preference by the industry for B.Sc. degrees rather than B.A.

Radio is a science and the word art does not embellish it, but shows instead an attempt to find a better description where none is needed.

St. Ives, Hunts. H. S. KING (G3ASE).

"*Component Tolerances*"

IN his article in the November *Wireless World*, H. S. Jewitt appears to have over-simplified the question of component selection. His reasons for selecting composition resistors in preference to high-stability carbon resistors completely ignore the well known fact that these two types of resistors have marked differences as far as stability of value are concerned. It is pointless to specify a component to be within a selection tolerance of $\pm 5\%$ of a nominal value if that component has a secular drift of as much as 25%. One of the major advantages of the high-stability carbon resistor over its cheaper counterpart is that its rate of drift is very much lower. The difference between selection tolerance and stability, which terms Mr. Jewitt seems to have confused, is made clear in RCG 110, paragraph 10, which states:

> "It should be noted that there is no connection between stability and selection tolerance. Thus a Grade 2 resistor, having a nominal value of 100 ohms and a section tolerance of 10% may be supplied originally at any value between 90 ohms and 110 ohms, but in certain conditions of use it may drift away from the initial value by as much as 25%. Hence it would be misleading to offer a selection tolerance of less than 10% for Grade 2 resistors, and only this tolerance is listed in RCL 112. In general, resistors within the range 1,000 ohms to 100,000 ohms possess a degree of stability in excess of the lower and higher values."

RCS 112 (2.3) requires that Grade 2 resistors be stable to $\pm 25\%$ under service conditions. Grade 1 resistors are required to be stable to $\pm 5\%$ under similar conditions.

It is surely false economy to save a few pence in the initial cost of expensive apparatus by using unsuitable components in critical positions and thus lay trouble in store for the purchaser as the cheaper components drift out of the specification limits and jeopardize the performance of the apparatus.

A further aspect of resistor selection which the author has not considered is that due allowance must be made for the changes in value which occur when resistors are operated under certain conditions of voltage and temperature. The high-stability carbon resistor shows to considerable advantage over the composition resistor when the temperature coefficients and voltage coefficients of each type are compared.

RCS 112 gives a temperature coefficient limit of 0.08% for popular values of the Grade 1 component, and ±0.12% for similar values of the Grade 2 resistor. This specification limits the voltage coefficient of Grade 1 resistors to 0.002% per volt, and that of Grade 2 resistors to 0.025% per volt (under 1 megohm) and 0.05% per volt (over 1 megohm).

It is evident that Grade 1 resistors will change 50% less than the Grade 2 component when subject to a similar temperature rise, and when both types are subject to the same magnitude of voltage stress the change in value of a Grade 2 component will be of the order of 10 times greater than that of a Grade 1 resistor.

The author's statement that in a batch of ±10% resistors there is a tendency for the values to lie in two bands towards the edges of the permissible range of values should be qualified by adding that this is only true of batches of Grade 2 resistors, which have been denuded of values in the middle range when the ±5% resistors were previously extracted from the batch. So far as this company is concerned, Grade 1 resistors are made to value by a process which yields 80% of the total production falling within ±1% of the nominal value. When small quantities are supplied from stock a slight bias in the distribution around nominal may be evident, but the distribution of values around nominal in a bulk quantity will be more even.

It is hoped that these observations have shown that there is much more to selecting a suitable resistor for a given application than considerations of price and delivery, as Mr. Jewitt implies, and that in critical applications, where stability is important, the high stability resistor is preferable to the composition type.

G. FRANCE.

Welwyn Electrical Laboratories, Ltd.

H. S. JEWITT in his article in your November, 1955, issue, would appear to have overlooked the fact that a circuit when correctly designed must "tolerate" variations in its component values due not only to their initial tolerance but also to their subsequent instability.

Take the author's simple example of the potentiometer made up of two resistors R_1 and R_2. If by assuming a resistance variation of ± 10% the circuit has been "tolerance engineered" to meet the minimum bias requirement, surely it would be asking too much to expect 100% success on reproduction, using 10% tolerance resistors of any grade.

The proper solution in this particular example would be to assume a resistance variation of ± 10% (or more strictly speaking −9.75%, and +10.25%) and on reproduction use 5% tolerance Grade I resistors having a 5% stability. With such a solution one could say without doubt that the "all adverse" circuit condition had been well met; no other factor of safety would be needed.

Richmond, Surrey. E. NEWELL.

The author replies.—No consideration was given to the question of stability in my article, as the prime purpose was to indicate the need for tolerance engineering. If stability is to be included a fresh factor must be introduced in the tolerance calculation, as indicated by both correspondents. In answer to Mr. France, composition resistors are only selected in preference to high-stability types when their special properties of low inductance, low capacitance and low cost are important. In certain applications they are technically necessary, and one of the aims of tolerance engineering is to make it possible to use cheap components successfully rather than the more costly high-stability types. There was no confusion between tolerance and stability in the article for only one of these topics was dealt with.

H. S. JEWITT.

"Q Measurement"

IN the article by S. Kannan in your December, 1955, issue, there was a mathematical error in the derivation as printed of the formula for Q (equation 2).

From $$Q''\omega L_1 = \frac{QQ'''\omega^2 LL_1}{Q\omega L + Q'''\omega L_1}$$

it follows that $$Q = \frac{Q'''\,Q''}{Q''' - Q''} \cdot \frac{L_1}{L}$$

Inspection of the published formula reveals that Q would be less than unity for typical values of Q‴ and Q″.

We are of the opinion that the following method for determining the Q of a parallel tuned circuit incorporating variable tuning is somewhat easier to use and has the advantage of giving the Q value of the tuned circuit rather than that of the coil. It is, of course, the former Q value upon which the performance of an i.f. stage is partially dependent.

The procedure is as follows:—

(1) Set the Q meter to the frequency (*f*) at which measurements are to be made.

(2) Connect to the "Inductor" terminals a suitable coil (L_1) of fairly high Q value and resonate this to *f* with capacitance C_1. Note the value Q_1.

(3) Connect the parallel circuit (L_2 C_2) under test to the "Capacitor" terminals and restore resonance by variation of either L_2 or C_2 (usually by means of the dust core).

(4) Note the magnification factor, Q_c, this being the Q value of L_1 with L_2 C_2 connected across C_1.

(5) Determine by inspection or measurement the value of C_2.

Then $$Q_2 = \frac{Q_1\,Q_c}{Q_1 - Q_c} \cdot \frac{C_2}{C_1}$$

where Q_2 is the Q value of the circuit L_2 C_2.

This is derived as follows:—

At resonance L_2 C_2 behaves as a resistance, R_2, shunted across the "Capacitor" terminals and it may be shown that:—

$$R_2 = \frac{Q_c\,Q_1}{Q_c - Q_1} \cdot \frac{1}{\omega C_1}$$

But

$$R_2 = \frac{Q_2}{\omega C_2}$$

Hence the expression for Q_2 follows.

K. W. STANLEY.
E. SPIELBERG.

Hayes, Middx.

Magnetic Tape

A. H. BEAN asks (your November issue) about "print through" on tapes that have been stored.

In my library of tapes I possess several which were recorded 5 years ago and I can find no trace of "print through." Some authorities have suggested that tapes should be re-wound every six months, but I have not adopted this policy, neither have I stored them in metal canisters but in cardboard boxes at normal room temperature.

All the same, I understand the B.B.C. do not rely on storing programmes on tape and that the Western German broadcasting organization re-record all their tapes every 5 years.

Hemel Hempstead, Herts. RICHARD ARBIB.

UL Output Transformers

By D. M. LEAKEY*, B.Sc., and R. B. GILSON†

Stability of "Ultra Linear" Push-Pull Output Stages at High Frequencies

THE advantages afforded by the "ultra-linear" circuit for push-pull output stages have now been well established, but the necessary conditions to be met when designing the associated output transformer have not always been given the attention they deserve. This is especially true of the high-frequency performance, where one of the main troubles is the appearance of peaks in the frequency response, which in extreme cases lead to continuous oscillation. In this article it is hoped to explain the two main modes of possible oscillation and to show how, by suitable transformer design, and in extreme cases, with external components, these troubles can be minimized. Due to the distributed nature of the relevant components in a transformer (e.g., stray capacitance) any "lumped constant" explanation can at the best be only approximate, and the following arguments should not be taken as rigorous proofs, but only as simplified indications of the factors involved.

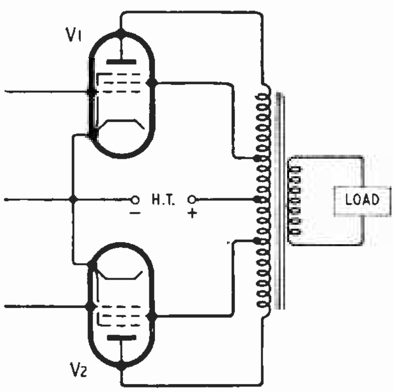


Fig. 1. Basic circuit of a push-pull UL output stage.

To conclude the article a transformer suitable for an N709 "ultra-linear" push-pull output stage, such as in the Osram "912" amplifier, is described.

The two main modes of oscillation in a push-pull UL stage can be classified as:—

(i) Oscillation involving cross-coupling between the valves in the output circuit.

(ii) Oscillation of one or both of the output stages, more or less independently.

Fig. 1 shows a typical basic circuit of a push-pull UL output stage. Unfortunately an equivalent circuit at high frequencies consisting of an array of leakage inductances cannot be drawn for such a circuit. Hence, to show the causes of the above modes of oscillation it is necessary to simplify the circuit. The maximum number of windings which can be dealt with if an equivalent high-frequency circuit is drawn is three, whereas in the above circuit there are effectively five windings. For a three-winding transformer the equivalent leakage inductance circuit can be drawn as three star-connected leakage inductances as illustrated in Fig. 2.

To consider the first cause of oscillation the original transformer winding arrangement must therefore be simplified as shown in Fig. 3.

Now, assuming this simplification is valid, it can be seen that if $L_{A1} >> L_{A2}$ then at high frequencies the screen of V1 becomes effectively coupled to A2 and not to A1. If, at the same time the screen of V2 becomes effectively coupled to A1, then a cross-coupled system similar to a multivibrator results. Besides this mode of cross-coupling it is also possible for one to be formed by stray capacitances.

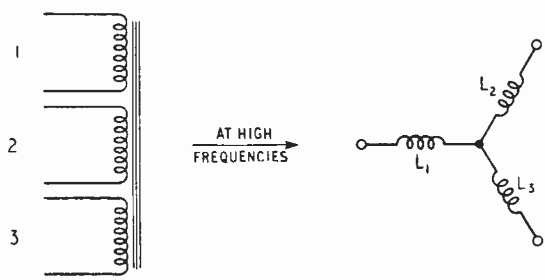


Fig. 2. Three-winding transformer and its equivalent circuit at high frequencies. L_1, L_2 and L_3 are leakage inductance components associated with each winding. An "ideal" transformer should be inserted in two of the limbs to allow for differences in impedance level, but these will be omitted.

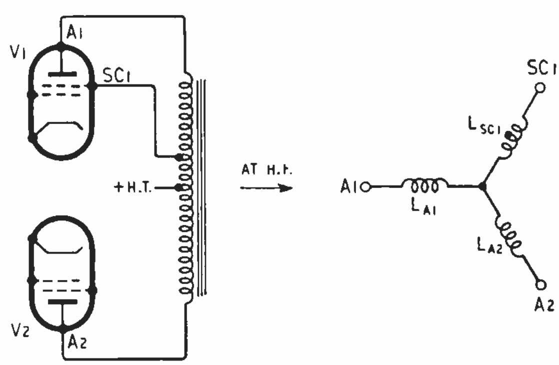
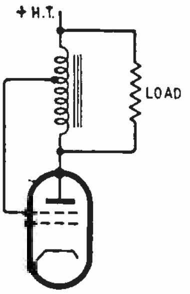
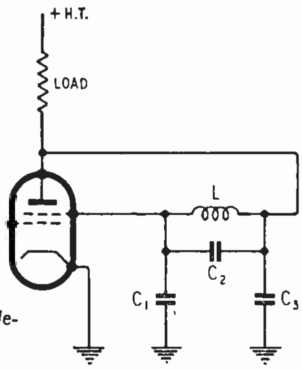


Fig. 3. Illustrating the origin of cross-coupling between opposite halves of a push-pull stage.

* Research Laboratories, G.E.C.
† R. F. Gilson, Ltd.



Above : Fig. 4. Simple single-ended UL output stage.



Above Right : Fig. 5. Equivalent circuit of Fig. 4. L is leakage inductance and C_1, C_2, C_3 are stray capacitances.

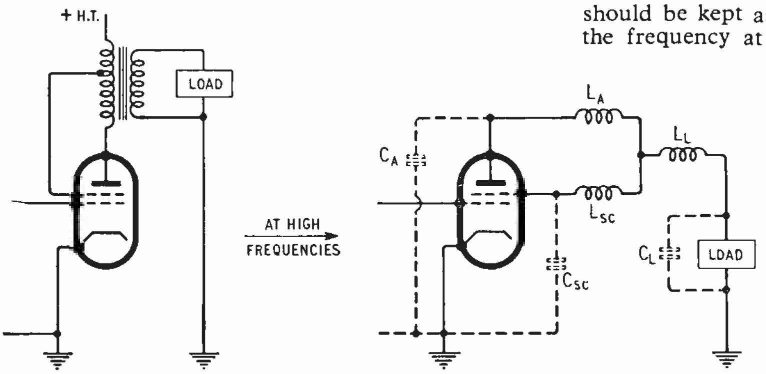


Fig. 6. The addition of a secondary winding modifies the conditions shown in Figs. 4 and 5. L_A, L_{SC} and L_L are leakage inductances and C_A, C_{SC}, C_L stray capacitances associated with the three elements of the transformer (and load).

Hence for stable operation both of the above faults must be avoided. If a transformer happens to violate the above conditions, matters can often be improved by connecting small capacitors between anodes and their respective screens.

The second cause of oscillation can best be dealt with by consideration of a single-ended output stage. Fig. 4 shows the simplest of output stages with a tapped choke and the load connected directly to the anode.

Assuming that the choke can be represented as a two-winding transformer, an equivalent circuit as shown in Fig. 5 can be drawn.

This is the Colpitts oscillator circuit, and if the damping is sufficiently small and the ratio of the stray capacitances correct then oscillation can result. If this trouble occurs it can usually be cured by artificially increasing C_2 or better by increasing the damping at high frequencies only, by connecting a series resistor and condenser combination across C_2. The condenser is necessary to avoid loss of power within the working range.

The inclusion of a secondary winding on the simple tapped choke circuit of Fig. 4 produces an additional complication. Fig. 6 illustrates such a circuit with the equivalent high-frequency circuit.

By suitable winding arrangements it is possible to reduce either L_A, L_{SC} or L_L effectively to zero. Fig. 7 illustrates this point.

The first and second of these possibilities can be used, but in general the third should be avoided unless the load is purely resistive. If the load has a shunt capacitive component (as in Fig. 6) then a capacitance exists directly between the junction of L_A and L_{SC} and earth. A two-section L-C ladder filter type of network is then produced which causes considerable phase shift with little attenuation, so increasing the possibility of oscillation.

From the foregoing brief discussion the relevant conditions to be observed can be summarized as:—

(i) The inductive coupling between a screen and its associated anode must be kept tighter than with the other anode or the load.

(ii) Stray capacitive coupling between a screen and the opposite anode must be kept small.

(iii) The magnitude of the leakage inductances, anode (1) to screen (1) and anode (2) to screen (2), and the anode and screen capacitances to earth should be kept as low as possible since the higher the frequency at which "single-sided" oscillations are liable to occur the more easily they will be effectively damped.

To satisfy these requirements there is one main condition to be observed:—

"Each half-primary should, if possible, be wound without being sectionalized with the other half-primary or the secondary. If it is necessary to sectionalize each half-primary, then the sections must contain screen and anode subsections in the same propor-

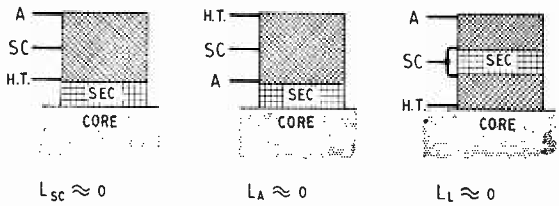
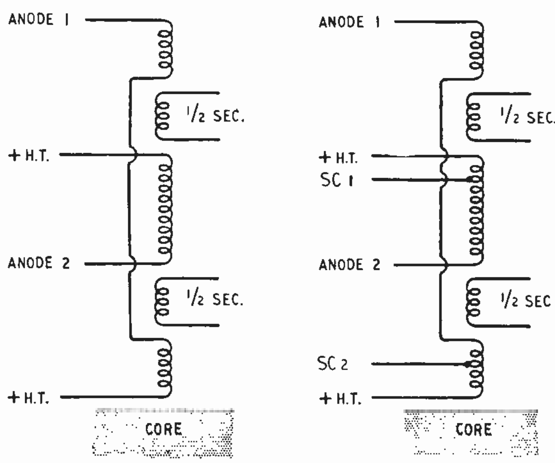


Fig. 7. Winding arrangements required to reduce any one of the three principal leakage inductances to a minimum.



Figs. 8 and 9. Typical sectionalization of output transformer for normal operation with triodes or tetrodes. If tapped for UL operation in this manner, instability is likely.

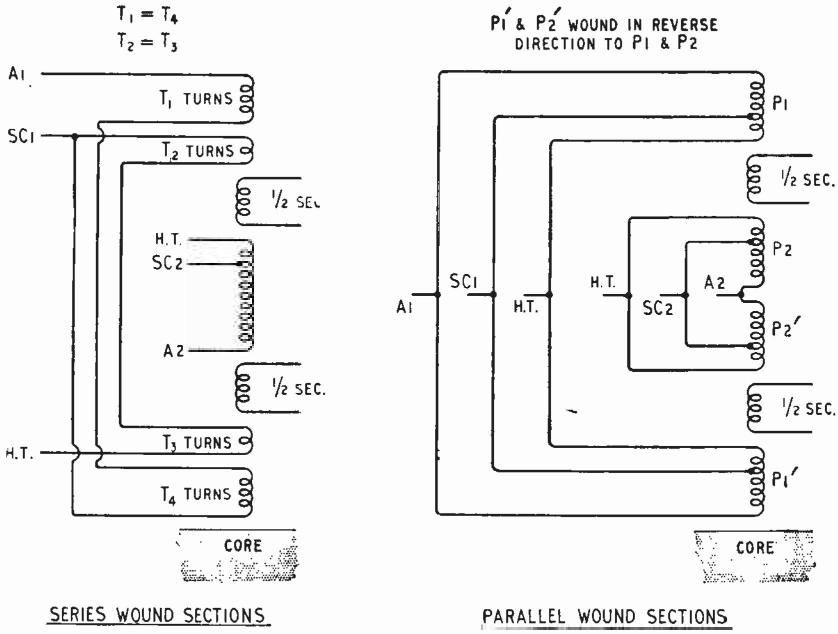


Fig. 10. Alternative ideal winding arrangements conforming to the criteria for stable operation in the UL circuit.

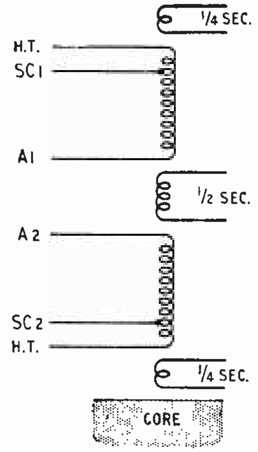


Fig. 11. Simplified winding arrangement for UL operation which gives good results in practice.

tion as the complete half-primary. Alternatively the sectionalizing can be done by connecting complete half-primary sections in parallel."

To clarify this statement the following case can be considered. Fig. 8 shows a typical winding arrangement for use with triodes or tetrodes. To convert this to "ultra-linear" operation the simple arrangement of Fig. 9 should not be used, since it violates the design condition and is liable to be unstable. Instead the arrangements shown in Fig. 10 can be used, both of which conform to the design condition. The first employs series-connected sections and the latter parallel-connected sections. Unfortunately both are rather complicated and if a very low half-primary to half-primary leakage inductance is not of prime importance, then, by reversing the positions of the primary and secondary windings, a much simpler but nevertheless very satisfactory winding arrangement results. Fig. 11 illustrates this winding arrangement which is suitable for most "ultra-linear" output stages up to the 30-watt class.

As a rider to this section it must be said that transformers not designed to the above principles are not necessarily unstable but in general require external

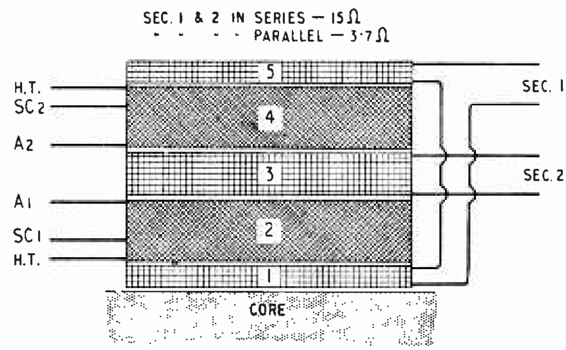


Fig. 12. Practical winding sequence equivalent to the circuit of Fig. 11. Details of a transformer for use with N709 valves in UL push-pull are given in tabular form below.

stabilization, whereas the above designs in general do not.

Before specifying the design of the output transformer, which as far as low and middle frequencies are concerned can be designed along conventional lines, one factor which is often questioned should

Design for UL Output Transformer for N709 Valves in Push-pull.

Core: 1¼-in stack of No. 29a, 0.014-in thick Stalloy laminations.

Windings (from core)—See Fig 12:

(1) 45 turns of 22 s.w.g. enamelled copper wire, wound in one layer.
2 turns of 5-mil. Empire cloth.
(2) 1,940 turns, tapped at 390 turns, of 38 s.w.g. enamelled, 178 turns per layer, 3-mil. paper interleaving each layer.
3 turns of 5-mil. Empire cloth.
(3) 90 turns of 22 s.w.g. enamelled in two layers.
3 turns of 5-mil. Empire cloth.
(4) 1,940 turns, tapped at 1,550, 38 s.w.g. enamelled. 178 turns per layer, 3-mil. paper interleaving.
3 turns of 5-mil. Empire cloth.
(5) 45 turns of 22 s.w.g. in one layer.
1 turn of 5-mil. Empire cloth.

Test Specification:

Primary d.c. resistance	520 ohms, anode-to-anode.
Secondary d.c. resistance (on "15 ohms")	1.2 ohms.
Primary inductance at 5V, 50c/s	75 H
Leakage inductance, primary—secondary, referred to primary	28—30 mH
Leakage inductance A1 – SC1	10 mH
Leakage inductance A2—SC2	9 mH
Leakage inductance ½ primary to ½ primary	24 mH

be explained. It is often asked how such small "ultra-linear" transformers (e.g., Gilson W0710) can possibly have the low-frequency performance specified. This can be explained as follows. Distortion at low frequencies for a given transformer is approximately proportional to $\frac{r_a \times R_L}{r_a + R_L}$, where r_a = effective a.c. anode resistance and R_L = effective load resistance; and hence the lower the effective r_a the lower will be the distortion. Tetrodes have a high effective r_a, and triodes a low effective r_a but also, unfortunately, a low power efficiency. Transformer dimensions increase as the standing anode current increases owing to the greater space required for the primary winding which carries the sum of the standing valve current plus the current due to the power absorbed in the load. Now the "ultra-linear" circuit combines a low effective r_a with a high efficiency and hence the transformer need not have an excessively large primary inductance and can be wound with relatively thin wire. This produces a transformer whose dimensions are therefore smaller than those of a similar component for either a triode or a tetrode output stage.

An important advantage of this is that in a practical case the leakage inductances can be kept small without complicated sectionalization, such as would be found necessary for a transformer in a triode output stage.

TECHNICAL MAN-POWER

Education, Recruitment and Training of Engineers and Technicians

"WE are acutely aware that the demand for highly trained technologists is going to grow and at an ever-increasing rate as fields like electronics and nuclear energy are exploited and as more and more established fields of industry apply modern techniques. Only the strongest measures will prevent the present gap between supply and demand becoming greater than it is already." So concludes the report on the recruitment of scientists and engineers by the engineering industry, recently issued by the Government's Advisory Council on Scientific Policy*.

This is but one of the many warnings on the deficiency of technical man-power during the past few weeks. Whilst it is true that there is an increasing shortage in industry generally, it is particularly true of the radio industry.

Speaking recently at a luncheon of the Radio Industries Club, Ian Orr-Ewing, M.P., who in addition to being a director of Cossor's is also a governor of Imperial College, reviewed the technical man-power position of the nation generally and the needs of the radio industry in particular and went on to outline steps that could be taken to meet this need. That there is a shortage is undeniable. Of 206 situations vacant in a recent issue of the *Daily Telegraph*, 142 were for technical personnel; unfilled vacancies on the Technical and Scientific Register of the Ministry of Labour on November 14th totalled 5,090. Not only is there a shortage in industry and in the technical branches of the Government services, but, by comparison with the U.S.A. and the U.S.S.R., we have—per head of population—less than one-half the number of technical and scientific staff in our technical schools, colleges and universities.

Increased Government Help

Much is, of course, already being done by the Government to increase the facilities for technological studies. In London £15M is being spent on expanding Imperial College and, as Mr. Orr-Ewing pointed out, the Government is stepping up construction of new buildings in other parts of the country, in fact the expenditure in 1956/57 will be double that of 1954. On the question of the expansion of university facilities for technological studies, opinions differ. One firm in the light engineering industry submitting evidence to the Committee on Scientific Man-power (set up by the Government's Advisory Council on Scientific Policy) stated:— "We believe that any large expansion of university facilities for technological students may well have an adverse effect on the quality of the boys entering industry as student apprentices."

To help independent and direct-grant schools where facilities for teaching science subjects are seriously inadequate through lack of capital resources an "industrial fund for the advancement of science education in schools" has been set up by seventeen major industrial organizations. Among the sponsors are Associated Electrical Industries (which includes B.T-H., Metrovick and Siemens), B.I. Callender's Cables, English Electric (which includes the Marconi companies) and G.E.C.

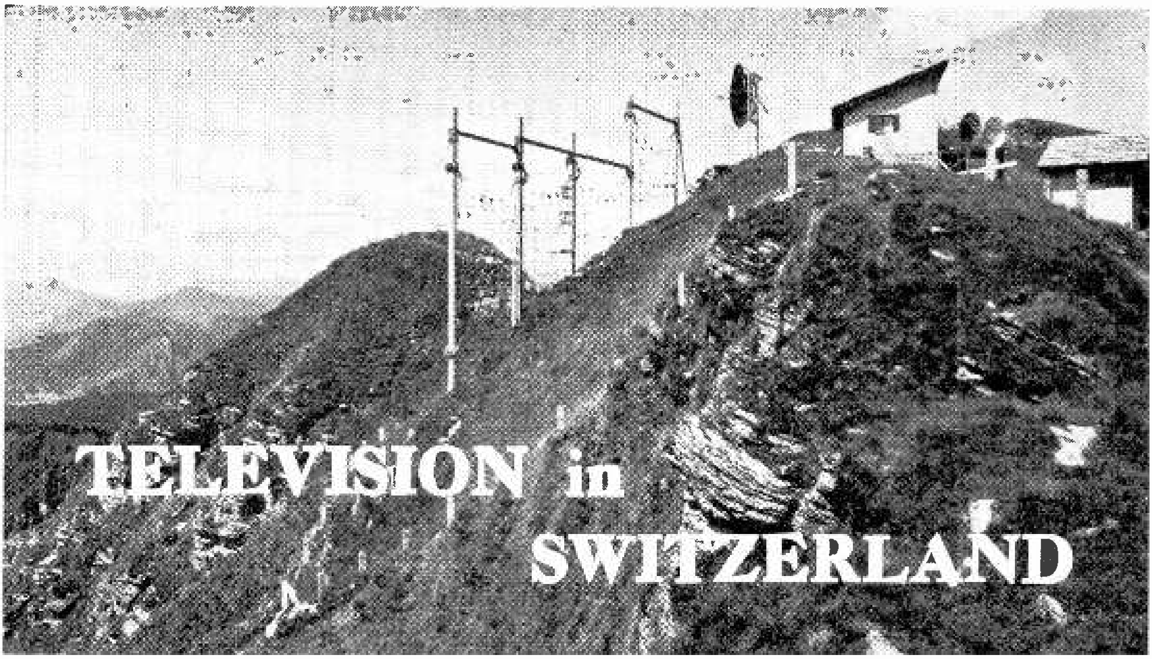
What can the radio industry do to meet its annual need of one thousand professional electronic engineers of graduate standard and several thousand technicians and technologists with National and Higher National Certificates? In addition, according to the Radio and Television Retailers' Association, there is at present an estimated shortage of some 5,000 trained service technicians in retail shops. On this point, Mr. Orr-Ewing said that if and when colour television arrives we shall need science graduates as service technicians!

Many firms have apprentice schemes which, having been approved by the Ministry of Labour, provide for deferment of National Service until the completion of the apprenticeship. But, as Mr. Orr-Ewing pointed out, more than half the people in the radio industry are employed by firms with no such apprenticeship scheme. The growing tendency towards the introduction of sandwich courses for trainees (alternately six months in the works and six months at college) is a good thing but all too often boys having received their basic technical training in the radio industry leave to join other industries, many of which (although using electronics) have no such training scheme as that sponsored by the Radio Industry Council.

Among the many suggestions made by Mr. Orr-Ewing to "sell radio and electronics to the schools" was the fostering of friendly relationships between science and maths. masters and local firms. He pointed out that many of these masters could undertake consulting and laboratory work, technical writing and holiday jobs and thereby promote a two-way flow of ideas between the academic staff and industry. He also suggested that, in reverse, more part-time teachers could be lent by the industry to local schools.

* *"Report on the Recruitment of Scientists and Engineers by the Engineering Industry," H.M.S.O.*

TELEVISION in SWITZERLAND



High-altitude site of a microwave relay station.

Achievement in Turning Difficult Topography to Advantage

WHEN a television service for Switzerland was first suggested the idea was viewed with misgivings by many technicians, who considered that the mountainous nature of the country would make reception poor or impossible in a number of areas because of local screening. It was thought that the only solution would be to operate a large number of low-power stations. The Swiss Post Office, however, which was given the task of investigating the possibilities of television, approached the problem in an original way and arrived at the conclusion that the mountains could be used as an aid to television rather than being a hindrance. By siting stations on high ground in suitable places not only would reception be possible over relatively long ranges, but the interconnection of the various transmitters by radio links would be simplified. Moreover, with receiving aerials placed at the transmitting sites it would be possible for outside broadcasting vans to work into the network from considerable distances. In keeping with their international outlook, the Swiss also recognized that installations on high points would be of great value in the relaying of programmes between the various countries of Europe.

The philosophy of the P.T.T. (Post Office) was accepted and a plan for an experimental service was put into operation some three years ago. This called for four stations working in thickly populated areas (see Table I) and the service given by these is now covering a large part of the country. There are actually two main programmes: a German-language programme which originates from studios at Zurich and is transmitted from Uetliberg, Bantiger and St. Chrischona, and a French-language programme which comes from studios at Geneva and is radiated from La Dôle. In addition there is a common programme which is transmitted several times a week by all the stations. The programmes run for about two hours every evening, starting at 8.30 p.m., and the average for the week is approximately 14 hours. As would be expected in Switzerland, the European standard of 625 lines with f.m.

Table I
DETAILS OF SWISS TRANSMITTERS

Station	Altitude (feet)	Area Served	Mean Altitude of Towns in Area (feet)	E.R.P. Vision	Frequency (Mc/s)	
					Vision	Sound
Uetliberg ..	3,000	Zurich ..	1,500	20kW	55.25	60.75
Bantiger ..	3,500	Berne ..	1,800	30kW	48.25	53.75
La Dôle ..	5,000	Lausanne and Geneva.	1,500	100kW	62.25	67.75
St. Chrischona	2,000	Basle ..	900	3kW	210.25	215.75

sound has been adopted, and the stations operate on frequencies laid down by the Stockholm Plan.

The actual transmitters are of conventional design. They are crystal controlled and use low-level modulators followed by wide-band r.f. amplifiers. The two outputs from the vision and sound transmitters are fed into a filter in the form of a Maxwell bridge which prevents feedback between them when they are working into the common aerial. The aerial at the Bantiger station (see Fig. 1) consists of 24 dipoles in four groups of six on the sides of a 200-ft. tower. Microwave relay aerials are also mounted on the structure.

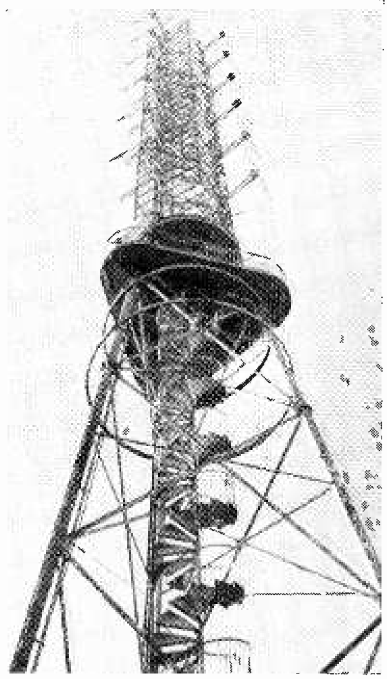


Fig. 1. Aerial of the Bantiger station at Berne.

From Table I it will be noted that the transmitters are situated on high ground at least 1,000 ft above their respective receiving areas. In spite of the mountain sites of the stations, however, many towns are so positioned that there is no direct path between them and their nearest transmitter, and indeed a number of towns and villages lie behind mountains. In such localities it would be reasonable to suppose that television reception would be either non-existent or very poor. In many cases, however, this is not so, as indirect reception by diffraction is utilized. The possibility of exploiting this effect was foreseen in the original survey made by the P.T.T. and, after being proved by field tests, was quite an important factor in the development of the Swiss "orography television" philosophy.

The "ghost" problem is, of course, very real, when there are perhaps several mountain peaks reflecting back energy to a receiving site, but it has been largely overcome by the use of carefully arranged directional aerials—usually of the Yagi type. The mountains have also influenced to a large extent the choice of polarization, which is horizontal. It appears that there is a change of polarization when the waves pass over a sharp mountain peak, and the amount of this change—and the consequent reduction in signal strength—depends on which plane of polarization is used. Immediately behind the peak the signal strength is greater with vertical polarization, but at distances beyond this, on the lower ground where the populated area is normally situated, it is horizontal polarization which gives the better signal. Another small point which partly controlled the choice of polarization was that the directional properties of horizontally polarized aerials are not so much affected by their vertical support masts.

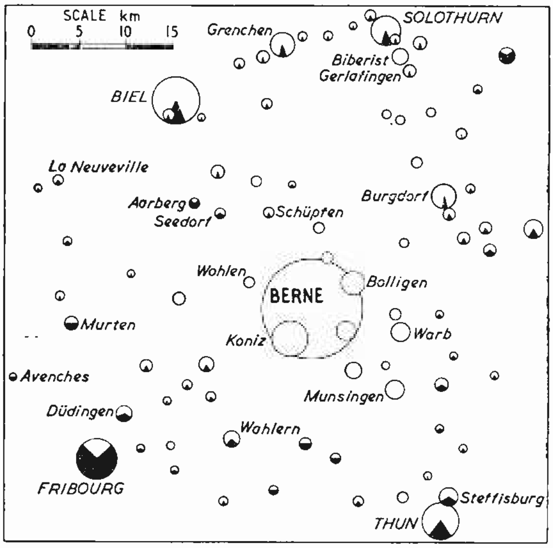


Fig. 2. Method used for presenting the coverage of Swiss television stations. This map refers to the Bantiger station at Berne.

Where an area to be served is situated on the side of a mountain it has been found advantageous to site the transmitter not on the highest possible point nearby but on the opposite side of the valley at a somewhat lower level. The effect known as "height gain" is then utilized and the populated area receives a stronger signal than it would if the transmitters were situated at a higher point.

The phenomenon of diffraction mentioned above, although useful in providing a signal for "shadowed" areas, can also be a cause of trouble. When the Stockholm Plan was formulated in 1952 and frequencies were allocated, it was naturally assumed that the Alps would form an adequate barrier against mutual interference between Swiss and Italian stations operating on the same frequencies. In practice, the Alps, instead of acting as a screen, have been the cause of persistent abnormal reception in Switzerland of Italian transmissions—in particular from the station at Monte Penice, which is about 175 miles from Berne. The signal strength from Monte Penice in the Bernese Oberland area is, in fact, about $100\mu V/m$. It appears that the only way of overcoming the trouble will be an alteration of frequency.

When the P.T.T. were faced with the task of preparing field strength diagrams for the various stations they decided that the usual system of contours would be too complex and difficult to interpret with the particular topography of the country. A novel method was therefore developed in which sampling measurements were made in each town, using a 30-ft aerial and calibrated receiver, and the results were classified by two standards of reception—passable and poor. The originality of the method lay in the manner in which the information was presented, and this can be seen in Fig. 2, which gives the results obtained from the Bantiger station at Berne. On this map each town is shown as a circle, the total area being proportional to the population, while the white area corresponds to passable reception and the black area to poor reception. From this it is possible to see immediately the kind of conditions to be expected in a certain town.

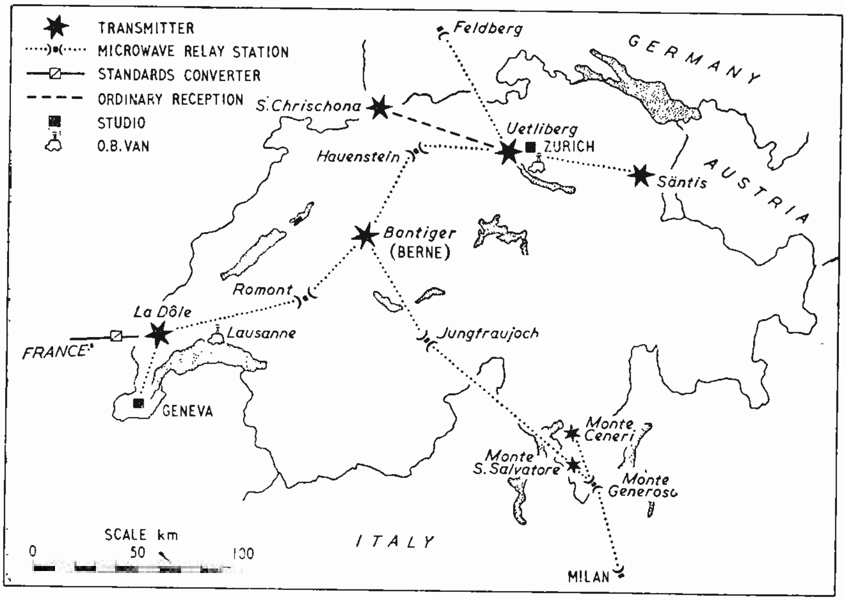


Fig. 3. A forecast of how the Swiss television network will be arranged by the end of 1957. The stations at Mte. Ceneri and Mte. S. Salvatore will broadcast mixed Italian, German and French programmes.

Field strength measurements are sometimes made by a travelling motor van with an aerial mounted on its roof. It is not practicable to make a direct record of the instantaneous field strength, however, since this tends to fluctuate violently as a result of reflections and standing-wave patterns as the van travels along. Instead a "gliding mean" is calculated from the measurements (by an analogue computer) for each kilometre of distance along the road and this is automatically registered on a recording device coupled to the van's *compteur de kilometres*. Maps are then prepared with the various mean values marked in different colours along the roads, and from these it is possible to shade in broad areas of country having a given field strength and to compile charts of the kind shown in Fig. 2.

As already mentioned, the mountains are used to good purpose in providing high-altitude sites for the relay stations of the 2,000-Mc/s radio-link system which feeds programmes to the transmitters. Three of the stations, Chasseral, Rochers de Naye and Monte Generoso, are about 5,000 ft above sea level, while the one on the Jungfrau is as high as 12,000 ft. One advantage of the high-altitude sites is that they either keep the radio beams well above the tropospheric disturbances occurring in the lower parts of the atmosphere or cause them to pass through these disturbances at a sharp angle (when, for example, one station is on a mountain site and the other is at ground level). As a result the communication given by the radio-link system is extremely reliable and free from noise. In practice it has been found that a radio beam passing through the region of disturbances must do so at an angle greater than $1\frac{1}{2}°$ if good results are to be obtained.

Another advantage conferred by the mountainous country is its ability to disperse the ground reflections which can cause interference with the main beam between two relay stations. For this reason it has been found desirable to arrange the stations of a link so that the beam passes over a series of sharp peaks rather than a fairly smooth bowl or plain. The link between the Jungfrau and Monte Generoso is particularly well placed in this respect. Apart from this, the P.T.T. have found it possible to mitigate the effects of ground reflections by using the diversity principle with aerials arranged at different heights.

Incidentally, one of the unexpected difficulties of operating the relay station on the Jungfrau is that the maintenance staff has to be very carefully selected to withstand the fits of "altitude depression" to which a great many people are subject at high altitudes. This malady may be caused by the lower content of oxygen in the atmosphere at 12,000 ft. It appears, too, that high altitudes also have a bad effect on television receivers in Switzerland, which suffer breakdowns of e.h.t. insulation at heights above 2,000 ft. If small c.r. tubes with anode voltages of 5-7kV are used, however, the trouble is not too serious.

Of course, the transmitters at present in use do not give coverage for every part of the country. To fill in the gaps the Swiss ultimately intend to set up a number of small local transmitters with output powers of 1-50 watts. These will work in a channel (216-233 Mc/s) reserved at Stockholm in 1952 and known as the "Swiss common channel."

Band-III Transmissions

THE possibility that Band-III television transmissions from different stations might overlap in some areas was mentioned at a recent I.E.E. discussion meeting on Band-I and Band-III reception (opened by E. P. Wethey). Investigations in the U.S.A. into the forward scatter properties of Band-III transmissions had shown that, depending on atmospheric conditions, these were far in excess of the calculated distances. It was suggested that viewers in the Midlands might well experience difficulty when the Band-III transmitter at Lichfield was operating on full power, as the Croydon transmissions were already being received in the area to be served by Lichfield.

Ionospheric Scattering at V.H.F.

Mechanism of Propagation : Practical Application to Long-Range Communication

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

THERE has recently developed a great interest in long-distance, or " beyond-the-horizon," propagation of very high frequency waves. It is known that scattering plays a large part in the establishment of these long-range fields, but there seems to be a certain amount of confusion as to whether the scattering takes place in the troposphere (lower atmosphere) or in the ionosphere. In fact scattering of radio waves can and does take place in both regions of the atmosphere, but the two processes are of importance for different distances of transmission and for different frequency ranges; there is also a considerable difference in the bandwidths which can be transmitted without distortion in the two cases. This article is mainly concerned with ionospheric scattering, but before discussing this in detail it is proposed briefly to describe the general features underlying all forms of scattering.

Scattering Process.—Whenever there is a change in the refractive index of the medium in which waves (of any nature, though our present concern is with electromagnetic waves) are travelling, scattering of the radiation takes place. If a number of scattering centres are involved the scattering may be either coherent at one extreme, or incoherent at the other. For example, at a smooth boundary between two media, large in extent compared with the wavelength, coherent scattering takes place, and we have the phenomena of reflection and refraction as generally understood. On the other hand, when there are random fluctuations of refractive index extending over a large region of the medium incoherent scattering occurs; that is the waves scattered from the various centres of irregularity arrive at any given receiving point with random phase relationships. In such a case the energy intercepted by a receiving aerial is the sum of the individual contributions from each of the scattering centres.

Consider first a single scattering centre, assumed for simplicity to be spherical. Suppose the deviation of the refractive index in the irregularity from the mean value of the surrounding medium is correlated over a distance of at least several wavelengths—looked at crudely this means that we have a scattering " particle " of diameter large compared with the wavelength. The re-radiated or scattered energy has a pattern in space characterized by maxima and minima, i.e., it has a " lobe " structure, when observed at a distance great compared with the size of the particle. As the diameter of the particle decreases the lobe structure begins to disappear, and when the diameter of the particle is of the order of the wavelength, and less, there is only a general diffuse scattering of incident radiation.

The principles which govern the scattering of light by particles small compared with the wavelength were first discussed by Lord Rayleigh in 1871, and he showed that the energy of the scattered light varies inversely as the fourth power of the wavelength; thus blue light should be scattered about ten times as much as red, and it was in this way that Lord Rayleigh explained the blue colour of the sky. He further showed that the scattering from the individual molecules of the air, without help from particles of foreign matter, would be sufficient to give the observed amount of scattering. Later, Smoluchowski and Einstein suggested that the blue of the sky may be due not to air molecules acting individually, but to transient, very local, variations in density (and hence of refractive index) which are constantly occurring due to the random thermal motion of the molecules.

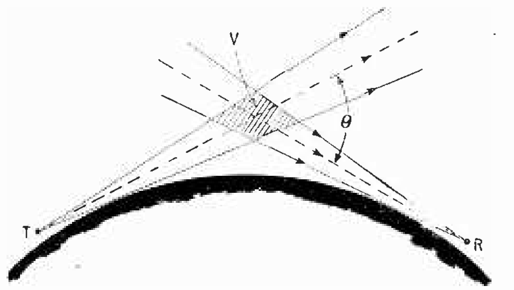


Fig. 1. Beyond-the-horizon reception by scatter propagation requires that receiving and transmitting aerial beams overlap.

Tropospheric Scattering.—Such fluctuations of refractive index on the molecular scale are insufficient to produce any significant scattering of radio waves. The troposphere is, however, always in a state of turbulence, though the degree of this turbulence may vary from time to time and from place to place. As a consequence fluctuations of refractive index of the air occur on a much larger scale than that responsible for the scattering of light. Turbulence causes a series of eddies in the atmosphere in each of which the refractive index is different from the overall mean value; and the size of these eddies varies over a wide range, the most important from the radio point of view being of the order of a few tens of metres up to perhaps 100 metres in diameter. Such eddies are the cause of appreciable scattering of very short radio waves.

The theory of radio wave scattering in the troposphere has been developed by E. C. S. Megaw in this country, and by H. G. Booker and W. E. Gordon in the U.S.A. When the size of the scattering centres is small compared with the wavelength the scattered energy is inversely proportional to the fourth power of the wavelength (exactly as for Rayleigh scattering) but when the irregularities are

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

large compared with the wavelength most of the scattering takes place within a narrow beam surrounding the forward direction of propagation of the incident radiation, and within this beam the intensity in a given direction is independent of the wavelength.

The conditions of scattering in the troposphere are such that the process can be usefully employed in the frequency range of roughly 500 to 5,000 Mc/s (wavelengths of 6 to 60 cm), though appreciable scattering occurs at lower and higher frequencies. The transmitting and receiving aerials (of high directivity) must be orientated so that their beams overlap, as is shown in Fig. 1, and energy is then received due to scattering within the common volume V: The scattering angle θ should be as small as possible. The bandwidth of signals which can be transmitted without distortion depends upon the dimensions of V, and it has been shown by H. G. Booker and J. T. de Bettencourt that bandwidths of several Mc/s should be obtainable; though to do this it is necessary to use aerials having apertures of the order of 10 to 20 metres in diameter. (The longer the wavelength the greater the aperture required.) With powers of the order of 10 to 100 kilowatts it should then be possible to relay multi-channel telephony or television signals over distances of 300 to 400 kilometres. Links using the mechanism of tropospheric scattering are, in fact, already being exploited in the U.S.A.

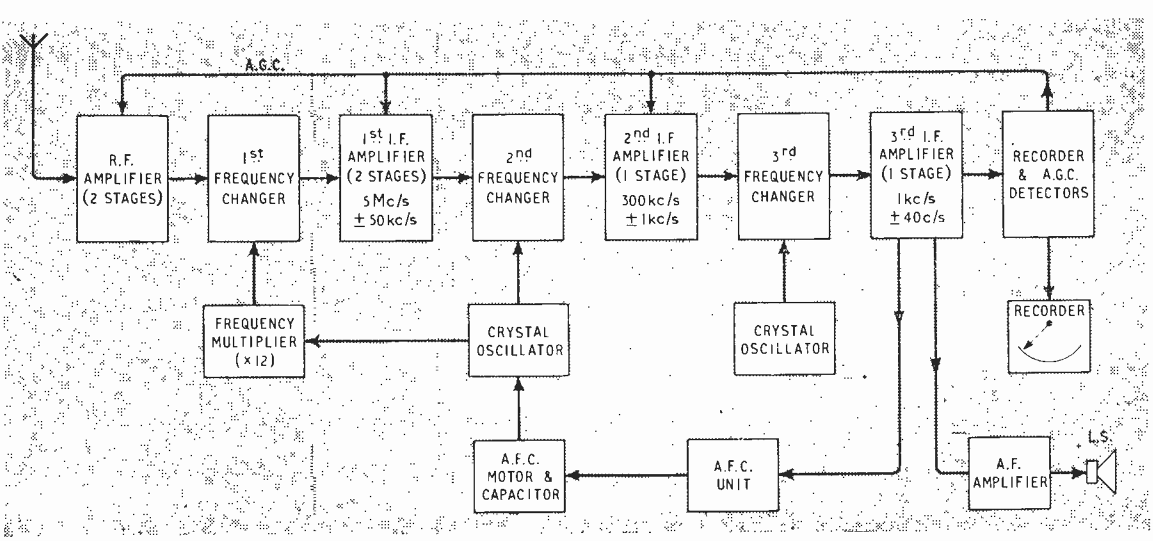
Ionospheric Scattering.—The fact that the E region of the ionosphere must be regarded as a complicated structure of ionic clouds with ever-present irregularities in the density of ionization (and therefore also of the refractive index) was pointed out by T. L. Eckersley some 25 years ago. His experimental investigations were mainly concerned with back-scattered radiation, or else with forward scattering at large angles over relatively short distances, but he certainly appreciated that scattering would be an important factor in practically all shortwave transmissions. Eckersley's observations were made in the wavelength band of 14 to 50 metres, and showed that there was more scattering the longer the wavelength, for which he gave a theoretical explanation.

In 1952 there was a major development in the study of E region scattering. D. K. Bailey and a number of co-workers in America showed that forward scattering on a frequency near to 50 Mc/s occurred with an intensity such that, provided a high-power transmitter and directive aerials were used, it was possible to observe a continuous signal, though generally of rapidly varying amplitude, over a path of 1,245 km. The disclosure of this information aroused great interest amongst radio communication engineers, for it pointed to the possibility of providing long-distance point-to-point links in the v.h.f. band which would not be subject to the vagaries of performance experienced with h.f. links operating in the normal manner.

It appears that this American work on ionospheric scattering was stimulated by the knowledge previously gained concerning tropospheric scattering; for the ionospheric transmission experiments followed a theoretical prediction of the feasibility of such transmission at metre wavelengths which was based on an adaptation of the Booker-Gordon treatment of tropospheric scattering, it being assumed that the winds known to exist in the ionosphere would produce turbulent fluctuations of refractive index in the E region. The troposphere is for all practical purposes non-dispersive throughout the radio-frequency spectrum, i.e., the refractive index is independent of the wavelength, but this is not so with the ionosphere, where the refractive index, which depends on the electron density, varies with the wavelength. This leads to a different dependence of the characteristics of scattering due to turbulence upon the wavelength in the ionospheric as compared with the tropospheric case, quite apart from any differences in the sizes of the turbulent eddies.

It should perhaps be pointed out at this stage that there is a school of thought which maintains that the observed scattering of v.h.f. waves in the ionospheric can be explained solely on the basis of reflections from the ionized trails of meteors, which

Fig. 2. Schematic arrangement of a receiver for scattered signal reception.



are constantly being formed in the E region. Both the turbulence and meteor-trail theories indicate that, other conditions being constant, the scattered power should decrease rapidly as the frequency is increased. The experimental results obtained both in the U.S.A. and in this country confirm this prediction, and suggest that the range of frequencies over which it is likely that use can be made of ionospheric scattering for communication purposes is from about 25 Mc/s to perhaps 60 Mc/s. It must, however, be remembered that many existing services make use of this band.

An account of an investigation of ionspheric scattering at v.h.f. carried out in the United Kingdom was given in a paper* recently read before the Radio and Telecommunication Section of the Institution of Electrical Engineers. The investigation, which was carried out jointly by the General Post Office and the Radio Research Station, D.S.I.R., covered measurements made at frequencies of 27, 41 and 89 Mc/s. and extended, in all, over a period of some eighteen months. The work included a detailed examination of the characteristics of the received signal, mainly over paths of 935 and 1,185 km, and also tests to explore the possibilities of this mode of propagation for frequency-shift telegraphy and telephony transmissions.

The scattered signal is generally very weak, for what may be termed the average effective "reflection" coefficient is only of the order of 10^{-4} or 10^{-5}, giving an attenuation of 80 to 100 dB relative to the free-space signal for the same distance. This means that high effective radiated powers, and sensitive receivers with strongly directive aerials are needed if a good signal-to-noise ratio is to be maintained. A receiver typical of the kind found useful for measurements on the scattered signals is illustrated schematically in Fig. 2; such a receiver with a final bandwidth of 80 c/s enables an accurate measurement to be made of signals as small as 30 dB below 1 μV across a 75-ohm input. The order of magnitude of the e.r.p. required is several hundreds of kilowatts if the signal is to be received at all times.

Characteristics of the Scattered Signal.—A signal transmitted by the process of scattering in the ionosphere is always of extremely variable amplitude. There is at all times a residual or "background" signal which varies rapidly over a range of 20 to 30 dB, though when the slow variations in the general signal level are included the total range of variation of the background signal is some 70 dB. The rapid variations occur at a rate of about 10 dB per second for most of the time, with level fluctuations of more than, say, $\pm$6 dB occurring at rates of about 30 per minute. The median level (i.e., the level equalled or exceeded for 50 per cent of the time) of the background signal is subject to large diurnal and seasonal variations. For a transmission path of about 1,000 km in length from the north to the south of Great Britain the daily maximum of the background signal occurs around noon; and for an effective radiated power of about 350 kilowatts at a frequency of 41 Mc/s, the noon median level appears to be about 0 to -5 dB relative to 1 μV across a 75-ohm receiver input in the summer months with a receiving aerial having a theoretical plane-wave gain of 18 dB: the corresponding level in the winter is about -5 dB and at the equinoxes -10 to -15 dB. The daily minimum signal occurs around 20.00 hours g.m.t. and the average difference between the daily maximum and minimum values varies from 10 or 15 dB in summer and winter to not much more than 5 dB in spring and autumn.

Superimposed upon the background signal are numerous sudden enhancements lasting for a time of the order of a second up to, on occasion, perhaps half a minute. It is considered that these bursts of signal, which cause increases above the background level of as much as 40 dB, or more, are due to reflections from the ionized trails of the larger meteors. Meteoric reflections can also produce short deep fades in the received signal when the component due to such a reflection is out of phase with the background signal and of appropriate magnitude.

Providing the frequency is not too high (not in excess, say, of 60 Mc/s at most) it is possible at times for very strong signals, 60 to 100 dB above the background, to be transmitted by reflection from clouds of sporadic E ionization. At such times, and at times of intense F region ionization in the years of maximum sunspot activity, it would be possible for mutual interference to occur between an ionospheric scatter link and other services operating in the same frequency band; though this might to some extent be mitigated by the use of highly directional aerials for the scatter link.

The manner in which the scattered power falls off with increasing frequency, other conditions being constant, is shown in Fig. 3. Here the relative received power has been plotted as a function of frequency, for a constant transmitted power, and for systems having aerials scaled according to the frequency, i.e., of equal gain.

It is, as yet, not clear exactly what mechanism is responsible for the residual or background signal. The influence of large meteors is clearly apparent, and it is reasonable to suppose that the multitude

(*Continued on page* 39)

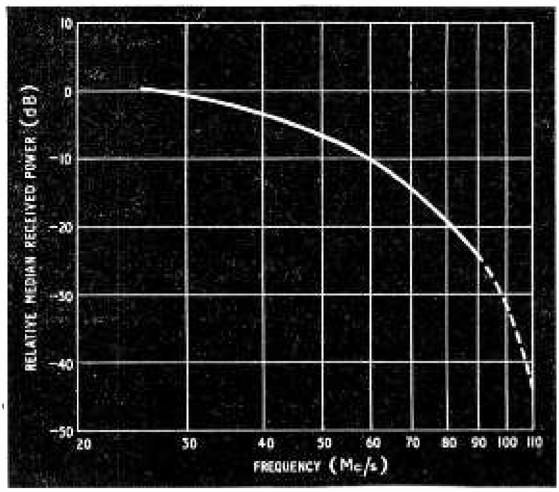


Fig. 3. Relationship between received signal power and frequency for scattered signal propagation.

* "V.H.F. Propagation by Ionospheric Scattering and its Application to Long-Distance Communication," Paper 1920R, Part B, by W. J. Bray, J. A. Saxton, R. W. White and G. W. Luscombe; read on October 31st, 1955.

of smaller meteors which bombard the upper atmosphere make some contribution to the background signal. The daily minimum of this signal at 20.00 hours corresponds to the time of minimum meteoric ionization, and there is also evidence of a correlation between the seasonal variation of the signal and meteoric activity. On the other hand the behaviour of the background signal during daylight hours shows a correlation also with the variation of the total electron density in the E region, and this would appear to indicate that scattering due to turbulent fluctuations in the ionospheric refractive index may at such times play a more important part.

It thus seems probable that more than one mechanism may be responsible for the background signal, and that the relative importance of turbulence and meteors may vary from time to time. It should also be added here that G. A. Isted has further suggested that partial ionization of the E region by conduction currents of atmospheric electricity may be a cause of v.h.f. scattering. The accurate assessment of the relative importance of these various scattering processes must await the results of further investigations.

Aerial Performance.—It has already been mentioned that aerials having high directivity are essential if the fullest use is to be made of ionospheric scattering. Rhombic aerials having plane-wave gains relative to a half-wavelength dipole of 18 to 20 dB have been used both for transmission and reception; a vertical array of four yagi aerials (gain 12 dB), as illustrated in Fig. 4, has also been used for receiving purposes. It appears, however, that the effective gain of a directive aerial (whether used for transmission or reception) is a variable quantity for ionospheric scatter propagation, and it is seldom that the full gain obtainable under ideal plane-wave conditions is achieved. In fact it seems that at best the median effective gain (i.e., the gain realized for 50 per cent of the time) is only of the order of the square root of the full theoretical gain; and there is little benefit to be obtained by increasing the gain of the transmitting aerial unless a receiving aerial of similar directivity is used, and vice versa.

Range of Propagation.—Since the scattering takes place in the E region of the ionosphere, and since the effective reflection coefficient is so small, only "single-hop" transmission is feasible. This means that the maximum distance over which useful scattered signals may be obtained is not likely to be much in excess of 2,000 km.

Application to Communication.—The geometry of the transmission path is similar to that shown in Fig. 1, but in view of the large distances involved and the great height of the ionosphere relative to the troposphere, the scattering volume V is very much larger in the ionospheric than in the tropospheric case, even with the most directive aerials likely to be achieved. This fact alone, which permits of large path differences between different components of the signal, and is conducive to selective fading, quite apart from the general nature of the signal, and its relatively low level even with high effective radiated powers, means that the bandwidth possible with ionospheric scattering is much less than with scattered signals in the troposphere.

The investigations carried out so far in this country do, however, show that it would be possible to establish on a continuous basis a 50-baud

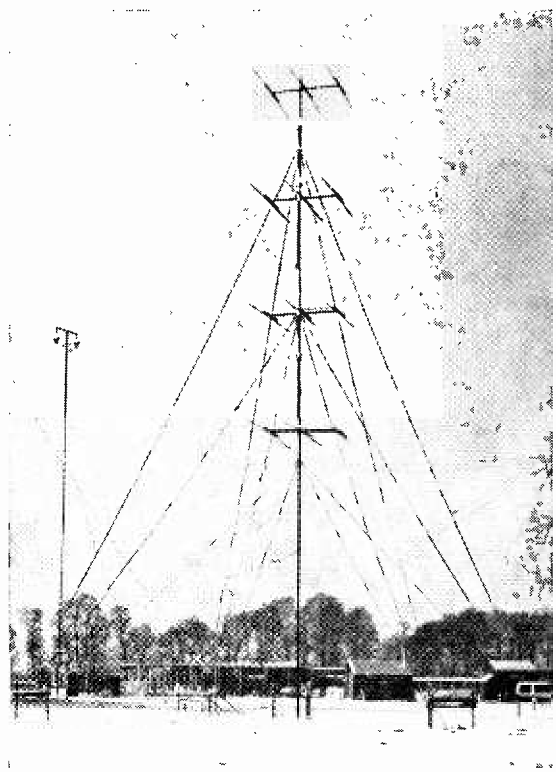


Fig. 4. A vertical array of yagi aerials (gain 12dB) can be used for reception of scattered signals.

frequency-shift telegraphy service of quite low error rate, using a 200 c/s shift and a bandwidth of 300 c/s. To do this at a frequency of about 40 Mc/s would require some 60 kilowatts of actual radiated power together with transmitting and receiving aerials each having a median effective gain of 13 dB (implying a plane-wave gain of about 26 dB). If the radiated power were reduced to 35 kilowatts the circuit would still be available for continuous use during the summer months, and even in March (the time of lowest signal levels) the availability would be about 60 per cent, most of the lost time being during the night. Diversity reception can be used with advantage.

Some improvement in performance may be expected by using frequencies somewhat lower than 40 Mc/s, though the improvement is not likely to be large: on the other hand if frequencies appreciably higher than 40 Mc/s were used the system performance would deteriorate rapidly. The continuous operation of high-speed single-channel telegraphy links, or multi-channel time-division telegraphy links, is unlikely to be satisfactory, except perhaps for circuits carrying only a few channels.

The transmission of telephony is a much more difficult matter. Frequency modulation, phase modulation and single-sideband amplitude modulation systems have been investigated. Frequency modulation is definitely inferior to phase modulation, and the single-sideband amplitude modulation system appears to give slightly better results than the phase modulation system. Receivers having bandwidths of 3 to 5 kc/s were used for these investigations, and it appears that, whereas a continuous telegraphy circuit seems to be a possibility, a telephone circuit giving continuous service would necessitate an uneconomic or even impracticable transmitter power; though a service having over 50 per cent availability confined mainly to daylight hours is within the bounds of possibility.

One further point concerning the characteristics of the scattered signal should be added. The signal does not disappear at times of ionospheric storms and geomagnetic disturbance, indeed it has been suggested that it may even be enhanced. There is evidence, however, that when an aurora occurs over the transmission path the fading of the signal is so violent and so rapid that communication of any kind over the link becomes practically impossible.

Manufacturers' Products

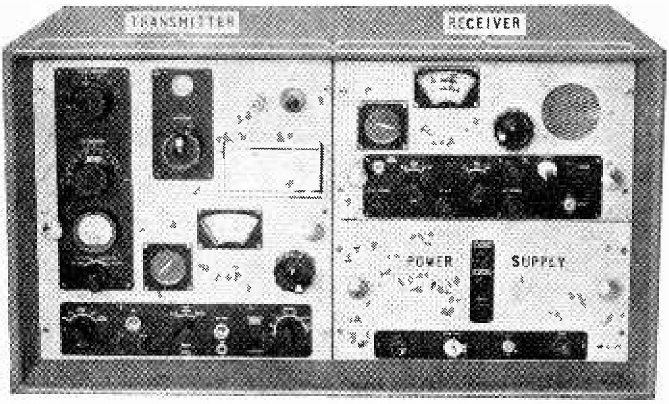
NEW EQUIPMENT AND ACCESSORIES FOR RADIO AND ELECTRONICS

Compact Transmitter-Receiver

THE illustration shows the latest Redifon self-contained short-wave transmitter-receiver Type GR250 which is designed for fixed (a.c. mains) or mobile (12V d.c.) operation on c.w. or m.c.w. telegraphy and on radiotelephony. The transmitter can be operated either as a continuously tunable set over the range 2 to 12.5 Mc/s (in three ranges) or by crystal control on five spot frequencies with self-contained crystals. The power output is 25-50W into a 70-Ω line. The normal reliable communication range is 200 to 300 miles on telegraphy and about half this on telephony.

The receiver is an r.f.-mixer-2 i.f. superhet with b.f.o., noise limiter (2 crystal diodes), audio and output stages; it has a continuous coverage of 2 to 25 Mc/s in three ranges.

Transmitter, receiver and power supply unit are assembled in a single steel case with the panels recessed to give protection to the controls. The overall size is 31¼in wide, 18¾in high and 14in deep. The total weight, with a.c. power supply unit, is 135 lb, and with d.c. power unit, 115¼ lb.



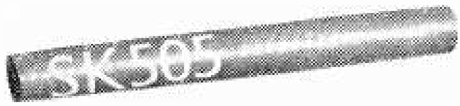
Short-wave transmitter-receiver, Type GR250, made by Redifon.

A subsidiary facility is provision for a loudhailer for which the 20-W audio output from the transmitter modulator can be used. The makers are Redifon, Ltd., Broomhill Road, Wandsworth, London, S.W.18.

Cable Marking

REVERSE transfers, described as "PVC Decals," made especially for marking PVC covered cables are now obtainable in sheets of letters and numerals in three different sizes, 3/32in, 1/8in and 1/4in respectively. The transfers are normally white and each sheet contains about an equal number of letters and numerals. While cables may be put into service within 15 minutes of marking, about 24 hours must elapse before the markings become really hard. They have a good appearance, are easy to apply, are acid, oil and petrol resistant and are available in colours if required. They are suitable also for application to polystyrene surfaces.

These decals must be applied by the special solvent 7640, of which the main constituent is cyclohexanone, which softens the PVC of the cable cover and the decal to some extent and so ensures a firm bond between the two. A coating of varnish 5607A gives the markings a hard surface finish.



Murry-Hill "PVC Decals" applied to PVC plastic sleeving.

The suppliers are The Murray-Hill Company, Link Hill, Sandhurst, Hawkhurst. Kent, and prices are as follows: sheets of 1/4in Decals, 1s 6d; 3/32in and 1/8in, 1s 3d; 7640 solvent and 5607A varnish, 2s each per bottle.

Record Friction Discs

WITH some types of gramophone record, particularly those of small diameter, trouble may be encountered through lack of driving friction between their surfaces when stacked on the turntable of a record changer.

To overcome this difficulty Richard Walker & Company, 7 Potters Lane, New Barnet, Herts, have devised a thin circular pad ("Grippadisk") for use as an interleaf to increase friction. The material, which is of a synthetic fibrous nature, resembles chamois leather.

Three sizes are available: Type A, for 78 and 45 r.p.m. discs with small centre hole; Type B for 45 r.p.m. discs with 1½ in diameter centre hole; Type C, for 33⅓ r.p.m. discs with normal small centre hole. Prices per set of nine pads are 4s 9d for Types A or B and 5s 10d for Type C, including purchase tax.

Epoxy Resin Adhesive

THE "Araldite" brand of adhesive, used among other things for bonding non-porous materials such as metals, glass and glazed ceramics, is now available in small kits from ironmongers and other retailers. The resin and hardener are packed in separate tubes and should be mixed before use in equal quantities. The new pack costs 6s and the makers are Aero Research, Ltd., Duxford, Cambridge.

TELEGEE

Proposals for a New System of Air Navigation

By D. A. LEVELL,* M.Sc., A.M.I.E.E.

THIS article is aimed at promoting thought and discussion upon the possibility of using the time-synchronized signals received from three television stations of a synchronized chain as the means of determining the position of an aircraft in hyperbolic co-ordinates.

Since television stations that are operating as synchronized chains already exist on many aircraft routes, it appears that there would be considerable economic advantage in using such stations for navigation as an alternative to installing and maintaining special navigational-aid transmitting chains.

Facilities in the U.K.—Five B.B.C. high-powered (up to 100 kW) television stations operating in a synchronized chain on channels 1 to 5 are at present existing at Alexandra Palace, Sutton Coldfield, Holme Moss, Kirk O'Shotts and Wenvoe. These stations are tied together by permanent links provided by the G.P.O. It would be necessary for the time delays introduced by the links to be kept at known constant values for the purposes of navigation.

The service area of each station is up to about 80 miles radius to receivers situated at ground level around the stations. The service area to aircraft would be considerably greater, due to the increased height of the receiving aerial. It would probably be more than 200 miles radius to aircraft above 10,000 feet and more than 400 miles radius to aircraft above 20,000 feet. Thus aircraft operating over Britain would be able to receive three B.B.C. stations in most locations.

The vertical coverage pattern of a television transmitting station contains a number of regions of low signal strength where destructive interference occurs between the direct path signal and the ground reflected signal. However, the power transmitted from each station should be sufficient to enable a sensitive airborne receiver to detect signals in these regions of low signal strength.

Possible form of the Airborne Equipment.—A wideband omni-directional airborne aerial could be used to feed three receivers tuned to the vision frequencies of three television transmitters. A receiver bandwith of only 1 Mc/s would be adequate on each channel. Each receiver contains a precision frame synchronizing pulse separator that provides an output at some predetermined time during the frame synchronizing pulse train; e.g., at the start of the eighth synchronizing pulse. The times between the arrival of the frame sync pulses in each receiver are then measured, either by means of a calibrated trace on a cathode-ray tube such as in a Gee indicator, or by means of automatic time-measuring circuits such as in a DME meter indicator. A pair of hyperbolic co-ordinates are then obtained so that the position of the aircraft may be determined by reference to a chart similar to those used in the Gee and Decca systems.

The airborne equipment could be provided with a multichannel turret tuner on the front end of each receiver so that the aircraft could operate on television chains in other countries. Switching could be provided to select positive or negative modulation on stations working with 405-, 525-, 625- or 819-line systems.

The line sync pulses received at the aircraft might be used as calibration markers to simplify the airborne time-measuring circuits. There might also be some virtue in using phasemeters to indicate the relative phases of the line and frame pulses received from different stations. The accuracy of time measurements in both cases then depends upon the line repetition frequency which in turn generally depends upon the supply frequency of the electricity mains of the country in which the transmitters are situated.

Similarity of Telegee and Existing Systems.—The Gee chains at present in use operate on frequencies in the band 20-85-Mc/s at peak pulse powers of the order 25-500 kW. The stations are normally sited some 80-100 miles apart and have transmitting aerial arrays similar to, but often not so high as, television transmitting aerials. A Gee chain comprises a master and two or more slaves that operate on the same frequency. Each station transmits a pulse of bandwidth 700 kc/s so timed that in all directions the master or A pulse is the first of the group received at the aircraft. The A pulse is transmitted 500 times per second whilst the B and C pulses are alternately transmitted 250 times a second. An additional A pulse, or "ghost", is transmitted a short time after the A pulse on alternate transmissions to enable an observer to discriminate on the c.r.t. display between a B or C pulse.

The coding information transmitted from Gee ground stations is insufficient to enable simple automatic circuits to be used to distinguish between, first, an A, B, or C pulse and, secondly, a Gee pulse and a noise pulse. Thus it has not, so far, been found possible to develop a satisfactory meter presentation of Gee co-ordinates. The development of a meter presentation of Telegee co-ordinates should, however, be a relatively simple task as, first, each station is separated by virtue of its r.f. channel, and, secondly, a train of at least six frame synchronizing pulses constitutes the trigger signal for the measuring circuits.

When two stations are separated by a spacing of 100 nautical miles, the maximum variation of time difference between arrival of the two signals at an aircraft is 1,230 microseconds. Thus a Telegee measurement is made during only about $\frac{1}{16}$th of the 20-msec period between transmission of frame synchronizing pulses.

Gee pulses are emitted at the high basic repetition frequency of 250 p.p.s. mainly in order to minimize the number of dividing stages carried in crystal controlled airborne time-measuring circuits. A basic rate of information of 50 p.p.s. would, however, be more than adequate to satisfy operational requirements.

* *A. C. Cossor, Ltd.*

The number of stations that can be used in a Telegee chain is unlimited, as each operates at a different frequency, whereas a Gee chain is limited to about four stations on the same frequency.

The meter presentation of Telegee co-ordinates would be similar to that of the Decca system. However, compared with Decca, Telegee has the advantage of working at higher frequencies, thereby giving less susceptibility to interference and propagation errors.

Shared Television Channels.—At the present time there are several existing low-powered television stations that share channels with high-powered stations that are transmitting in the same synchronized chain. The signals from these stations would interfere with those from the high-powered stations in certain areas of the system coverage. It is thought that airborne circuits can be designed that will ignore the weaker stations provided that the frame synchronizing pulses of the weaker stations occur at times outside the interval of normal measurements. Thus a fixed delay of about 5-15 msec is required at a low-powered transmitter before retransmission takes place. Such delays can be achieved by mercury delay lines as used in M.T.I. radar.

Practical Problems.—It would be necessary to arrange that the delays between transmissions from stations in a chain be monitored and maintained at known constant values. In Great Britain this task would probably best be undertaken by the G.P.O. which provide the facilities for linking the stations.

A 24-hour service would be essential for navigational purposes, so relay facilities and transmitters would have to be permanently in service. Where desirable it could be arranged that a standby transmitter and aerial that sends out only frame sync pulses be put into service during television off-duty periods.

Marine Audio Equipment

THERE is a side to the Marconi International Marine Communication Company's activities which is probably less well known than the installation, operation and maintenance of ships' radio apparatus with which they have been concerned for the past half-century. This was brought into the limelight at a recent demonstration of their sound reproducing equipment.

Sound reproduction is interpreted in its widest sense, as equipment enabling passengers and crew to use their own broadcast receivers in cabins and quarters was included. This equipment, known as "Pantenna," is a communal aerial system and up to 80 receivers can be used simultaneously in various parts of a ship without mutual interference. Even a fraction of this number of personal aerials would be anything but a pleasing sight, quite apart from the disturbing effect they might have on the ship's radio navigational aids.

The "Pantenna" covers 22 to 4.5 Mc/s and 1.5 to 0.5 Mc/s thus providing for reception on all normal broadcast wavelengths. Provision is made to reject the ship's transmitter frequencies.

So far as sound reproduction itself is concerned the main emphasis was on magnetic tape players for providing background music. Magnetic tape has obvious advantages at sea, but disc gramophone players are available when required; a combination tape and disc record reproducer was among the various exhibits. The Marconi Marine Company have compiled a library of over 50 high-quality double-track tape recordings for use with their equipment aboard ship. It caters for all tastes in music and each spool gives about one hour's playing time. A self-contained tape player is included.

The Mimco ships' sound reproducing equipment follows much the same pattern, whether for operating 10 or 200 loudspeakers. A typical installation comprises a radio set, a tape reproducer with or without a disc gramophone, microphone for announcements by the ship's officers over the system and, as an extra, an electronic alarm for broadcasting warning tones in the event of fire or other emergency. Switching enables three or more microphone positions to be employed with one taking overriding control of the whole system, should the need arise. The various functions mentioned are provided by separate units, which, like bricks, can be assembled to form a single installation of any desired pattern. Several other items of sound producing and reproducing equipment were shown on this occasion; an interesting one being a self-contained power megaphone operated by readily obtainable flash-lamp batteries.

Although primarily marine equipment, much of it is applicable to shore use, the "Pantenna" communal aerial, for example, being ideal for use in blocks of flats.

Display of the sound reproducing equipment, with murals showing some of its applications, made by the Marconi International Marine Communications Company.

The Nyquist Diagram at Work

Dealing with Feedback over more than One Stage

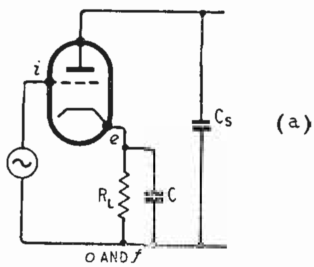
By "CATHODE RAY"

CONSIDERING that a moving-coil loudspeaker was patented in 1888 and transatlantic radio was achieved in 1901, it is surprising that it was not until 1934 that anybody pointed out the usefulness of negative feedback. Another surprising thing about it is how much has sprung from such an extremely simple idea. So much, in fact, that the hi-fi fan who chooses to design his own amplifier instead of just copying someone else's is liable to get into a daze. It was with the object of ameliorating his condition—and that of anyone else in trouble with negative feedback—that last month I expounded the Nyquist diagram as an aid to visualizing the workings of feedback circuits. There was only time then to apply it to very simple situations. So now I propose to go on to the more complicated cases where it really begins to pay.

But before doing so let us recapitulate. The basic idea of negative feedback is, as I said, so simple: some of the output voltage of the amplifier is put against the input voltage, so that to maintain the same level as without feedback the input voltage has to be increased until it is equal to the original input and the fed-back voltage combined. I say "combined," because although with perfectly negative feedback they would simply be added together, feedback can never be made perfectly negative at all frequencies simultaneously, and when the phase of the feedback is not exactly 180° simple addition fails. The thing can be dealt with by the usual methods for a.c., but a great help is a vector diagram, in which the original or net input voltage to the amplifier is shown as a fixed vector 1 unit long, at zero phase (denoted by pointing to 3 o'clock). The fed-back voltage is a vector that varies in length and phase with frequency, and the gross input required is equal to both together.

As an example, shall we take the one I gave last month to work out? It was a cathode follower, Fig. 1(a), in which the valve had a g_m of 6 mA/V and an r_a of 10 kΩ, R_L was 4 kΩ, and C was 0.002μF. C_s can be regarded as a short-circuit. The question was to find the "turning frequency" f_t (at which the total resistance and total reactance in the equivalent parallel or series circuit are equal) and the loss and phase shift caused by C at that particular frequency.

To facilitate comparison with last month's diagrams, I have used the same lettering. So *e* and *i* in Fig. 1(a) are the direct input terminals; and the unit signal voltage that is assumed to be maintained there, whatever the frequency, is represented in the vector diagram (b) by a line *ei* 1 unit long. The output terminals are *eo*, across which A units of signal appear, A denoting the voltage amplification. A fraction B of this output voltage is tapped off between terminals *ef* and fed back, this voltage being represented by vector *ef*. So the overall input terminals are *fi*. A special feature of the cathode follower is that *all* the output voltage is fed back (i.e., B = 1), so terminals *o* and *f* coincide.



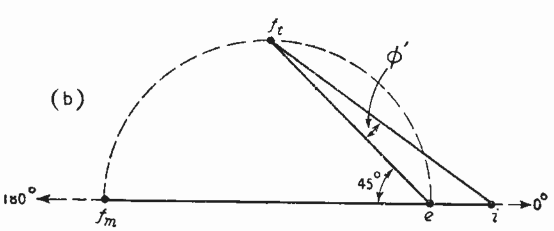


Fig. 1. (a) The essentials of a particular cathode-follower circuit, and (b) the diagram used for investigating its performance at high frequencies. f_m and f_t are particular values of f.

Constructing the Vectors

The first stage of constructing the vector diagram in every case is to draw *ei* 1 unit long, pointing to 3 o'clock. The next is to calculate AB under perfect negative-feedback conditions and draw an *ef* vector that number of units long pointing in the opposite direction. In this case AB = A, and A can of course be calculated by the well-known formula derived from the valve equivalent voltage generator, which is expressed as follows:

$$A = \frac{-\mu R_L}{R_L + r_a}$$

The minus sign is to remind us that there is a phase reversal in the valve, if both output and input are reckoned from *e*. We were not told μ, but as it is equal to $g_m r_a$ it must be 60. So A = − 60 × 4/(4 + 10) = − 17.1.

That would be the most likely method of calculation if C had not to be considered, but as it has we might as well adopt the equivalent *current* generator from the start, because being in parallel with the load it greatly simplifies calculation of parallel circuits. The reason I used the voltage equivalent just now is in case there are any doubters who need to be convinced that both equivalents give the same answer, and that it is purely a matter of convenience which is used. The current generated is $-g_m V_{ei}$, and as we have made $V_{ei} = 1$ it is equal to $-g_m$ in this case. The output voltage is developed by this current flowing through r_a and the load in parallel; and 10 $k\Omega$ and 4 $k\Omega$ in parallel is 2.85 $k\Omega$, denoted by R. Therefore A = $-$ 6 × 2.85 = $-$ 1.71 as before.

So to continue the diagram we draw *ef* 17.1 units to the left (that being the negative direction, in contrast to *ei*). To distinguish this particular *f*, corresponding to frequencies low enough for C to be ignored, let us call it f_m. The gain of the valve used as a cathode follower (i.e., with 100% negative feedback), denoted as usual by A′, is the ratio of output to gross input, so is represented on the diagram by the ratio of $f_m e$ to $f_m i$, or 17.1/18.1 = 0.945. Note that the output voltage is reckoned from terminal *f* in Fig. 1(a), that being the "earthy" output terminal of a cathode follower, so the output voltage is represented by *fe*, not *ef* as in anode-loaded amplifiers, and is positive. This corresponds to the well-known fact that in a cathode-follower stage there is no phase reversal, and illustrates how the lettered diagrams help one to take strict account of signs.

The same result can, of course, very easily be found by using the basic formula A′ = A/(1 − AB), in which A too must be reckoned as positive if *f* is the reference terminal:

$$17.1/(1 - [-17.1]) = 17.1/18.1 = 0.945.$$

Drawing the Diagram

Having got the position of f_m, we can draw the Nyquist diagram, because we found that for a single parallel combination of R and C it is a semicircle standing on $f_m e$ as diameter. We also found that the point representing the turning frequency f_t, at which the reactance of C is equal to R, is half-way along it, so that can be plotted and $f_t e$ and $f_t i$ drawn in. Of course, the brighter boys wouldn't have bothered to draw ef_m or the semicircle at all; they would straightway have drawn ef_t at 45°, $A/\sqrt{2}$ long. All my rather lengthy rigmarole was for the benefit of any readers who were absent last month and started on this second article without a clue.

The actual value of f_t, for which you were asked, could have been worked out as soon as R, the resistance effectively in parallel with C, was found to be 2.85kΩ, for f_t is the frequency at which the reactance of C is equal to that; i.e., $1/(2\pi f_t \times 0.002 \times 10^{-6}) = 2{,}850$, from which $f_t = 27{,}900$ c/s. (The 10^{-6} is to bring 0.002μF to farads, as is necessary if f_t is to be in c/s rather than Mc/s; the bright boys would have left C in μF and R in kΩ and got f_t in kc/s.)

The last thing to be found was the phase shift and loss in A′ caused by C at frequency f_t. If there were no feedback, the phase shift would be 45° and A would drop from 17.1 to $17.1/\sqrt{2} = 12.1$; a loss of just on 30% or 3 dB. But in the cathode follower the phase difference between input and output is represented on the diagram by the angle between the corresponding vectors, marked ϕ'. When the diagram is drawn to scale (Fig. 1(b) is not) this angle turns out to be just over 3°—a remarkable improvement on 45°.

The new A′ is represented by $f_t e/f_t i$ of course, and you will have to draw the diagram on an enormous scale to detect any difference between it and the medium-frequency A′, given by $f_m e/f_m i$. According

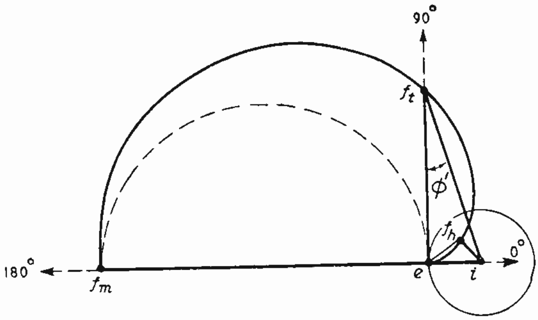


Fig. 2. Here the Nyquist diagram for a single CR circuit such as in Fig. 1. is repeated as a dotted semicircle, and the heart-shaped diagram for two such circuits is shown in full line. The small circle on the right marks the area within which feedback is positive.

to my rough calculation it is between 0.1% and 0.2% less, or say 0.01 dB—anyway, utterly negligible. This just shows why cathode followers are so popular in spite of their non-existent voltage amplification; a severe capacitive shunt across the load fails to pull down the output voltage appreciably, and has very little effect even on the phase angle. Lest I be accused of flattery, I should add that if the *gross* input voltage *fi* is kept up, instead of being allowed to drop from $f_m i$ to $f_t i$, the signal current through the valve goes up accordingly and there may be a risk of overloading. This particularly applies to sudden pulses, containing very high frequencies, which can put cathode followers momentarily out of action (see W. T. Cocking in the March, 1946, issue.).

More Complicated Situation

That has been rather a long recap, even though some cathode-follower lore has been thrown in for good measure, so we must get on with the more complicated cases; in particular, feedback over more than one stage. The importance of this is that feedback over a single stage, while it may be delightfully simple to apply and effective in reducing distortion, does rather cripple the amplifier as an amplifier—as we have just seen. The effectiveness of feedback depends on the quantity 1 − AB, which also is the amount by which the original voltage amplification is divided. Now to be really worth having, −AB must be much larger than 1. One can then say that the effectiveness is approximately proportional to AB. As the books invariably point out, the basic formula A′ = A/(1 − AB) then becomes $A' \simeq 1/-B$, which means that roughly the amplification depends only on the fraction of output fed back, which can easily be made very constant. In other words, the voltage amplification is virtually independent of the amplifier itself, and of any changes therein caused by ageing valves or fluctuating supply voltage—always provided that its amplification remains high enough for $-AB \gg 1$. The consequences of this particular condition can be seen in the diagram by making *ei* comparatively very small.

In a single stage, applying such effective feedback destroys practically all its gain; but the same sacrifice in a three-stage amplifier still leaves the gain of two stages, which should be enough to reduce the input to a level at which feedback in preceding stages, if any, is unnecessary.

All right, then; what are we waiting for? Let's apply feedback to three stages ! If I may be allowed to restrain the natural impatience a little longer, however, may I suggest that as a preliminary step we first draw a Nyquist diagram for two stages? To simplify the process let us assume that the stages are identical and that there are no couplings other than those deliberately provided.

Fig. 2 shows the now familiar dotted semicircle for one stage, from which the diagram for two can be derived. Take the turning-frequency point f_t, for instance. The second stage shifts the phase another 45°, making a full right angle, and it reduces the amplitude by another factor of $1/\sqrt{2}$, making it exactly half of the original tf_m. Filling in a sufficient number of such points to draw through, we get the full-line curve. Note that at f_t the phase angle ϕ' is still only a small fraction of the 90° lag that would be effective but for feedback. At a higher frequency still, f_h, we find that the input voltage f_hi is actually less than it would be without feedback (*ei*). Consequently A′ is greater than A; that is to say the effect of feedback is to increase the amplification, which means that it is positive. At that frequency the gain curve will not only not fall off; it will rise to a peak. (Even so, note that the phase lag with feedback is less than it would be without.)

It is quite easy to mark on the diagram the boundary between positive and negative feedback. Positive means that *fi* must be less than *ei*; negative, that it must be greater. So the boundary is where *fi* and *ei* are equal, which is on the circumference of a circle with radius *ei* (which is 1 unit) and centre *i*. Clearly, feedback that starts off purely negative can never be made positive by a single CR circuit, but with two it is bound to be positive at all frequencies above a certain figure. If you try different amounts of feedback on paper, by varying the size of the "semi-heart" Nyquist trace, you will find that the greater it is the greater the phase lag (and therefore the higher the frequency) before feedback becomes positive. But when it does become positive, it does it more thoroughly.

At this stage it will be a good idea to draw some ordinary graphs of the magnitude and phase of the output against frequency, corresponding to the Nyquist diagrams we already have. In doing this we will follow what is now the standard practice with regard to the frequency scale: (a) using a logarithmic scale, so that 1 to 1 occupies the same distance as 0.1 to 1 and 10 to 100, and (b) making f_t the unit of frequency, so that the graph is of general application, and the scale readings only have to be multiplied by the particular value of f_t to adapt it to a particular case. (This practice is known as "normalizing" the scale.) Another advantage is that if the curves are turned around, left to right about $f/f_t = 1$, they apply in their entirety to the low-frequency cut-off caused by series coupling capacitors, where used. And as it is relative magnitude to output that matters, rather than actual voltage, we will show it in decibels. The result of this whole scale policy is that the shapes of the curves plotted will be standard. At least, that is so with no feedback. The shapes of the curves with feedback depend on how much is used.

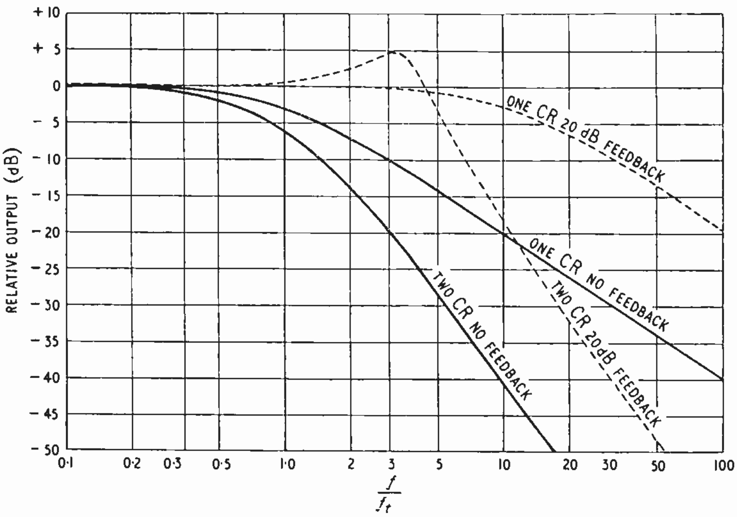


Fig. 3. Relative output plotted against frequency (relative to the turning frequency, f_t) for one and two CR circuits with and without 10:1 (= 20dB, feedback.

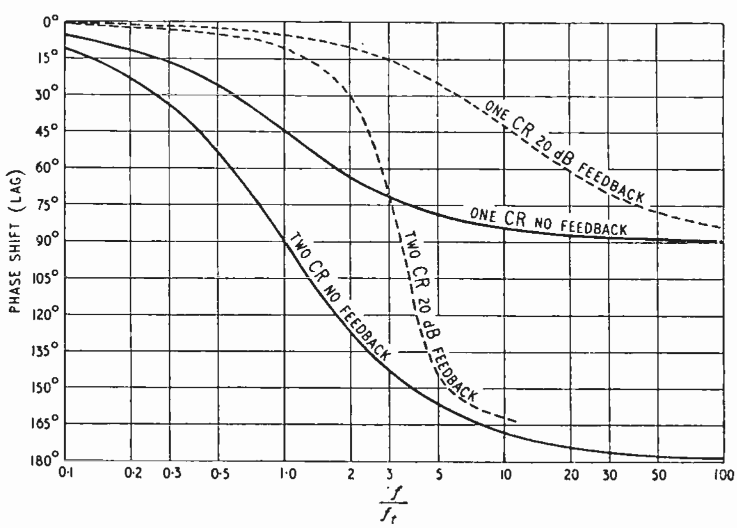


Fig. 4. Phase shift graphs corresponding to Fig. 3.

Fig. 3 shows in full line the relative-amplitude curves for one and two identical stages with capacitive top-frequency cut-off, and Fig. 4 the corresponding phase shift curves. (Note that if reversed to show low-frequency cut-off the phases would be *leading*, not lagging.) These curves show in a different way some of the things we already know; for instance, that at the turning frequency ($f/f_t = 1$) the loss is 3 dB for one stage and 6 dB for two, and that the corresponding phase lags are 45° and 90°. They also show that at very high frequency the lag approaches double these figures. More clearly than the Nyquist diagram, Fig. 3 shows that at high frequencies the loss tends to increase at a steady rate. This rate is 20 dB (1 : 10 ratio) per decade of frequency (1 : 10 ratio) for one stage, and 40 dB for two; but these rates are more often quoted as (almost exactly) 6 dB and 12 dB per octave (1 : 2 ratio).

Comparing Figs. 3 and 4 we see that these slopes are approached just as the 90° and 180° phase lags are approached. This is no accident; in fact it applies in the same proportion to any number of simple combinations of resistance and reactance or two opposite reactances (transmission lines and certain filters excluded). So if you look at a frequency characteristic curve of an amplifier (without feedback) in which the slopes are caused by such circuit combinations, and find that at some frequency the slope is at the rate of 12 dB per octave you are thereby provided with the important information that at that frequency the phase shift is 180°. If negative feedback were applied, it would at that frequency actually be positive, and if enough gain

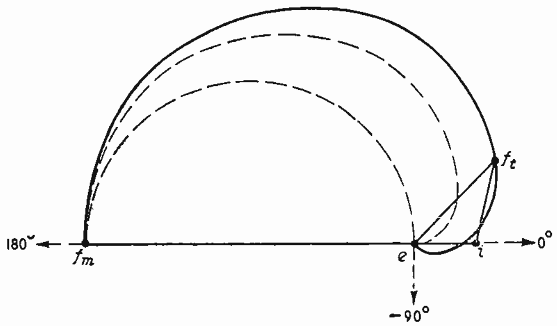


Fig. 5. Nyquist diagram for three CR stages, compared with those for one and two (dotted) repeated from Fig. 2.

were left at the same frequency to make the fed-back voltage at least equal to the input voltage the amplifier would oscillate.

There is no fear of that with one CR circuit; or even with two, for 180° shift is attained only at infinite frequency, at which the gain is zero.

Another fact is that at half the ultimate phase shift the dB curves have half their ultimate slope. It happens at $f/f_t = 1$, where the slope is 3 dB per octave with one CR and 6 with two. This might easily lead one to suppose that at one-third the phase shift the slopes would be 2 and 4 respectively, and so on, pro rata. I confess I thought so myself at one time, but on checking up mathematically found that this half-way proportionality was a fluke; the slope is not in fact proportional to the phase angle but to n times the square of the sine of one nth of that angle, n being the number of CR circuits.

However, you will not be so interested in how "C.R." came to see the light as in what happens when negative feedback is applied over the CR circuits. This is shown by the dotted lines in Figs. 3 and 4. They apply to 10 : 1 (= 20 dB) feedback; that is to say at f_m AB = 10, represented by making ef_m in Fig. 2 ten times ei. The dotted curves were derived from Fig. 2 (or rather a larger scale version of it) by measuring distances, but afterwards in another burst of enthusiasm I worked out formulae for them and plotted them again by computation. Fortunately the two lots agreed (when finally I got the formulae right!), but for initial study I unhesitatingly recommend the Nyquist diagram, even though it does mean a bit of work with drawing instruments. The procedure is of course the same as for the cathode-follower example. The phase angle with feedback, marked ϕ' in Figs. 1(b) and 2, is pretty obvious; but it may be as well to repeat that what are plotted in Fig. 3 (after conversion to dB) are the ratios of output/input ratio at the frequency in question to the same ratio at f_m. At f_t, for instance, it is represented by the ratio of f_te/f_ti to f_me/f_mi; viz., $(f_te \times f_mi)/(f_ti \times f_me)$.

It looks as if the dotted curves for one CR are the same as their full-line counterparts, except for being pushed higher in frequency. My original drawings help one to be more precise and suggest 11 times higher in frequency. This is 10 + 1, which leads one to guess that the use of n:1 feedback pushes the frequency characteristics $n + 1$ times higher in frequency. This time a mathematical check completely upholds the guesswork. It is a nice, simple thing to remember that feedback not only reduces gain $n + 1$ times but extends the frequency range (as regards cut-off and phase-shift) that number of times.

Rise in the Gain Curve

Unfortunately this simple rule applies only to one CR circuit, which is not very useful in practice except in connection with cathode followers. A glance at the two-CR curves shows that their relationships are decidedly less simple. The effect of feedback on the gain curve is to make it rise before plunging steeply—a characteristic that is quite useful if not carried too far. The rise is nothing to be surprised about, seeing we have already observed in Fig. 2 that two stages bring us within the positive-

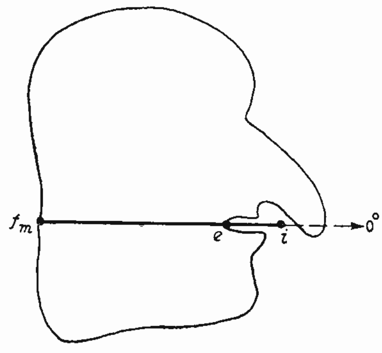


Fig. 6. This kind of Nyquist diagram, in which the oscillation point i is not enclosed, but which crosses the 0° axis beyond it indicates what is called conditional stability. Some Nyquist lines have very strange shapes.

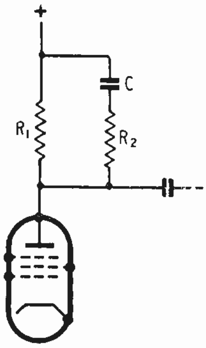
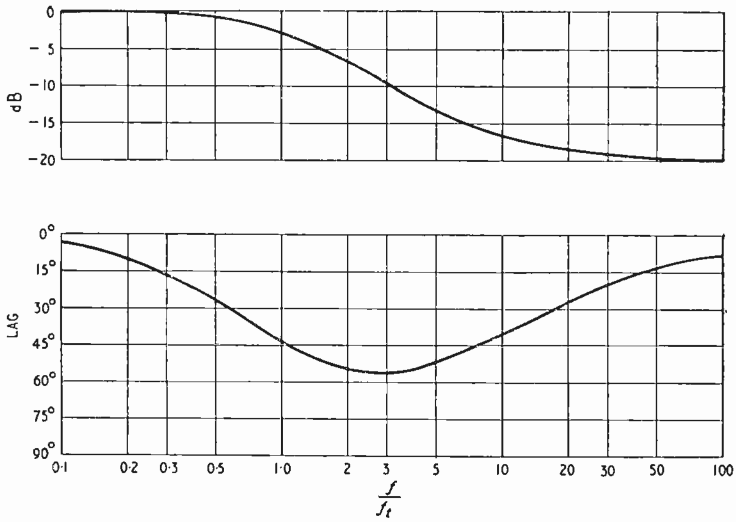


Fig. 7. One type of "step" circuit for cutting down gain witho it increasing high-frequency phase shift.



Right : Fig. 8. Typical characteristics of step circuit such as Fig. 7.

feedback circle. The more the feedback, the sharper the peak; but it can never go right through the roof and cause oscillation—with only two CR circuits. If this widening and peaking performance reminds us of the effect of over-coupling two resonant r.f. circuits, we may not be surprised to know that the mathematical formulae for the two things are somewhat similar in form.

As regards phase shift, we see that feedback postpones it to a higher frequency, but when the plunge comes it is all the steeper.

One could meditate still longer over Figs. 2-4, but must hurry on to the more practically important three-stage case. The Nyquist diagram (full-line in Fig. 5) can be derived from the two-stage in the same way as that was derived from the one-stage semicircle; both of those are shown dotted for comparison. The vitally unpleasant feature about the latest curve is that it passes through 180° phase shift (0° line) when it still has quite an appreciable fraction of the original (f_m) gain. It is an easy matter to calculate how much. When the total phase shift for three circuits is 180°, each (being identical) must be contributing 60°. The semicircle diagram, or Fig. 4 in relation to Fig. 3, show that at 60° the amplitude is halved; and halving three times leaves one eighth. So if as much as 8 : 1 (=18 dB) feedback is used over three CR circuits having the same f_t there will be oscillation. Such a situation is represented by the Nyquist curve passing through point *i*.

Double Crossing Curves

Last month I gave a rather qualified answer to the awkward gentleman I imagined to be asking what would happen if the curve passed through the 0° line *beyond i*—to its right. The reason for the slight hesitation was that some of the more complicated kinds of amplifiers are known to give Nyquist curves that cross the 0° line beyond *i*, *and then cross back again, also beyond it*, as in Fig. 6. The rule that Nyquist achieved fame by establishing is that if the whole curve is drawn, to include all frequencies from zero to infinity, and it *encloses* the point *i*, then oscillation is certain. The state of affairs represented by diagrams such as Fig. 6 is called conditional stability, which means that if the feedback is put into effect at the full force shown there will be no oscillation, but that if it grows gradually while heaters are warming up there probably will. It is unlikely that people who are reading this would find themselves keeping their amplifiers from oscillating by means of this sort of Nyquist curve, and if they did they would be well advised to think of some other way. For practical purposes we may regard the aim as being to keep the curve well to the left of *i* if it has to cross the 0° line at all. In other words, somehow we must increase the loss of the amplifier-feedback circuit—i.e., reduce AB—by the time the total phase shift amounts to 180°.

How to accomplish this aim is a big subject—too big a subject to start just now, and all I can do here is to refer readers to the practical procedure described in the March 1951 issue by Thomas Roddam.* Although something can be done by seeing that the stages do *not* all have the same turning frequency, the most useful weapon is the step circuit, which is a combination of a reactance with two resistances, as for example C, R_1 and R_2 in Fig. 7. The value of this device is that its amplitude curve doesn't continue to plunge for ever, like Fig. 3, but flattens out at a lower level. This reduction of slope is accompanied by a proportionate reduction of phase shift (Fig. 8). So what one gets at the high-frequency end is a substantial cut in gain without much phase shift. Which is just what one wants.

The need for such devices is all the greater because of the desirability of including the output transformer in the feedback loop. As regards high-frequency phase shift, a transformer is equivalent to two CR "stages," so even if there is only a single CR in addition it is enough to get one into difficulty.

Obviously, only just stopping an amplifier from oscillating isn't good enough; the slightest rise in mains voltage or change of load or valves or even a slight drift in component values might set it off again. Some margin is needed, and there should be a standard method of specifying how much.

One method gives it in the form of phase margin—the smallest angle between the Nyquist curve and *i*.

* A short summary of it is given in *Radio Designers Handbook*, 4th edn., pp. 363-365.

In Fig. 1(b) this angle is 90°, which is more than adequate. But the diagram for two CR stages, Fig. 2, goes right down to 0°, which is no margin at all; yet we know perfectly well that oscillation is impossible, because this angle is reached only when the fed-back voltage is down to zero.

So H. W. Bode† recommended a combination of an angle and an attenuation or loss. For instance, if the phase margin were 30° it would be bounded by the dotted radial lines in Fig. 9, which is a close-up of the *ei* end of an imaginary Nyquist diagram. This boundary itself would necessitate the amplifier cutting completely off at all frequencies giving a phase lag or lead of more than 150°, which is asking too much. So the Nyquist curve is allowed within the forbidden angle provided the designed gain is sufficiently below 1 (=0 dB) for there to be no risk of its reaching 1 with upper-limit valves, etc. One might decide that 6 dB margin was enough (gain $=\frac{1}{2}$), marked by the dotted curve *pq*. The danger area would then be as shown by shading. This particular Nyquist curve does trespass slightly at one corner, but a two-fold increase in gain would have to be combined with quite a considerable increase in phase lag to cause oscillation.

Seeing that *i* is the point to be avoided at all costs, a natural sort of margin is the distance between it and the nearest point on the Nyquist curve. We saw in connection with Fig. 2 that a circle drawn around *i* with radius *ie* (= 1) cordons off the area within which feedback is positive. If the whole curve for an amplifier keeps outside this circle, that means there is no frequency at which the use of feedback raises the overall gain A′ above the feedbackless gain A. That, of course, is being excessively cautious. The nearest point on our Nyquist curve is f_n, and at that frequency the ratio of A′ to A is ei/f_ni. This ratio, expressed in dB, is what W. T. Duerdoth‡ regards as the stability margin. A criticism I have of it is that a larger stability margin figure means a smaller margin. In Fig. 9 $ei/f_ni = 2$, which is 6 dB; but if the nearest approach were on the outer circle the margin would be 0 dB, which sounds less but is greater. The number of dB really means the height of the peak caused by feedback. Another thing; using this margin alone, an amplifier that was only conditionally stable might yet have the same stability rating as a cathode follower! The 6 dB so-called margin in Fig. 9 would allow the Nyquist curve to follow the inner circle round to the point P, which a reduction in gain of only $3\frac{1}{2}$ dB would cause to coincide with *i*. So Duerdoth admits the need for the circular boundary to be supplemented on the right by a radial boundary, which, however, might be perhaps ±15° instead of the ±30° shown.

Other ways of specifying the margin of stability could be devised, and all of them might be best for some particular purposes or conditions, but the Bode system should be good enough for most people most of the time.

† "Network Analysis and Feedback Amplifier Design," p. 453.
‡ *Proc. I.E.E.*, Pt. III, May 1950, p. 142.

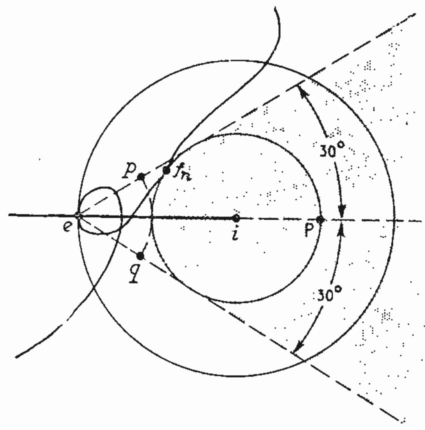
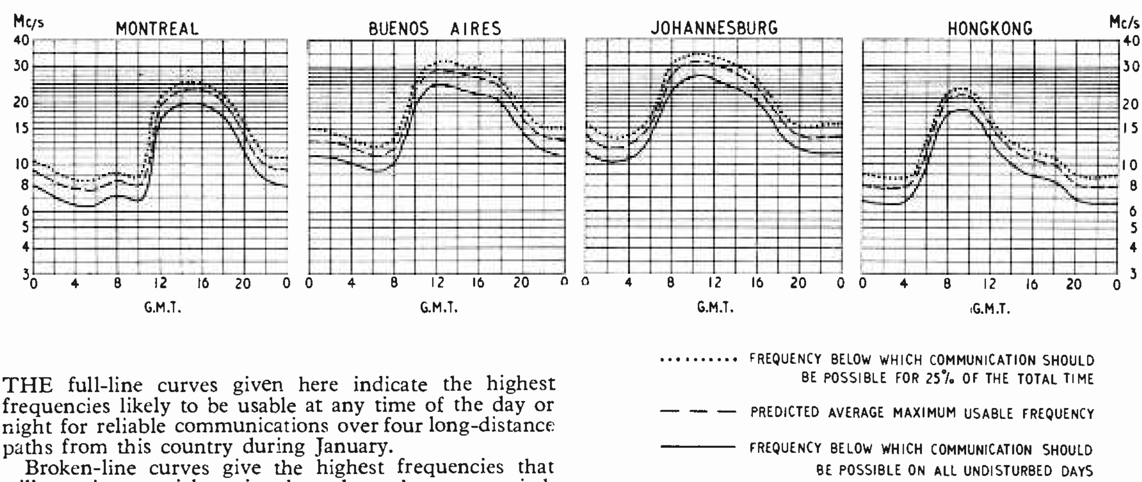


Fig. 9. Enlarged view of the positive-feedback region of a Nyquist diagram, showing the danger area (shaded) as specified by a Bode two-part stability margin.

SHORT-WAVE CONDITIONS

Predictions for January



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

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

JANUARY MEETINGS

LONDON

5th. Brit.I.R.E.—"Domestic tape recording applications with special reference to stereophonic reproduction" by M. B. Martin and D. L. A. Smith at 6.30 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

9th. I.E.E.—Discussion on "The efficient use of technical personnel" opened by the president at 5.30 at Savoy Place, W.C.2.

11th. I.E.E.—"Pulse-time-modulation terminals for music transmission over radio links" by R. F. Rous at 5.30 at Savoy Place, W.C.2.

13th. Radar Association.—"Radio astronomy" by Professor A. C. B. Lovell at 7.30 at the Anatomy Theatre, University College, Gower Street, W.C.1.

19th. Television Society.—Fleming Memorial Lecture, "Non-entertainment aspects of television" by Professor J. D. McGee at 7.0 at the Royal Institution of Great Britain, 21 Albemarle Street, W.1. Admission by ticket only.

20th. B.S.R.A.—"Magnetic recording equipment in feature film production" by A. W. Lumkin and M. Bradbury at 7.15 at the Royal Society of Arts, John Adam Street, W.C.2.

23rd. I.E.E.—"Particle accelerators" by E. L. Wiblin at 5.30 at Savoy Place, W.C.2.

25th. Brit.I.R.E.—Symposium on electronic methods of pictorial reproduction—"Facsimile communication" by H. F. Woodman and P. H. J. Taylor; "Facsimile transmission of weather charts" by J. A. B. Davidson; "Tone reproduction with electronic stencils" by Dr. R. Lant and "Electronic engraving" by G. S. Allen at 6.30 at the London School of Hygiene and Tropical Medicine, Keppel Street, W.C.1.

27th. R.S.G.B.—Presidential address by R. H. Hammans (G2IG) at 6.30 at the I.E.E., Savoy Place, W.C.2.

BOURNEMOUTH

18th. I.E.E.—"Artificial reverberation" by Dr. P. E. Axon, C. L. S. Gilford and D. E. L. Shorter at 6.30 at the Grand Hotel.

CARDIFF

25th. Brit.I.R.E.—"Magnetic amplifiers" by Dr. O. I. Butler at 6.30 at University College of South Wales and Monmouthshire.

CHATHAM

12th. Institution of Production Engineers.—"Electronic control in industry" by E. Heys (Metrovick) at 7.30 at the Assembly Room, Sun Hotel.

CHELMSFORD

10th. I.E.E. (Students).—"An introduction to the transistor" by A. V. Bryant at 7.0 at the Public Library.

CHESTER

25th. Society of Instrument Technology. — "Pneutronics" by J. E. Fielden at 7.0 in the Board Room of the Chester and District Hospital Committee, 5 Kings Buildings, King Street.

FARNBOROUGH

11th. I.E.E.—Discussion on "The applications and limitations of electronic and other computers" opened by Dr. L. G. Brazier at 7.30 at the R.A.E. Technical College.

LEEDS

9th. Institution of Production Engineers.—"Automatic inspection—the anatomy of conscious machines" by J. A. Sargrove at 7.0 at the Hotel Metropole, King Street.

LIVERPOOL

4th. Brit.I.R.E.—"Electronic instrumentation for nuclear power" by R. J. Cox at 7.0 at the Chamber of Commerce, 1 Old Hall Street.

LUTON

31st. Institution of Production Engineers.—"Electronic computers" by a member of Ferranti Limited at 7.30 at Skefko Ball Bearing Company's works.

MANCHESTER

5th. Brit.I.R.E.—"Radio and television interference—its growth and effects" by M. Smith at 6.30 at the Reynolds Hall, College of Technology, Sackville Street.

11th. Television Society.—"Aerials for Band III reception" by P. Jones (Aerialite) at 7.30 at the College of Technology, Sackville Street.

26th. B.S.R.A.—Exhibition and demonstration of new reproducing equipment, pick-ups, motors, etc., at 7.30 at The Times Recording Studio, Deansgate.

NEWCASTLE-UPON-TYNE

11th. Brit.I.R.E.—"Some interference problems associated with the television service" by J. C. Belcher at 6.0 at the Institution of Mining and Mechanical Engineers, Neville Hall, Westgate Road.

16th. I.E.E.—"The application of the Hall effect in a semi-conductor to the measurement of power in an electromagnetic field" and "The design of semi-conductor wattmeters for power-frequency and audio-frequency applications" by Professor H. E. M. Barlow at 6.15 at King's College.

OXFORD

10th. Institution of Production Engineers.—"Production by electronics" by E. R. Davies (English Electric) at 7.15 at the Town Hall.

PORTSMOUTH

4th. I.E.E.—"Receiving aerials for British television" by F. R. W. Strafford at 6.30 at the Central Electricity Authority, High Street.

PRESTON

11th. I.E.E.—"A Transatlantic telephone cable" by Dr. M. J. Kelly, Sir Gordon Radley, G. W. Gilman and R. J. Halsey at 7.15 at 19 Friargate.

STAINES

19th. Institution of Production Engineers.—"Electronics in industry" by J. A. Sargrove at 7.30 at the Social Club, Petters Limited.

SWANSEA

13th. Institution of Production Engineers.—"Electronics for production" by J. A. Sargrove at 7.30 at the Central Library, Alexandra Road.

WOLVERHAMPTON

11th. Brit.I.R.E.—"Computer control of machine tools" by H. Ogden at 7.15 at Wolverhampton and Staffordshire Technical College, Wulfruna Street.

RANDOM RADIATIONS

By "DIALLIST"

On Low Power

AN editorial footnote to a recent paragraph in these notes pointed out that the B.B.C. does transmit an indication that the pictures from some of its stations are temporarily not up to standard. This takes the form of a superimposed vertical bar, appearing every so often. It is used at transmitters fed by direct radio reception to show that the received signal is below par: it isn't used as an indication that output power is below normal. What several readers have asked for (and I'm sure all harassed dealers would welcome) is a simple and unmistakable sign on the picture that the signal is "down" owing to one of those technical hitches. Well, here's some good news. I wrote to the B.B.C. on the subject and they've replied that they fully realize the importance of letting people know when any station is sending out a weakened signal and that the matter is now under active consideration. All being well, then, it shouldn't be long before the sort of indication that's wanted comes into use.

All for a Quiet Life

THINKING it over carefully, I'm not a bit sure that I'd like to live in one of those "high-fidelity homes" that have been described recently in *Wireless World.* It's not that I don't like good quality, for indeed I do. It's rather that I should view with something akin to horror and dismay the prospect of living in a house which had loudspeakers, concealed or otherwise, built into every room. The idea of wireless while I'm shaving or having my bath appals me. I don't want to get up to the sounds of "Bright and Early." Strange though it may seem to some, my ideal home is a quiet place. Unlike several people I know, I can't read or work with a background of noises, however sweet they may be. Give me *one* room with a first-rate television set and high-quality sound equipment and I'm content.

Music on Tap

Talking about background noises, someone recently back from America told me of a grim 24-hour service available in most of the bigger towns over there. You can, if you feel so minded (and many Americans must, or it wouldn't pay), subscribe to a concern called Background Music Inc., or something of that kind. Your house, your office, your workshop, or whatever it may be is then supplied with soft music the livelong day and night. This comes from a central distributing station, provided with a vast collection of l.p. records. Originally these were changed by operators, who worked round the clock in shifts. But now I understand that the centres work unattended save for regular visits for magazine loading and maintenance. I sincerely trust that in this country we shall be spared from continuous piped background music, for I personally can't imagine a much more awful experience than a visit to the home of one of its addicts.

Looking Forward

THE PART of East Anglia in which I now live is for the time being rather badly served by both sound and vision broadcasting. We're on the very outside edge of the fringe area of the temporary Norwich transmitter, with the result that even high, four-element aerials often don't bring in a good enough signal to make viewing worth while. Pictures are frequently so jittery and so full of "noise" that it tears the eyes out of your head to look at them. All that should be a thing of the past in a few months when Tacolneston (may I remind you that it's pronounced "Tackleston"?) gets its permanent transmitter to work. The trouble with sound broadcast reception is mainly interference, which can be pretty bad at times. Here the improvement won't come quite so soon, for the f.m. transmitter at Tacolneston isn't due to start regular transmissions before next summer.

Deceiving the Eye

HAVE YOU noticed how low are the standards of picture quality that satisfy the average non-technical user of a television receiver? He or she will call your attention to the "perfection" of an image which is suffering from some bad fault—or even at times from a combination of several. In some ways it is as well that, up to a point, this should be so. If, for example, the eye of the domestic viewer was offended by quite small lapses from true linearity, the large-screen sets which are now so popular would necessarily cost a great deal more than they do. The whole basis of television presentation is to deceive the eye by making it believe it sees something which isn't really there; if it were able to follow the movements of the scanning spot, there couldn't be TV on the present lines.

Try it and See!

It's not to such minor imperfections that I'm referring, for they are neither here nor there. What does so often surprise me is to find people looking quite contentedly, and apparently unconscious that anything is amiss, at pictures of the soot-and-whitewash kind, or considerably out of focus or with height and width controls so badly adjusted that quite a bit of any scene is off the screen altogether. It's best, I think, not to comment on such things, unless you're asked whether you can improve the picture. Go to it then with a will, showing your friends how each adjustment is made and then getting them to do it under your supervision. Point out as you juggle with the contrast and brightness knobs how their correct setting brings out the detail of the picture. Convince them that the line linearity control does good work by letting them see how much more comely are the Television Toppers when their ensemble doesn't appear to consist of fat ones on the left and thin ones on the right. Demonstrate the improvement made by good focusing. Do these and other things and they'll be delighted and full of gratitude. But drop in a week later and you'll find them gazing enraptured at an out-of-focus, soot-and-whitewash, mis-shapen picture. . . .

Feeling the Draught

CURIOUS how anxious people are to have bigger and bigger television screens. With a 21-inch, or even a 17-inch, receiver in the average living room it has too often to be a choice, when the weather is bitter, between warmth *cum* lininess and shivering far enough from the screen but much too far from the fire. I must say I regret the passing of the 12-inch c.r. tube. Very few of this year's sets have them, though there's a lot to be said for them. Even in a small room you can usually manage to sit the necessary five or six feet from their screens; and when a replacement becomes necessary it's not nearly so heavy a blow to one's bank account.

UNBIASED

By FREE GRID

M & B Tablets

THIS month marks the thirtieth anniversary of the first demonstration of television, for it was on January 27th, 1926, that Baird ushered television into the world in that small room in Frith Street, Soho. There is a commemorative tablet on the wall of the house just as there is an outsize tablet on the monument at Poldhu to commemorate Marconi's bridging of the Atlantic on December 12th, 1901.

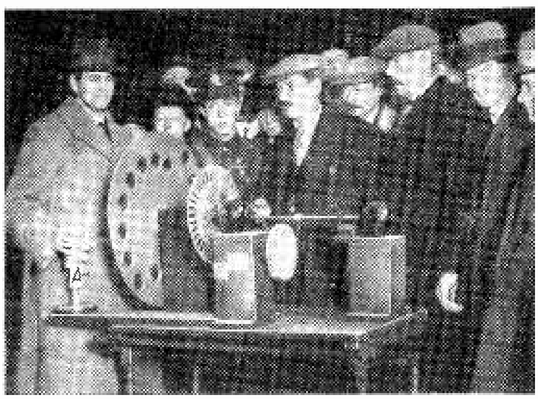
Indeed there are, I believe, quite a few of these M & B tablets scattered about the country commemorating the fact that one or other of these two pioneers was born, lived, died or did something there. The latest is to be erected at Ballycastle, Co. Antrim, to commemorate Marconi's experiments in linking Ballycastle and Rathlin Island. I hear, incidentally, that there is a controversy as to the date to be quoted on the plaque; was it 1898 or 1905? On good authority, I can assure the Antrim County Council that the earlier date is correct.

It is high time, I think, that radio should honour these two men by something more lasting than a stone tablet or graven image. It was once popular to discredit to some extent the importance of the work of Marconi and Baird in their respective spheres. Nowadays it is, I think, fully realized that even if these two famous men did not actually give birth to sound and sight radio respectively they *did* act as their midwives and deliver them to a not-very-interested world.

I have previously suggested in this journal that Marconi should be commemorated in the same way as Faraday and others by giving his name to some electrical unit of measurement. The Editor's words in the issue of December, 1947, confirmed me in my opinion that Marconi's key contribution to radio was the aerial. It seems obvious, therefore, that the Marconi should be the unit of effective radiated power; one Marconi equals 1kW e.r.p.

Now we must find a unit for Baird. What feature of television is especially associated with his early work and is still used, even if in modified form, in modern TV? The thing which comes to my mind is Baird's use of 30 lines for his original system of television. Could we not call 30 lines one "Baird." This would mean that we spoke of 13.5 Bairds instead of 405 lines, 819 lines would become 27.3 Bairds, 625 lines is a little more awkward.

This idea is merely a rather crude suggestion and I don't doubt that there is a much better unit to which the name of Baird could be attached if I could only think of it.



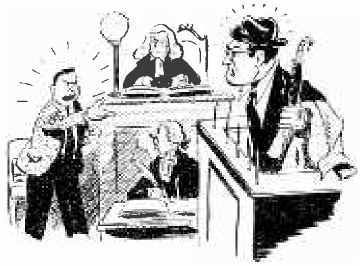
From my scrapbook: Baird at the 1926 Manchester radio show.

Sound-proof Houses

ONE of the worst bugbears of domestic wireless, no matter whether it be television or blind broadcasting, is the over-loud loudspeaker. I am not referring so much to the summer time when thoughtless people take a portable into the garden with the wick turned fully up, as to winter listening. In semi-detached houses and in flats the dull thumping of neighbours' noisy sets can be very irritating and undoubtedly leads to a lot of ill-feeling which is sometimes ventilated in the local police court as it usually leads to language or conduct "whereby a breach of the peace might have been occasioned."

The long-term policy lies in the hands of those who design new houses. They haven't yet woken up to the fact that we are living in 1956 and not 1906, and so they make not the slightest attempt to build flats or semi-detached houses with soundproof party walls.

They could, in fact, kill two birds with one stone by running our cold water pipes through the insulating material in such walls, for materials like sawdust and seaweed which are not good conductors of sound are also poor conductors of heat. This would prevent the annual freeze-up and so the cost of such insulation would be more than offset by the saving of the annual bill for damage caused by burst pipes.



Ventilators in the local police court.

Wisley Wisdom Wanted

LAST August I apologized in these columns for my ignorance of the fact that as long ago as 1939 it had been shown that r.f. oscillations affected the growth of plants. Glancing through some thirty-year-old issues of *Wireless World*, I find that the influence of aerials on vegetation was well known even then.

It is made clear in the Editor's correspondence columns of several issues of *W.W.* in 1925 that the presence of an earthed aerial over the garden can have a baneful effect on vegetation as it shields the ground from the influence of atmospheric potentials which are beneficial to plants.

It is all very confusing and I hope the Editor will invite some wizard from the Royal Horticultural Society's testing grounds at Wisley to give us his views on this matter.

Pirates' Corner

I SEE from a recent issue of the *Airport Post* that the G.P.O. authorities have threatened to swoop on the owners of the many pirate receiving sets which are said to be operating at London Airport. I am very glad to hear it and am wondering how many other nests of pirates have yet to be unearthed. The position so far as receivers in offices and works are concerned is analogous to those in homes. One licence covers any number of receivers in a building so long as they are operated by members of the licensee's family or business. Each separate company in a building must, therefore, have a licence to use a receiver.

What would be my position under the law if I took my portable on a transatlantic trip? Quite frankly I don't know. The occasional use of a portable away from my house is, of course, permitted by my licence but I doubt whether this extends to a sea voyage. I presume all members of the crew who take sets to sea are covered by the licence of the ship's wireless installation.*

* Free Grid's set would also be covered by the ship's licence.—ED.