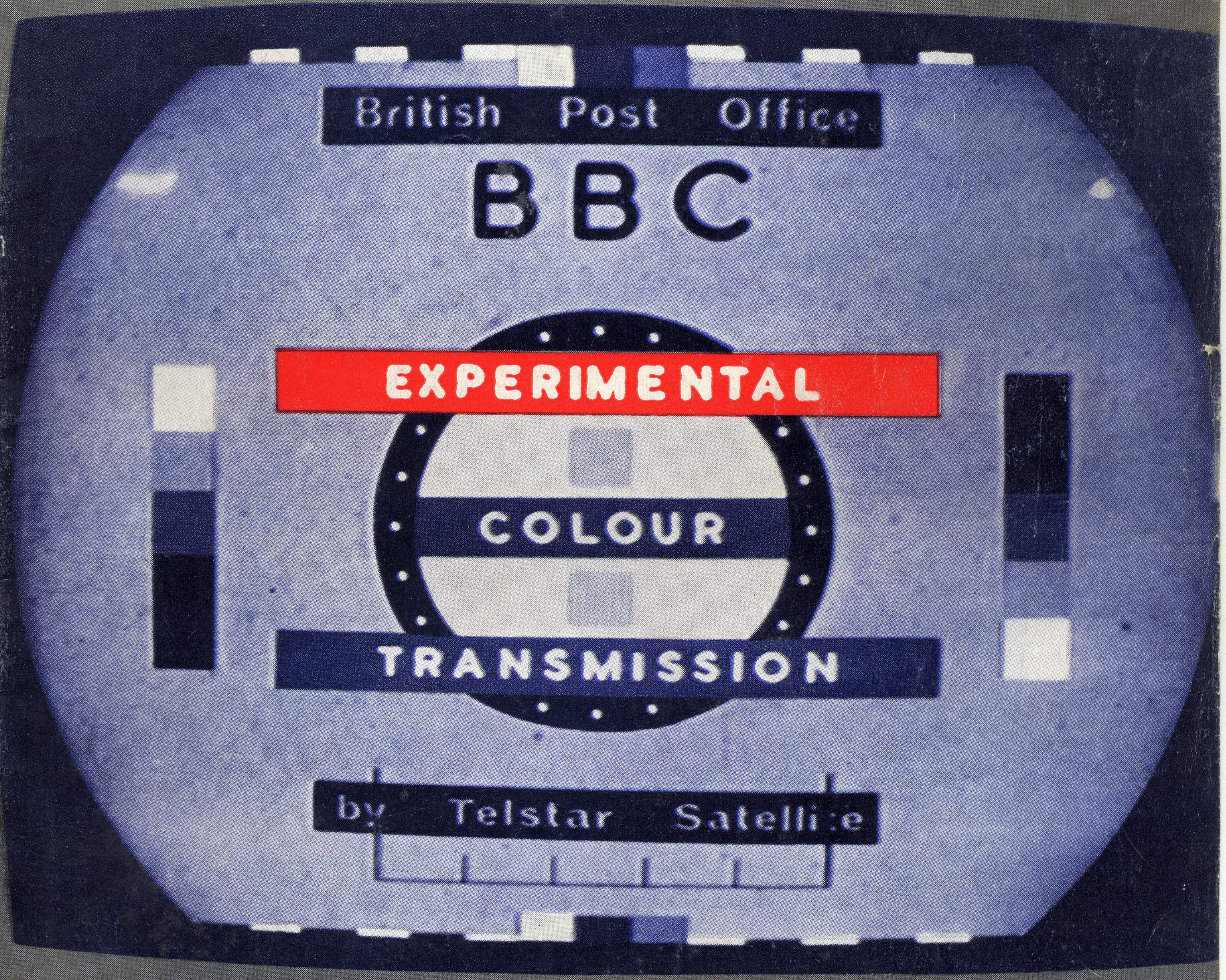
COLOUR TELEVISION SYSTEMS

Wireless World

ELECTRONICS
RADIO
TELEVISION

SEPTEMBER 1963 Price Two Shillings and Sixpence



Wireless World

ELECTRONICS, RADIO, TELEVISION

SEPTEMBER 1963

Editor:
F. L. DEVEREUX, B.SC.

Assistant Editor:
H. W. BARNARD

Editorial:
P. R. DARRINGTON
D. C. ROLFE
D. R. WILLIAMS

Drawing Office:
H. J. COOKE

Production:
D. R. BRAY

Advertisement Manager:
G. BENTON ROWELL

VOLUME 69 No. 9
PRICE: 2s 6d.

FIFTY-THIRD YEAR
OF PUBLICATION

Managing Director: W. E. Miller, M.A., M.Brit.I.R.E.
Iliffe Electrical Publications Ltd., Dorset House, Stamford Street, London, S.E.1

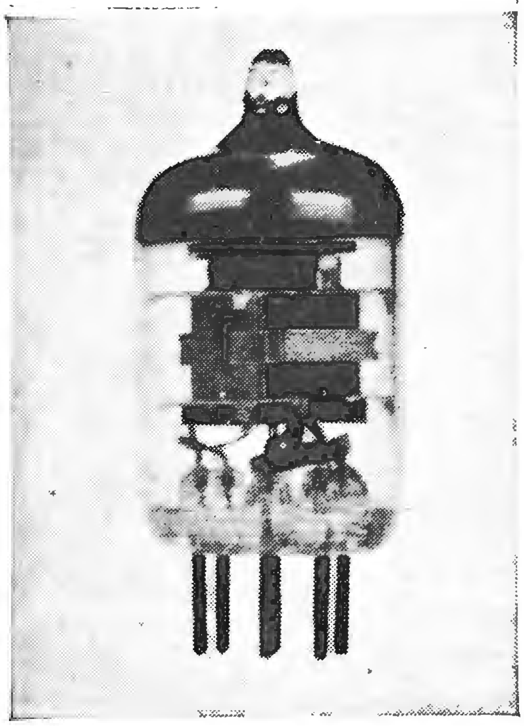
Please address to Editor, Advertisement Manager or Publisher as appropriate

PUBLISHED MONTHLY (4th Monday of preceding month). *Telephone:* Waterloo 3333 (70 lines). *Telegrams:* "Ethaworld, London. Telex." *Cables:* "Ethaworld, London, S.E.1." *Annual Subscriptions: Home* £2 0s. 0d. *Overseas* £2 5s. 0d. *Canada and U.S.A.* $6.50. Second-class mail privileges authorized at New York, N.Y. BRANCH OFFICES: *BIRMINGHAM:* King Edward House, New Street, 2. *Telephone:* Midland 7191. *COVENTRY:* 8-10, Corporation Street. *Telephone:* Coventry 25210. *GLASGOW:* 62, Buchanan Street, C.1. *Telephone:* Central 1265-6. *MANCHESTER:* 260, Deansgate, 3. *Telephone:* Blackfriars 4412. NEW YORK OFFICE: *U.S.A.:* 111, Broadway, 6. *Telephone:* Digby 9-1197.

PC900 NEW MULLARD R.F. TRIODE

for Simpler V.H.F. Television Tuners

In many television receivers, the circuitry of the v.h.f. tuner is now simplified by the use of a new r.f. valve — the Mullard frame-grid triode, type PC900.



The PC900, which is an improved version of the PC97, has been designed for use as a single-triode r.f. amplifier. In such a stage, it gives a noise factor which is of the same order as that of double-triode cascode stages.

The new valve possesses a very low value of anode-to-grid capacitance (350pF). Consequently neutralisation is easier than with earlier r.f. valves. The values of mutual conductance (14·5mA/V) and input impedance of the valve are high, and the input capacitance (80mpF) is very low. As a result, the gain of a single-triode stage using the PC900 is about twice that to be obtained with previously recommended r.f. triodes. Use of the PC900 in television v.h.f. tuners thus offers greater simplicity in the circuitry and a higher level of performance than hitherto attainable.

LCR2 Mullard Transistor Package for Car Radios

Now appearing in the latest car radios is the Mullard LCR2 audio package. This package comprises the OC82M miniature driver transistor and the AD140 output transistor. The output type has a high current gain, and possesses good linearity and frequency characteristics.

WHAT'S NEW IN THE NEW SETS

These articles describe the latest Mullard developments for entertainment equipment

The package forms a two-stage class A audio amplifier capable of delivering an output of 3W when driven directly from the detector of an all-transistor receiver. The sensitivity of the amplifier with respect to a 1kΩ source is typically 25mV for full output. The LCR2 is thus meeting the need for high audio gain in car radios, ensuring an excellent standard of performance while offering an economic design.

PCF801 Triode-Pentode for Television Tuners and I.F. Amplifiers

The performance and versatility of the recently introduced triode-pentode PCF801 make it an ideal choice for television receivers designed for both v.h.f. and u.h.f. reception. The PCF801 can function as an oscillator-mixer in v.h.f. tuners and as an i.f. amplifier following a u.h.f. tuner. Two frame-grids are incorporated in the valve: the triode grid and the pentode control grid, which has also been designed with a variable-mu characteristic. Outstanding properties of the PCF801 are small inter-electrode capacitances, a high conversion conductance and a remote cut-off characteristic.

As an oscillator-mixer, the triode oscillator performance is largely independent of supply voltage variations, and the frequency shift when bias is applied to the mixer control grid, is kept to a minimum. In the pentode mixer, a conversion conductance of 5mA/V is achieved with an r.m.s. oscillator signal amplitude of only 1·6V.

As a controlled i.f. amplifier, large i.f. signals from a u.h.f. tuner can be handled without risk of cross-modulation or over-modulation occurring. In addition, feedback of the i.f. signal to the r.f. bandpass filter is eliminated, so that difficulties in the adjustment of this filter are avoided.

MVE 1909

Wireless World

VOL 69 NO 9 SEPTEMBER 1963

European Colour Television

FROM time to time the mirage of colour television in Europe as a regular service takes on a nearer and clearer aspect, only to recede once again into the distant future. It is eight years since the American N.T.S.C. system was devised and shown to be capable of giving technically an acceptable public service, and since then in this country we have given demonstrations to prove our capacity to transmit and receive colour pictures of excellent quality by this and other systems. Many firms have put their experiments into cold storage, having satisfied themselves that they could go into production at the drop of a hat (if the P.M.G. does not wear one, no doubt a member of his Advisory Committee will lend one when the occasion ultimately arises), but last month the covers were off again—this time for the benefit of a distinguished delegation from the European Broadcasting Union and observers from the U.S.S.R. and other east European countries. The honour conferred on the B.B.C., who were entrusted by E.B.U. with the task of mounting the demonstrations, is fitting recognition of the quality and persistence of their research efforts in advancing the art of colour television broadcasting; and the radio industry who have supplied the B.B.C. with receivers can justly claim a share of the credit. The Independent Television companies have also made substantial contributions, particularly in studio techniques for handling programme material.

It now looks as though the long wait for something radically new to turn up in the way of a better display device than the shadow mask tube or a fundamentally different encoding system is at an end, and we may decide to make a start on this side of the Atlantic with what we already have.

Everyone who saw the B.B.C. demonstrations, and that includes representatives of the Press as well as the members of the E.B.U. delegation, has by this time either made up his mind as to which system should be adopted, or has decided, and this can still be done without disgrace, to remain a little longer with the " don't knows ". Elsewhere in this issue the technical merits and limitations of the three systems chosen for appraisal are reviewed and opinions expressed. On this page we will add only two points. First, that laboratory tests with artificially produced interference applied one type at a time may not be as conclusive a test of a system's susceptibility as would an extended field trial under conditions in which *real* interference might involve two or more dissimilar sources operating simultaneously. Second, that the N.T.S.C. system has already had that kind of field trial in the Americas and in Japan, and therein lies the advantage of its " antiquity ". Its faults as well as its merits are completely known.

Since " field testing " means, for us, the widespread use of commercially produced sets in the hands of non-technical viewers there can be no final judgment on alternative systems until they have been adopted. We must take a chance, as R.C.A. and others did with N.T.S.C. The public's choice, if they were given the opportunity, might well be governed by such peripheral considerations as the possibility of being able to adjust hue and saturation to their own liking or being debarred from doing so, i.e., whether they like or detest " knob twiddling."

Because the difference of line standards locks out the expensively produced American colour programmes to which otherwise we might have had access through the medium of tape recording (standards conversion *in colour* is at present impracticable), we must make sure that there is complete standardization in Europe, otherwise the cost of filling programme time by independent effort in each country is going to be prohibitive. It seems certain that colour is going to make us even more international in our outlook than monochrome, and experience to date through Eurovision is going to provide invaluable pointers.

We look forward with interest to hearing the E.B.U.'s official verdict in the course of the next few months, and the considerations which have influenced their final choice. Under favourable conditions the picture quality of all three contending systems is so good that the choice may rest not on why we should have any one in particular, but why we should not have the others.

One final point. It has been said that to choose any system other than N.T.S.C. is going to involve further considerable delay before a service can start. The fact that within six months of its announcement the B.B.C. has been transmitting on the PAL system, and manufacturers have already produced and demonstrated receivers, seems to give the lie to this contention.

Colour Television Systems

THE SEARCH FOR A EUROPEAN STANDARD

THE European Broadcasting Union is currently investigating the three selected systems of colour television—N.T.S.C., SECAM and PAL—with the object of advising the C.C.I.R. on its choice of a system for use in Europe, and thereby avoiding the haphazard jumble of types that seems to be the result of every invention from railways to valve bases. Demonstrations of three systems and associated equipment were given to the *ad hoc* committee of the E.B.U. during July, and the O.I.R.T., which is the Eastern European equivalent of the E.B.U. sent observers, so that it seems possible that the whole of Europe may be covered by a single standard.

It is some time since the subject was aired in *Wireless World*, and to keep our readers up to date with developments, we are giving a short description of each system, with comparisons of performance in several aspects.

N.T.S.C.

The American system was the earliest one in regular public use, apart from an even earlier mechanical type, also American, and was developed in co-operation with the National Television System Committee (hence the name). Like the other two, the system is compatible, which means that pictures transmitted in colour can be received on a black and white set with only a small deterioration in quality.

Ignoring, for the moment, a recent camera development, the video signal is obtained from three camera tubes, each with its colour filter, providing a signal corresponding to the three additive primary colours, red, blue and green. (Yellow is a subtractive primary, provided, for instance, by yellow paint, which absorbs and subtracts from white ambient light all colours but yellow.) After the camera outputs have been operated upon to cancel the effect of the non-linear light output/grid voltage law of a cathode-ray tube (gamma correction), a proportion of all three is applied to a resistive adding matrix in which they are combined to provide brightness, or "luminance" information, which can be displayed on an ordinary monochrome receiver. The red and blue signals, or rather the differences between these and luminance, are now used to modulate a subcarrier which, on a 625-line system, is 4.43Mc/s. The two signals are separated in phase by 90°, and as the subcarrier is amplitude modulated, they can be regarded as a vector, whose length determines the *amount* of red or blue, or the "saturation," and whose phase angle with respect to a transmitted reference signal denotes hue, i.e., whether the picture is red, blue, or a mixture of both.

It is conveniently found that the eye does not respond to colour pictures in quite the same way as it does to black and white ones. If a b. and w. scene is fuzzy (bad high-frequency response in a receiver, for instance) the result is objectionable. This is not so with colour, as can be illustrated by the "colouring-book" analogy. Children are not very skilful at keeping crayon or paint within the printed line, and the coloured areas tend to have ragged edges. These are not very noticeable, however, as the printed line, corresponding to television luminance or brightness information, defines the coloured areas precisely, and the ragged edges are not noticed. This effect enables the bandwidth of colour information to be considerably reduced and in fact, the wider bandwidth signal occupies only 1.5Mc/s. The vector components actually used do not correspond exactly to red and blue, but are offset slightly to place the narrow-band axis in the region where the eye is unable to distinguish changes in small areas of colour. This axis is consequently in the green/magenta part of the spectrum and is called the "Q" axis. The wider bandwidth signal is then in the orange/cyan sector and is called the "I" axis.

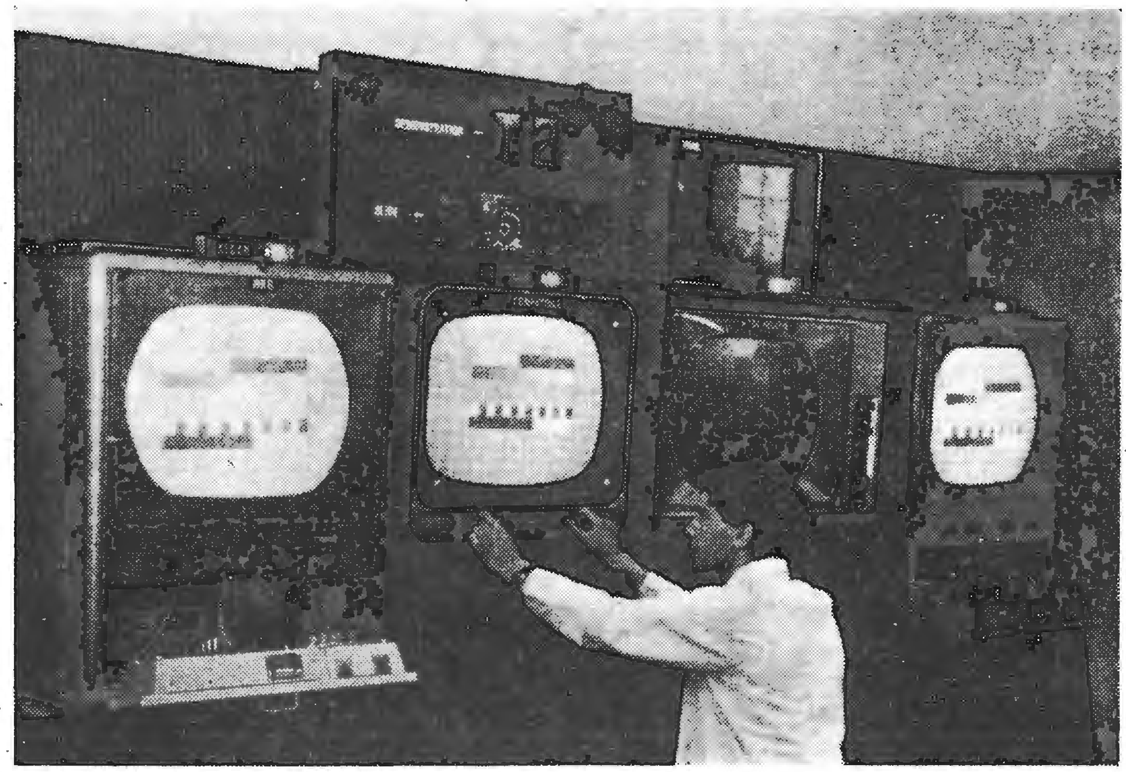
At the receiver, the red and blue information is derived by two synchronous phase detectors, fed by sine waves at subcarrier frequency 90° apart. The phases of these reference signals are kept correct by the transmission of a burst of subcarrier frequency on the back porch of the video signal. The phases of the colour burst and the reference oscillator are compared and, if any difference exists, correction made. The green information is obtained by combining the red and blue information with luminance in a resistive matrix at the receiver.

The three colour signals are now applied to the three grids of an R.C.A. shadow-mask tube, or to three tubes with colour filters projecting through an optical system on to a screen.

SECAM

The next system to appear was developed in France by the Compagnie Française de Télévision, and was originally known as the Henri de France system, after its inventor. It differs in two major respects from N.T.S.C. in that the red and blue information is transmitted on alternate lines, and in the fact that the subcarrier is frequency modulated.

It has been mentioned that the bandwidth of colour information can be reduced, which means that the horizontal definition of a colour picture will be limited. If the normal number of lines of colour are transmitted, the vertical definition will be greater than the horizontal, which does not make for a satisfactory balance. Moreover, it is found that the colour information in one line does not often differ appreciably from that in the preceding line. In SECAM, advantage is taken of these facts to transmit each colour, red and blue, on alternate lines.



Colour monitors being set up by an engineer of ABC Television, prior to a demonstration for E.B.U. delegates.

A delay line stores each line of colour information for one line period and it is then displayed, along with the new information of the other colour, in the next line. An electronic switch routes each line into the delay line in turn, so that two sets of colour information are always displayed, even though one really belongs to the preceding line. The result is about half the vertical colour definition obtained in an N.T.S.C. receiver.

As only one set of colour information is transmitted on any one line, frequency-modulation of the subcarrier is possible. This has the advantage that differential fading and phase errors which occur in the transmission path and in the input circuits of the receiver itself have virtually no effect on the colour rendering. A frequency-modulated carrier is not affected by these factors as long as there is sufficient signal to cross the threshold of the limiter in the frequency-discriminator which is used as a subcarrier detector. To make the channel switch operate in phase with the switch at the transmitter, lines transmitted during the vertical flyback have on their back porches a burst of subcarrier, which is alternately positively or negatively frequency modulated, corresponding to blue or red respectively. Pulses derived from this modulation trigger the switch in the correct phase.

PAL

The third system to be considered is the West German PAL (Phase Alternation Line) which was developed by Walter Bruch at Telefunken. It combines the advantages of SECAM with a basic similarity to N.T.S.C., and relies to a larger extent than other systems on the eye's insensitivity to small areas of colour.

As the name implies, the phase of one of the vectors, I as it happens, is reversed on alternate lines in both transmitter and receiver. If, therefore, the phase of the subcarrier is changed by a few degrees during transmission, and in the input circuits of the receiver, this error will appear to be of opposite sign on the succeeding line. If the error is less than about $\pm 7°$, the eye sees the average, or correct, colour rather than two slightly incorrect lines. This is the system known as "Volks PAL" and is the one shown to the E.B.U.

A slightly more expensive variety, known as "de luxe PAL," uses a delay line to help the eye to average out colour errors. The delay line is used in the same way as in SECAM, so that four colour signals are available on each line, I and Q from one line, delayed by one line interval, and I and Q of the succeeding line, the two sets having phase errors of opposite sign, which are thus cancelled.

Rather better vertical definition than in SECAM is claimed, and it is pointed out that N.T.S.C., Volks PAL and de luxe PAL receivers are so similar that modifications to receivers and transcoding between systems are quite simple. An incidental point in PAL's favour is the fact that although the colour subcarrier is a vestigial sideband transmission, the reversal of phase effectively re-establishes the missing sideband, with a corresponding improvement in performance when differential fading is a problem. It also means that the change in characteristics of i.f. valves and drift in tuners is not quite so serious.

It is extremely difficult, and probably unfair, to make a judgment on the three systems in the absence of about 90% of the evidence considered by the E.B.U. We will try, however, to put together the facts we have, and make some guesses at the rest.

Cost

Probably the first question that springs to mind is "How much?" It is justifiable to neglect the cost of transmitters and studio operations, and confine ourselves to home receivers. Most manufacturers are reticent in the extreme about prices, but the figure most often mentioned is 2.5—3 times the cost of a monochrome set. N.T.S.C. is the cheapest, PAL next (if no delay line) and SECAM third. The cost of the delay line determines the difference between the three, as otherwise they are all virtually identical in complication. Lines made by Corning International sell for 50 dollars at present, with the prospect of a substantial decrease for quantity use. The cost of the shadow-mask tube and its associated components, together with a stabilized power and e.h.t. supply is such that the cost of the delay line is insignificant.

Operation

Recovering from the shock of the probable cost, the next question is likely to be concerned with the "usability" of the receiver. We have all heard grim stories from the U.S.A. about resident service technicians "in every home" and wonder if things have improved in eight or nine years. It seems to be a fact that the N.T.S.C. system is still subject to phase distortions and differential fading affecting the hue, and a knob is invariably provided for correct setting. One can imagine the havoc that could be created by compulsive knob-twiddlers with a control which allows much variation in colour. The receivers shown at last year's Radio Show were all N.T.S.C. types, and as we said then, the variations of flesh colour ranged from a sickly pallor to rude, almost indecent, health. SECAM and PAL receivers have no colour controls at all; SECAM has its f.m. subcarrier, and PAL cancels phase distortions, giving the same colour signal as that as the transmitter.

From the studio point of view, N.T.S.C. has had the longest run, and techniques are well worked out. It was originally difficult to handle a SECAM signal in such operations as "wiping", fading and other effects due to the fact that an f.m. subcarrier is hard to fade. ABC Television have now evolved a method of doing this, so that SECAM compares with N.T.S.C. in this respect. PAL is similar to N.T.S.C.

Compatibility

The high cost of colour receivers makes it fairly certain that they will be "status symbols" for some years. For the man whose contempt for the Jones' is exceeded only by his overdraft, black and white receivers will suffice, and he will not want too much patterning on his screen from colour transmissions.

For reasons of economy in bandwidth, the colour subcarrier in all three systems is inside the vision frequency band. It is found that the energy of the luminance signal is mainly grouped about multiples of the line frequency, and if the subcarrier is fixed at odd multiples of half this frequency, interference will be a minimum. In practice, the subcarrier is a fairly high frequency, and the subcarrier breakthrough is not usually objectionable. It takes the form of brightness modulation of the picture and has been described as "boiling porridge." In N.T.S.C. and PAL, when the colours are not saturated, which is most of the time, the subcarrier is small and interference negligible. Worst patterns occur in heavily-saturated areas of the picture. It is possible to arrange a notch filter in the luminance channel with its trough on the chrominance subcarrier, which leaves the high end of the luminance response untouched. Rapid transitions of colour, however, produce sidebands outside the range of the notch filter and patterning is again seen. In SECAM the f.m. subcarrier is of small but constant amplitude, and although this gives less breakthrough than the other two on an average picture, two further operations can be performed. The phase of the subcarrier is controlled at the start of each line, so that the dot structure is stable. A shift of half a cycle of the subcarrier is then introduced between frames, which tends to interlace the pattern, and further phase-shifts at intervals of a few lines to break up the vertical pattern to reduce the effect of breakthrough still further.

Colour Rendering

In demonstrations we have seen recently, no difference could be detected between receivers that could be put down to differences in transmission systems. Whether this would be true under any but laboratory conditions is open to question.

Definition

The bandwidth of the colour information is limited, as has been seen. In SECAM, the vertical definition is also reduced. Due to the fact that two consecutive lines carry the same information almost-horizontal edges in the picture tend to jitter somewhat. The effect is not bad and only occurs rarely. PAL and N.T.S.C. have better vertical resolution than that in the horizontal direction. Definition on colour generally is noticeably poorer than on monochrome, as the lack of colour bandwidth does have some effect.

Recording

It is necessary, in order to maintain correct hue, to keep the phase of the N.T.S.C. carrier within $\pm 5°$, and it can be shown that the operations of recording and playback must be carried out at a tape speed which does not vary by more than $\pm 0.015\%$, or about ten times the constancy of speed needed for monochrome signals. SECAM, on the other hand, is less affected by phase errors, and as long as the tape speed, and therefore subcarrier frequency, is held within $\pm 0.4\%$, the colour rendering is correct.

Noise

No difference could be detected on the receivers we have seen when various types of noise were superimposed on the signal. No effect on colour rendering was observed, and the only remark we have to offer is that ignition noise on the 625-line, negatively-modulated signal was much less obtrusive than on 405-line positive modulation.

Conclusions

N.T.S.C. has been in regular use for about eight years. It is often said that this, in some indeterminate way, confers an advantage on it. It is difficult to see why age is any qualification for supremacy, especially as little development has taken place as a result of experience over this period. Phase errors, differential fading and difficulty with magnetic recording, are not negligible factors, and seem to us to put the system at a disadvantage.

SECAM is a simple system with much to recommend it, but also with its own peculiar disadvantages. Although free from colour errors due to a long and tortuous transmission path, the system would respond badly to a signal below limiter threshold level, which would also be the probable result of such a transmission path. If an N.T.S.C. or PAL colour signal is reduced to zero, the receiver reproduces black level. In SECAM, black level is dependent on the discriminator characteristic, which may drift. The SECAM method of colour coding gives only one colour per line from the transmitter. This rather rules out any possible future developments which could make it possible to increase colour definition, as the vertical resolution is fixed at the width of two lines.

On the available evidence, PAL appears to be the most attractive system. It is sufficiently close to N.T.S.C. to satisfy that system's enthusiasts. It transmits all colours all the time. It is less sensitive to phase and fading errors. It compares favourably in cost with SECAM. Operation by the viewer is simple. Small saturations produce less patterning, while SECAM has a constant amplitude subcarrier giving a constant pattern. PAL has better resolution than SECAM. PAL, like SECAM, is less affected than N.T.S.C. by phase distortion in magnetic recording, and has the further advantage of better vertical resolution.

Separate Luminance

In all three systems proposed, the luminance signal, which provides brightness or monochrome information, is formed by adding proportions of the red, green and blue camera outputs according to the equation $E_Y = 0.3E_R + 0.59E_G + 0.11E_B$, where E_R, E_G and E_B are the signals corresponding to the colour channels and E_Y is luminance. The receiver cathode-ray tube does not brighten in proportion to the voltage on its grid, and the luminance signal must therefore be "gamma-corrected" to take account of the (roughly) square law of the c.r.t. This entails raising the luminance signal to the power of $1/\gamma$, or 1/2.2, which gives

$$(E_Y{}^{1/\gamma}) = (0.3E_R + 0.59E_G + 0.11E_B)^{1/\gamma} \quad .. \quad (1)$$

The N.T.S.C. luminance signal, however, is given as

$$E_Y{}^{1/\gamma} = 0.3E_R{}^{1/\gamma} + 0.59E_G{}^{1/\gamma} + 0.11E_B{}^{1/\gamma} \quad .. \quad (2)$$

which is not the same as (1). The result is that the luminance is not properly reproduced, as on saturated colours it only reaches a fraction of its correct value. To make up the balance, some luminance is transmitted with the chrominance signals which are band-limited, and a loss in resolution is incurred. Furthermore, three wide-band camera tubes are needed.

Both E.M.I. and Marconi have produced cameras in which the luminance signal is kept completely separate from the chrominance information. In the E.M.I. camera, a 4½in image orthicon provides the luminance signal, three vidicons being used for the colour signals. Marconi's three vidicons are complemented by a new monochrome tube, the "Plumbicon," recently produced by Philips.

The only wide-band signal is now the 5Mc/s luminance channel, the three vidicons providing low-definition colour signals.

One small disadvantage is that, at the receiver, green is obtained by combination of luminance and red and blue signals. On a separate-luminance signal, a standard N.T.S.C. decoder would produce a slightly erroneous green signal. This could be avoided by a little extra circuitry in the receiver, but to be honest, the difference between the correct and incorrect greens is very little and seems hardly worth worrying about.

A separate-luminance camera is very much more sensitive than an ordinary RGB type, and it is found that pictures can be produced with an illumination of 100 foot-candles at an aperture of f/8. The registration of the colour camera tubes is no longer important, as they are low-definition types, and "lag" experienced in vidicon cameras, is not troublesome. With saturated colours, the correct luminance signal is presented to the receiver c.r.t. and better definition is given. The separate luminance principle is applicable to all three proposed systems.

P. R. D.

LONDON RADIO SHOWS

AS there will not be a national radio exhibition in this country this year, many of the manufacturers and some agents for overseas manufacturers are organizing independent trade shows during the normal show period. We list these below but stress that admission is limited to the trade and that some are not open at weekends. Several companies are also holding public shows in provincial towns.

In our next issue we shall be surveying some of the salient features of the new season's domestic television, radio and audio equipment.

Aerialite	Café Royal, Regent St., W.1	Aug. 27—30
Alba	Café Royal, Regent St., W.1	Aug. 28—30
Antiference	Café Royal, Regent St., W.1	Aug. 29 & Sept.4
Belling-Lee	Café Royal, Regent St., W.1	Aug. 26—30
Ben Nevis	2 King St., St. James, W.1	Aug. 26—30
Blue Spot & Uher ...	Bosch Ltd 205 Gt. Portland St., W.1	Aug. 26—30
Brown Brothers ...	Gt. Eastern St., E.C.2	Aug. 28—Sept. 5
Bush & Murphy ...	Savoy Hotel, Strand, W.C.2	Aug. 26—30
Clairtone & Braun ...	2 Ridgmount Place, W.C.1	Sept. 2—5
Dansette	Honeypot Lane, Stanmore	Aug. 26—Sept. 6
Decca	Café Royal, Regent St., W.1	Aug. 26—Sept. 6
Defiant	C.W.S., Leman St., E.1	Aug. 26—30
Dynatron	Hilton Hotel, Park Lane, W.1	Aug. 26—30
E.M.I. Sound Products	100 Wigmore St., W.1	Aug. 26—Sept. 7
Ekco & Ferranti ...	41/47 Old Street, E.C.1	Aug. 26—30
Elizabethan	May Fair, Berkeley St., W.1	Aug. 27—Sept. 3
Elpico	Hotel Russell, Russell Sq., W.C.1	Aug. 26—30
Eumig	Blazy & Clement, 26 St. Cross St., E.C.1	Aug. 26—Sept. 6
Falcon...	Café Royal, Regent St., W.1	Aug. 26—30
Ferguson	Thorn House, Upper St. Martin's Lane, W.C.2	Aug. 26—30
Fidelity	Hilton Hotel, Park Lane, W.1	Aug. 27—Sept. 3
G.E.C., Masteradio, McMichael & Sobell	Carlton Tower, Cadogan Place, W.1	Aug. 27—Sept. 5
Grundig	Hilton Hotel, Park Lane, W.1	Aug. 27—29
H.M.V.	Cadogan Pier, Chelsea, S.W.3	Aug. 27—29
K.B., R.G.D., Regentone, Ace & Argosy	Kensington Palace Hotel, De Vere Gdns., W.8	Aug. 26—30
Loewe-Opta, Ingelen & Perpetuum Ebner	Highgate Acoustics, 71/3 Gt. Portland St., W.1	Sept. 9—13
Lugton	Café Royal, Regent St., W.1	Aug. 27—Sept. 5
Marconiphone ...	Café Royal, Regent St., W.1	Aug. 27—29
Mullard	Mullard House, Torrington Place, W.C.1	Aug. 26—Sept. 6
Pam	295 Regent St., W.1	Aug. 26—Sept. 6
Perdio...	Savoy Hotel, Strand, W.C.2	Aug. 29
Philips, Stella, Cossor & Peto Scott ...	Fairfield Halls, Croydon	Aug. 26—Sept. 4
Retra	R.T.R.A., 19 Conway St., W.1	Aug. 27—29
Revelation Silvertone ...	W. Wood & Son, 24 Princes St., W.1	Aug. 28—30
Schaub-Lorenz, Trio & National ...	Winter Trading, 95/9 Ladbroke Grove, W.11	Aug. 24—31
Telerection	Carlton Tower, Cadogan Place, W.1	Aug. 27—Sept. 5
Tellux & Sony ...	De Vere Hotel, W.8	Oct. 9—10
Ultra	Hilton Hotel, Park Lane, W.1	Aug. 26—30
Unitra	May Fair, Berkeley St., W.1	Aug. 27—Sept. 3
Wolsey	Mount Royal Hotel, Marble Arch, W.1	Sept. 2—5

LASERS

2.—GASEOUS, LIQUID AND SEMICONDUCTOR JUNCTION TYPES

By AUBREY HARRIS, A.M.I.E.E., A.M.Brit.I.R.E.

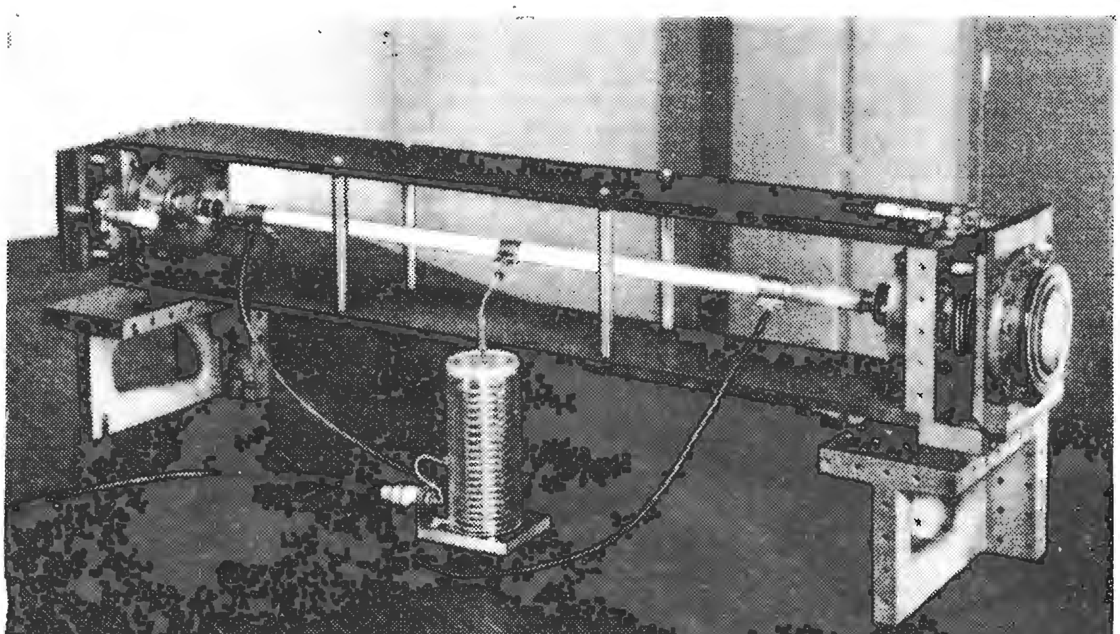
THE gas discharge laser although physically quite different from the crystal laser operates according to the same broad basic principles. The active medium is a mixture of gases, and the cavity is formed by a glass or quartz tube with polished reflectors at each end. Fig. 11 shows diagrammatically such a device. Quite often the gases used are helium and neon in the proportion 90% to 10% at a pressure of 1 to 2 millimetres of mercury.

The glass or quartz tube is 1 metre long and about 15 mm. in diameter. The end sections are flared out to accommodate the reflectors conveniently and for the mounting of suitable adjusting devices to permit their accurate parallel alignment. The reflectors are carefully polished to be flat within 1/20th of the output wavelength and then coated with twelve or thirteen layers of dielectric material. This in effect causes the mirrors to have about 98.9% reflectance at the output wavelength. Alternate coatings of high and low-refractive index material, deposited at a thickness of one-quarter wavelength at the desired frequency, serve to produce very high reflectivity. Part of the light in the tube (about 0.3%) passes through the reflector as useful output.

The energy level diagram relating to the helium-neon laser is shown in Fig. 12 indicating two separate possible energy states for the helium atoms and four distinct bands (including the ground state) for neon atoms.

Helium atoms are excited to states E_2 and E_3 by an external r.f. or d.c. power source. At these levels, of the order of 20 electron volts, they collide with neon atoms raising these to excited states E_4 and E_5 whilst losing their own energy. The states E_4 and E_5 are metastable and on further stimulation the neon atoms radiate in falling from level E_4 to E_6 and from E_5 to E_6. The E_6 level is a terminal level for laser action in neon. The energy levels E_4, E_5 and E_6 in fact consist of a number of very closely spaced discrete levels and emission due to loss of energy between E_4-E_6, and E_5-E_6 could be, theoretically, at any one of a number of frequencies according once again to the formula $h\nu = \Delta E$. However, the two strongest lines of radiation produced are at 6,329 angstroms (visible red) due to E_4-E_6 and 11,530 angstroms (infra-red) due to E_5-E_6. The actual output wavelength from the laser tube may be conveniently selected by the suitable choice of the reflecting coatings of the end mirrors and also by adjusting the spacing between them so that their separation (d) is equal to $\frac{n\lambda}{2}$.

One great advantage of the gas discharge laser is that a continuous mode of operation (as opposed to pulsed operation) is possible (at room temperatures). Only a modest amount of power is required, in the region of 80 to 120 watts. This is generally supplied by a small r.f. generator operating at 27-30 Mc/s connected through a coaxial line to external brass electrodes clamped around the discharge tube. The overall efficiency of this laser is rather low—the coherent light output amounting to only about 10 to 80 milliwatts. However, the spectral purity is far superior to any other type yet produced; line widths of as narrow as one cycle per second have been obtained, although line widths of a few kc/s are more normal. Even so, this is some ten to one hundred times less than that of the ruby crystal laser. The problem encountered in attempting to reduce the band of radiated frequencies is due partly to mechanical vibration, which affects the separation of the reflectors. Variation of the reflector spacing changes the resonant frequency of the cavity and so produces frequency jitter on the output. As will be



A helium-neon gas laser. The r.f. exciter feeds can be seen clamped around the glass tube.

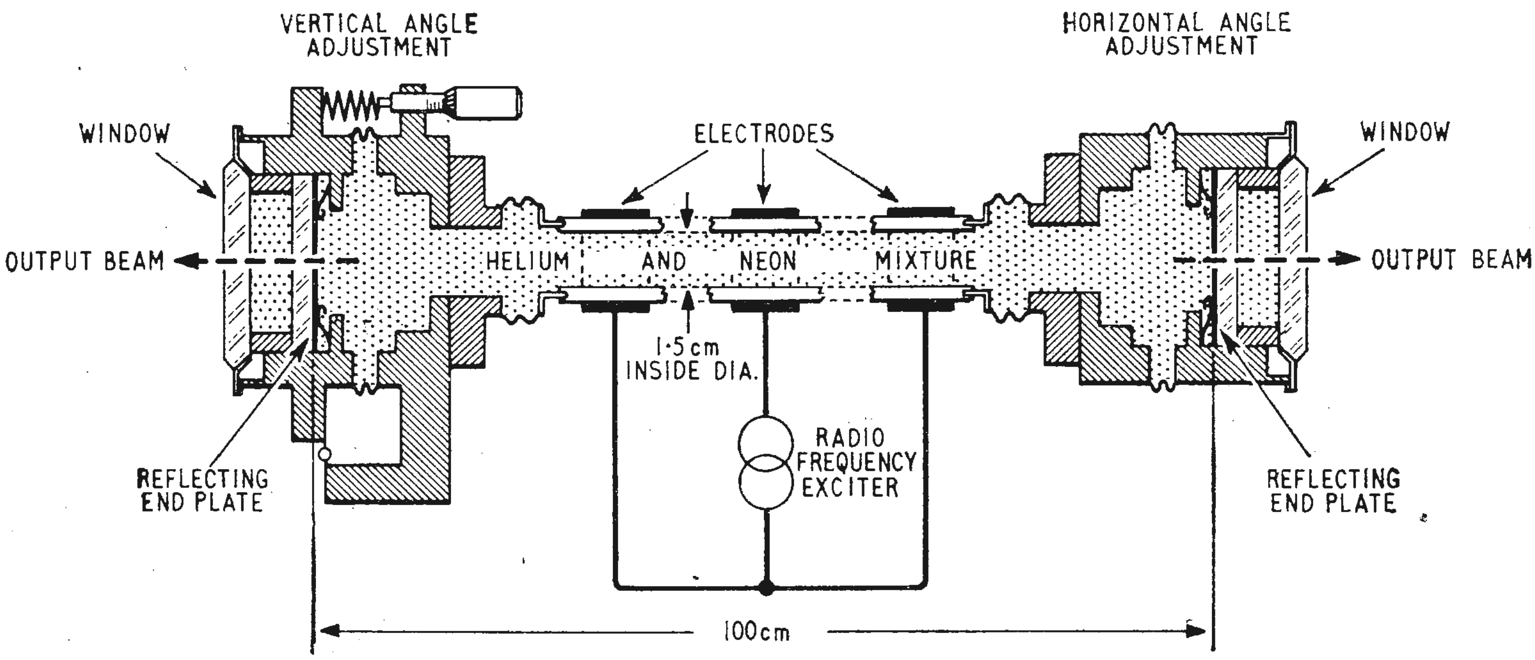


Fig. 11. Section of a gaseous laser (Bell Labs.).

imagined the slightest change in reflector spacing produces quite large variations in output frequency. For example, a movement of about 10^{-8} millimetre will produce a change of about 1000 c/s. Many gas type lasers are mounted on very dense bases to reduce frequency jitter due to vibration effects.

Variations in the separation between the mirrors due to temperature effects will also change the resonant frequency of the cavity and great care is necessary to reduce this to an absolute minimum; invar mountings are used for many of the components. Nevertheless a change in temperature of one quarter of a degree (Centigrade) at a wavelength of 10,000 angstroms in a one metre cavity is sufficient to change the mirror separation by a quarter of a wavelength. This is enough to cause cancellation instead of reinforcement of the waves of the light beam on successive reflection at the mirrors.

A slight variation of the mechanical arrangement as described above is often made in order to ease the mechanical problem of mounting the reflector adjusting mechanism on the body of the discharge tube. The alternative arrangement is shown in Fig. 13; the basic feature being that the reflectors are mounted outside the discharge tube and the light passes from the tube through "Brewster angle" windows. In a medium inclined at this angle the reflected ray is completely plane polarized perpendicular to the plane of incidence. The tangent of this angle is equivalent numerically to the refractive index of the reflecting medium. By the use of this configuration losses due to reflection in one particular plane of polarization are eliminated and the beam passes unattenuated to the reflectors.

With the intention of easing the mirror adjustment problem Godzinski of Breslau University has suggested[6] the use of total internal reflection prisms (Fig. 14). These prisms, which have three mutually perpendicular surfaces have the property of reflecting light rays antiparallelly, that is in the direction from which they are incident, regardless of the orientation of the prism.

With this arrangement the whole laser assembly

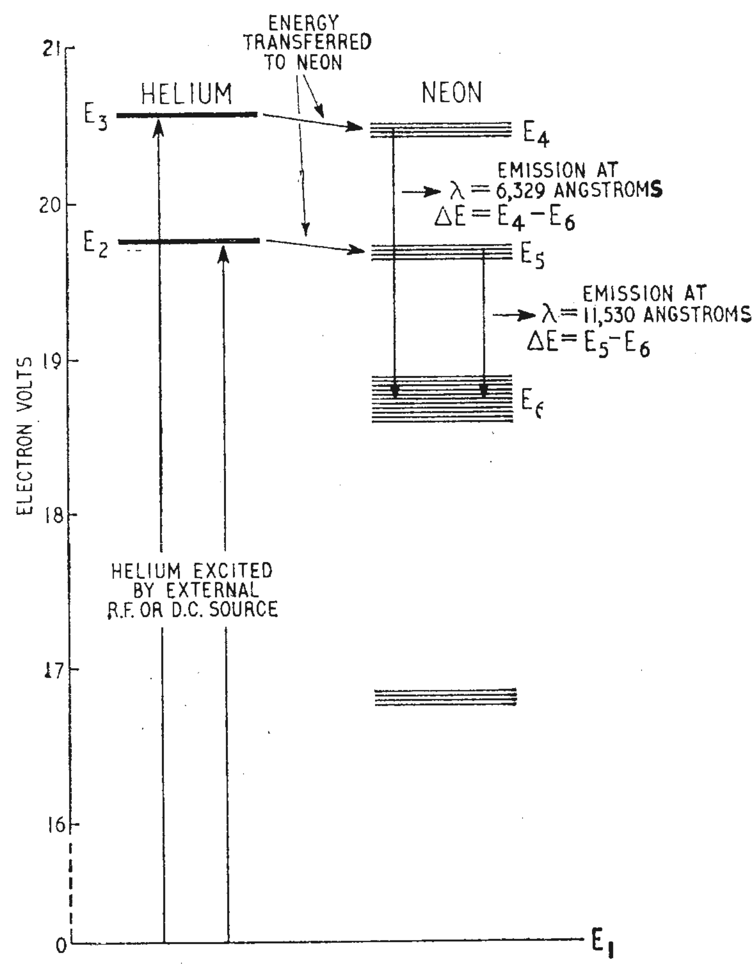


Fig. 12. Energy level diagram for the helium-neon laser.

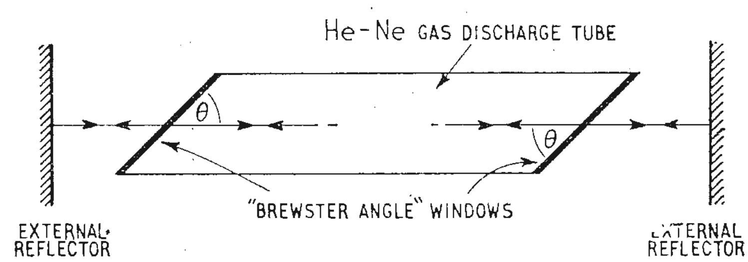


Fig. 13. Gas discharge laser with external reflectors. θ is the Brewster angle.

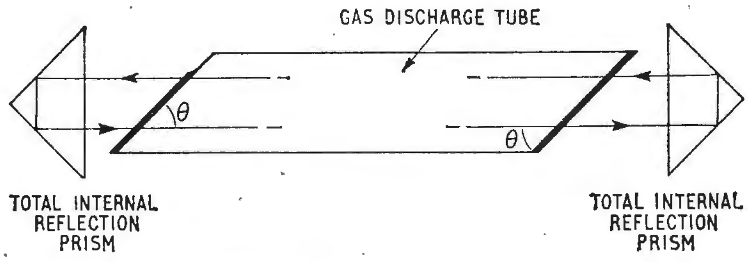


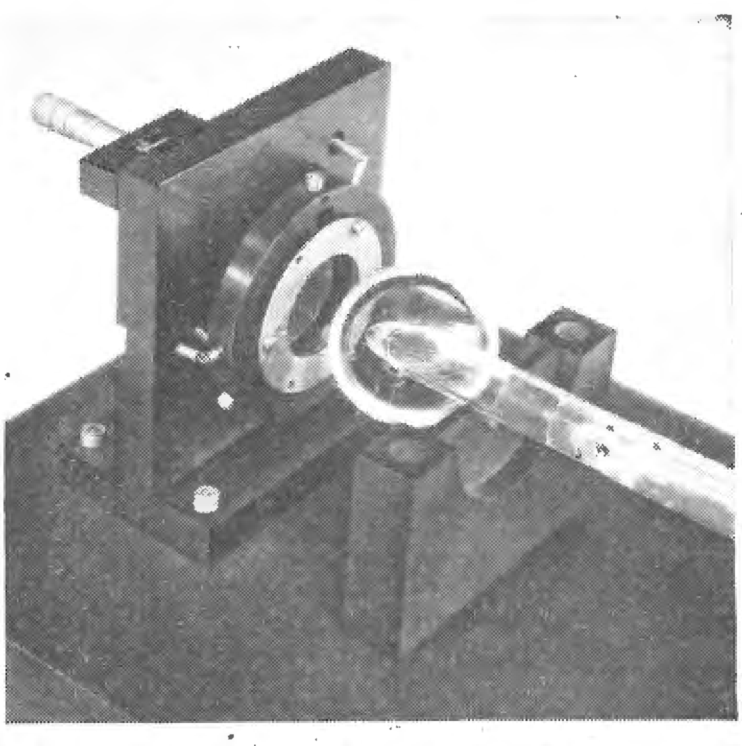
Fig. 14. Antiparallel reflecting prisms simplify alignment.

is greatly simplified as the reflecting surfaces are quite insensitive to alignment discrepancies.

The divergence of the output beam of the gas discharge optical lasers is extremely narrow, only about 1 part in 10,000. Theoretically the beam width could be less than this, but diffraction effects become the limiting factor.

Other gases which produce optical laser action are mixtures of neon-oxygen and argon-oxygen; argon, helium, krypton, neon and xenon by themselves are also suitable active media. One unusual medium, caesium vapour, produces radiation at 71,800 angstroms.

Semiconductor Junctions:—A rather different form of optical maser was developed at about the same time in three different laboratories towards the



End mounting of gaseous laser showing "Brewster angle" window and micrometer screw mirror adjustment.

end of 1962[7]. All three used a gallium arsenide (Ga As) semiconductor crystal. The p-type layer is formed by diffusing zinc into gallium, displacing some of these atoms. Tellurium, which has one more electron than arsenic, is used to dope this substance, replacing some of the arsenic atoms to form the n-type material. Both arsenic and gallium are produced as by-products from various processes and are available in great enough quantities for semiconductor purposes. Gallium at 30°C is a liquid metal (similar to mercury) and in the presence of arsenic vapour at a temperature of 1240°C molten gallium arsenide forms. The liquid is cooled slowly and eventually freezes into a crystalline form.

Although only in the early stages of development many desirable features are already apparent; it is extremely simple in construction and is small in size; it needs low input power; it has high efficiency, and probably most important of all it appears to be easy to modulate.

The construction of a typical Ga As diode laser is shown diagrammatically in Fig. 15. Rectangular in shape, its dimensions are 0.3 × 0.3 × 0.5 mm and it may conveniently be accommodated in a standard transistor case, with a transparent opening. The radiation is emitted co-planar with the junction of the diode; two of the edges of the crystal perpendicular to this plane are polished parallel to form a resonant cavity. No additional coating of these surfaces is required as the polished semiconductor material provides very high reflectance.

The device has been termed an " injection " maser in certain circles because electrons are injected directly into the junction region (a plane less than 0.0001-in thick). This injection process is analagous to the pumping necessary with the two previously described types of optical maser. The high current density at the junction produces a large number of photons which in turn produce stimulated emission.

In order to ensure that light is emitted from a semiconductor junction of this type certain conditions must be fulfilled. The substance must possess a large number of mobile carriers and electrons must be able to move freely between energy levels. These requirements can be fulfilled with various substances apart from gallium arsenide, for example, indium antimonide, indium phosphide and zinc phosphor. However, the former is more convenient to prepare, and is used widely for present experimental purposes.

By positively biasing the p-type material in the diode, holes flow from p to n and electrons from n to p. When a high current is flowing a large number of carriers build up in the n-region close to the junction, and light is emitted.

Great precision must be used in the formation of the junction, to ensure that it provides a smooth and parallel guide for the light which is reflected along it between the polished surfaces.

The output wavelength of the Ga As laser is 8400 angstroms although a more recent development using a gallium-arsenide-phosphide crystal produces radiation anywhere in the region 6200-8400 angstroms by variation of the phosphide content during preparation.

Power requirements for the diode are modest.

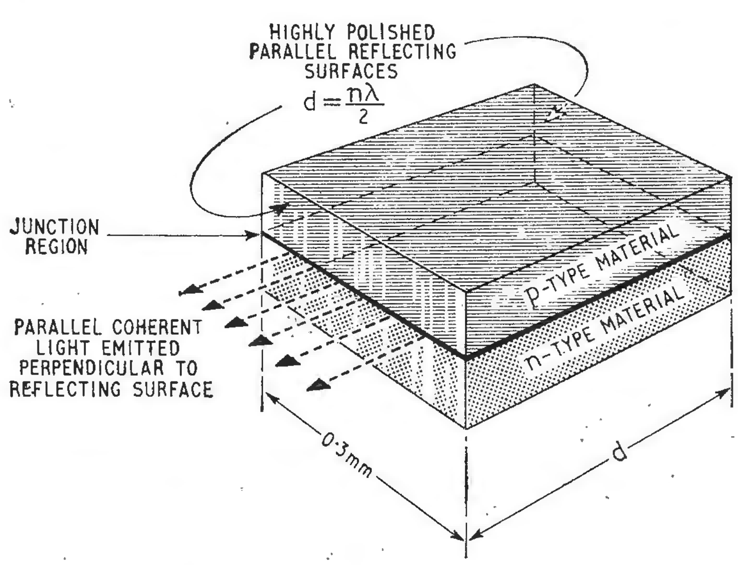


Fig. 15. Gallium arsenide diode laser.

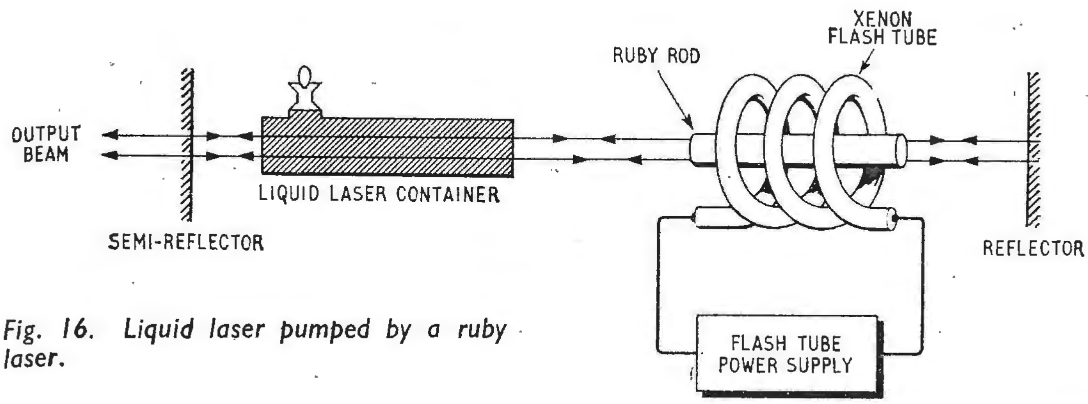


Fig. 16. Liquid laser pumped by a ruby laser.

crystal optical maser.

The schematic arrangement is shown in Fig. 16. The Raman active liquid is contained in a Fabry Perot resonator of dimensions 5 cm. dia. and 5 cm. long. The output beam from the ruby crystal is carefully aligned to concentrate its energy into the liquid resonator. Provided that the input power level from the pumping source is above a certain threshold level (dependant upon the Q of the Fabry-Perot resonator at the Raman scattering frequency) some of the power is absorbed by the liquid.

This power is then reradiated at the operating frequency of the liquid laser in a highly collimated beam.

Using a liquid as an active material proves extremely convenient as the fluid may be continuously circulated through the resonator for cooling purposes and also by simply changing the liquid the output wavelength may be changed—coloured light poured from a bottle, so to speak.

With an input of only 50mW direct current, at a potential of a volt or so, coherent light output of 10-25mW is obtained. Despite the low magnitude of input current the narrowness of the junction region results in very high current densities. For pulsed operation intense currents of up to 20,000 amperes per sq. cm. are applied and liquid helium cooling is required to prevent overheating and the consequent destruction of the device. Further development has produced continuously operating devices with lower current densities, about 100 A/cm^2.

The spectral distribution of the gallium arsenide laser narrows as the current density is increased. At about 1500 A/cm^2, which is below the threshold at which the laser action commences, a line width of about 125 angstroms is obtained, reducing to 3 to 5 angstroms (about 10^{11} c/s) at maximum current densities. The beam width is about 1-2 degrees. Although the Ga As optical maser, compared with the ruby crystal and gas discharge types, is inferior as regards its power output, spectral spread and beam width, it will no doubt be of the utmost importance in the communications field due to its ease of modulation. The d.c. power source is connected in series with the Ga As diode through a suitable modulator. The input to this latter varies the excitation current to the diode which then emits intensity-modulated coherent radiation.

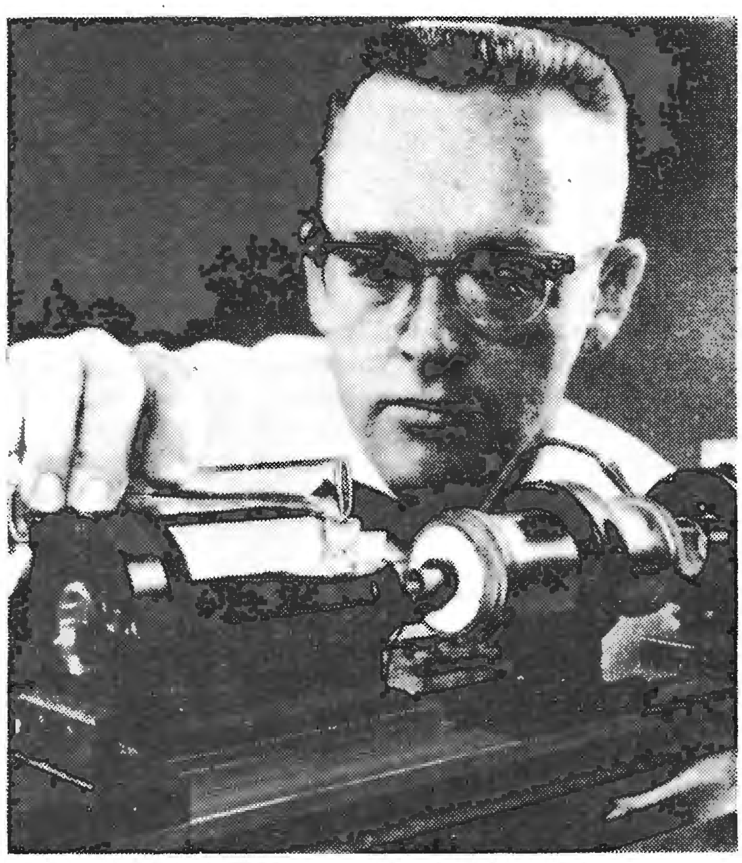
Liquid Lasers:—The most recent type of optical maser to be developed is that using a liquid as an active medium[8]. Advantageous properties are said to be the very narrow spectral width of 0.3 angstroms and the shortest wavelength so far produced—6129 angstroms. Emission at this wavelength has been produced by using europium incorporated in benzolacetonate, which is a liquid organic chelate. Many other organic compounds have been tried, among them benzene, nitrobenzene and toluene giving a dozen or so different wavelengths between 7430 and 9632 angstroms.

The radiation from liquid type lasers is not due directly to emission from atoms changing their energy levels but is caused by the Raman effect. The liquids used in these lasers possess the property of being Raman active, that is, when monochromatic light is directed through them, scattering of the light takes place. It is a particular characteristic of Raman active media that the spectrum of the scattered light contains in addition to the wavelength of the incident light, other fixed lines shifted by a definite and known frequency from that of the excitation source. The amount of shift is a function of both the frequency of the exictation and the scattering medium.

The method of exciting liquid lasers is indirect, normally by the use of a high-power short-pulse ruby

Laser Applications

The number of potential uses for optical masers seems to be very great indeed. Only five years ago it existed only in theory, yet since then laboratory development has indicated applications in a large number of fields—military, space and civilian. It would be difficult to predict at this early stage which of the suggested uses will prove most successful.



The active fluid being poured into a liquid type laser. Coherent light from nozzle of a ruby laser (right) is pumped through the liquid, which provides a kind of optical channel selection, previously possible only at radio frequencies.

Amongst the proposed applications of lasers are the following:

(a) Communications
(b) Radar
(c) High-speed photography
(d) Power transmission
(e) Control of metal machining and drilling
(f) Medical research and surgery
(g) Highly directional lighting beams for aircraft control

Perhaps the field most interesting to readers of this journal is that of communications; apart from terrestrial telephone, television and data transmission channels great promise is seen for inter-satellite and interplanetary communication. Related uses are likely in connection with radar systems, both navigational and for detection and ranging purposes, where the high resolution and extreme accuracy made possible by the very short wavelengths will be of great benefit. Exceptionally compact and highly manoeuvrable aerials are possible at these optical frequencies.

Communications:—Optical maser communications links will have low transmission loss because of the very narrow beam widths possible.

In conflict, however, with this advantage is the attenuation which is caused by normal atmospheric and meteorological disturbances at light frequencies. Cloud, fog, rain and even normal atmospheric turbulence would preclude the establishment of direct line-of-site links between two points on the earth or between earth and some extra-terrestrial body. For earthbound communications it will be necessary to " pipe " the laser beam along tubes or similar structures which have been evacuated. Great care would be necessary to ensure that mechanical instability of the terminal mounting devices would not cause displacement of the beam. A deviation of the beam of less than $\frac{1}{2}$ second of arc would at such frequencies be intolerable.

The standard transmission formula is

$$P_r = \frac{P_t A_r A_t}{\lambda^2 D^2}$$

where P_r = received power, P_t = transmitted power, A_r = receiver aerial aperture, A_t = transmitter aerial aperture, λ = wavelength of transmission, and D = distance between receiving and transmitting aerials From this it will be seen that as the wavelength is reduced the received power increases. Oliver[9] has calculated that a 4 Mc/s bandwidth laser communication channel will be possible with a 40 dB signal-to-noise ratio over a distance of 3,500 miles *without* the necessity of amplifiers en route. Reflectors would be used of course to overcome the effect of the curvature of the earth's surface.

An Electronic Gyroscope:—A method of using an optical maser beam as an angular rate sensor is shown in Fig. 17. A gas discharge laser is mounted on a solid structure together with four high-reflectance mirrors B, C, E and F and one semi-mirror D. Light is emitted from both ends of the gas tube (A), it travels in one direction via mirrors B and C and then through the semi-mirror D to the photomultiplier pick-up tube. In the other direction the light travels through E the semi-mirror D and is then totally reflected by the mirror F returning to D where it is reflected into the photomultiplier simultaneously with the other beam.

With the device at rest the two input beams to the photomultiplier are of the same and constant frequency, the beat frequency produced between them therefore is zero. If the device is rotated then the beams of light, which differ in path length by the dimension d, will be of different frequency on arrival at the photomultiplier.

Due to the fact that the beam travelling in the same direction as the rotation of the assembly moves through an increased distance, its frequency is lowered. The beam passing in the opposite direction travels a shorter distance and its frequency increases. This is a simple manifestation of the Doppler effect. The two beams are optically heterodyned at the photodetector, and the beat frequency so produced is a measure of the angular velocity of the assembly.

The shift in frequency (Δf) due to rotation is given by:

$$\Delta f = \frac{K\omega d}{\lambda}$$

where ω = the angular rotation,
d = dimension between mirrors,
λ = the wavelength of the light and
K is a constant of proportionality.

Thus by detecting and measuring the beat produced between the difference frequencies the rate of rotation of the device may be determined. There are advantages in using such apparatus as a form of electronic gyroscope. Present-day rate-sensing gyroscopes have sensitivities of between 0.01 and 0.1 degrees per hour. By using the device as just described, with an optical maser of stability of 0.01 cycles per second, a gyroscope could be produced some ten to one hundred times more sensitive. Further advantageous features are that the output of the photomultiplier may be processed in a digital form by counting the beat frequency; the output of conventional gyros is normally of analogue form. It is possible not only to obtain an instantaneous reading of angular velocity but also of absolute angular displacement. The sensitivity of the optical maser gyroscope is a function of the dimensions of the

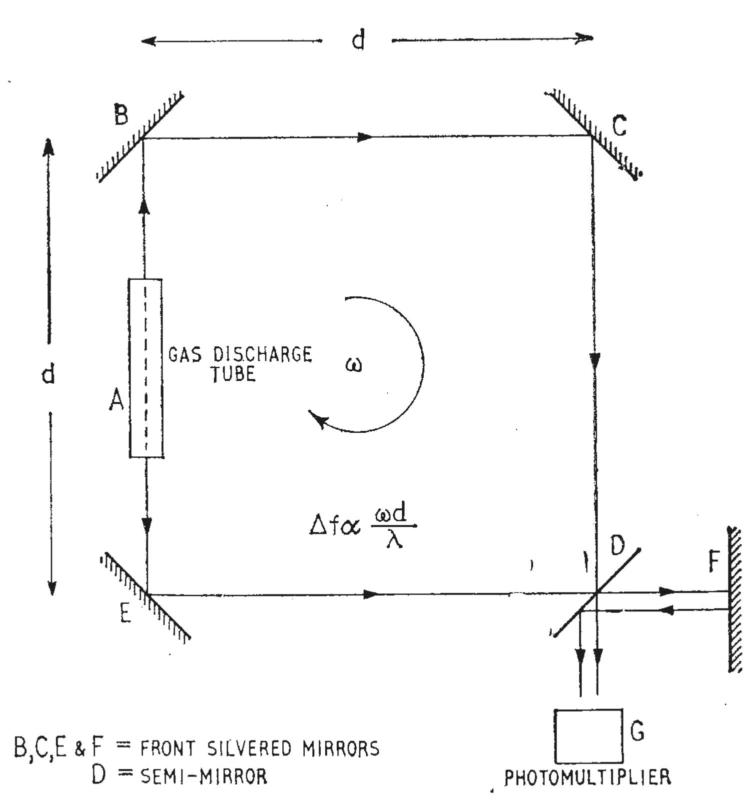


Fig. 17. Optical maser used as a rotational rate sensor.

apparatus as opposed to mass which is the case with mechanical gyros. Thus the former is unaffected by acceleration and gravitational forces. Finally, as there are no bearings or other mechanical moving parts, construction is greatly simplified.

Precision Metrology:—It is a well-known practice to use a light beam in an interferometer for the accurate measurement of extremely small dimensions. The principle involved is that of detecting the interference between direct and reflected beams of light originating from the same source; a variation in the reflected path length by only a fraction of a wavelength gives a change in the interference pattern. The great limitation with interferometers is that the coherence length (the distance over which the light remains in phase) of the light sources used is only about 10 cm. By contrast, the coherence length of the light from an optical maser is measured in miles.

The use of an interferometer with an optical maser light source for the measurement and control of the workpiece in a metalworking lathe is shown in Fig. 18. A beam from the coherent source A passes through the semi-reflecting mirror B to the workpiece D, it is reflected back to B and thence through an aperture E to the sensing device F. Some of the light from the source is reflected from the semi-mirror B on to the front surface mirror C. From here it is reflected back through the semi-mirror and through the same aperture to the detector. At this point optical interference between the two beams occurs, and any change in the dimension between the reference and the surface of the work results in a change of the interference pattern.

By basing the reference of the detector to the centre line of the workpiece, extremely precise measurements can be made of the profile of the work even while the piece is being turned. The measurements so obtained would be completely unaffected by tool wear, alignment discrepancies and other inaccuracies of the machine.

Conclusions

A tremendous amount of work is at present being carried out in many laboratories on the development of new and improved optical masers. Very intensive effort is being expended in the U.S., to a lesser extent in this country and also in the U.S.S.R. A recent report[10] on work geing carried out in the U.S.S.R. quotes twenty-four Soviet papers on the subject.

As indicated previously the range of applications to which optical masers may be put is enormous and we are no doubt only on the threshold of this new field of quantum electronics. There are many fields to explore; perhaps the most important are those concerned with modulation and demodulation processes, larger power outputs, higher efficiencies and also methods of tuning the devices to obtain a greater range of nominal frequency.

A technique which is being studied as a means of increasing the peak power output of pulsed optical masers is that known as Q-switching. This is done by temporarily removing one of the end reflectors from the resonant cavity (thus lowering the Q) which allows a concentration of energy to build up in the crystal. When the end reflector assumes its normal position, the high-Q condition is restored, the laser operates and gives a very intense burst of coherent light. Peak powers of up to 2 MW have been obtained.

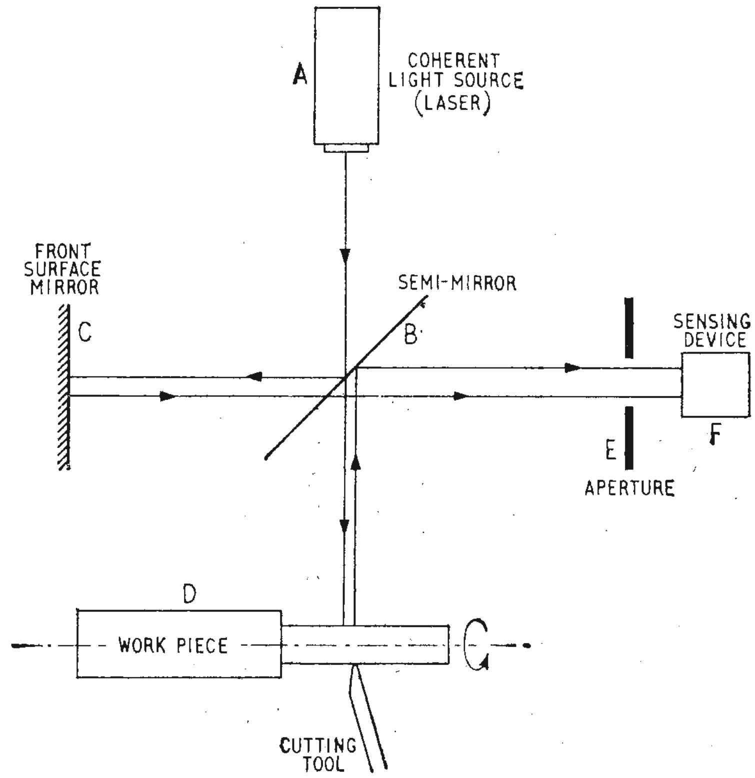


Fig. 18. Use of laser as light source for precision metrology.

At the moment only a limited number of basic frequencies in the complete visible and infra-red ban can be generated. It would obviously be of tremendous value if the " gaps " could be filled in, and any desired frequency obtained by some form of tuning.

As has been mentioned the GaAs type may operate at varying frequencies by the addition of specific amounts of phosphide as a further doping agent: this is not an entirely satisfactory arrangement as the amount of phosphide incorporated must be settled at the time of manufacture. Apart from thermal tuning it appears to be possible to produce other output wavelengths by harmonic multiplication and heterodyning. For example the second harmonic of a ruby crystal laser would give a wavelength of 3,472 angstroms, in the ultra-violet; by the addition of the outputs of the ruby laser (6,943 angstroms) and a glass-neodymium type (10,630 angstroms) a wavelength of 4,200 angstroms could be produced.

Acknowledgements:—Grateful thanks are due to the following organizations for their help in supplying information used in the preparation of this paper: the Raytheon Company, General Electric (U.S.), Sperry Gyroscope Company (U.S.) and Bell Telephone Laboratories.

REFERENCES

6 Z. Godzinski: " Application of Total Internal Reflection Prisms for Gaseous Lasers." *Proc. I.R.E.*, Vol. 51, No. 2, p. 361, Feb. 1963.

7 R. N. Hall, G. E. Fenner, J. D. Kingsley, T. J. Soltys & R. O. Carlson: "Coherent Light Emission from Gas Junctions", *Phys. Rev. Lett.* Nov. 1st 1962.

8 E. J. Woodbury: " Raman Laser Action in Organic Liquids " *Proceedings of the Third Conference on Quantum Electronics* (Paris), February 1963.

9 B. M. Oliver: " Some Potentialities of Optical Masers" *Proc. I.R.E.*, Vol. 50, No. 2, p. 135, Feb. 1962.

10 S. Kassel: " Soviet Laser Research " *Proc. I.R.E.*, Vol. 51, No. 1, pp. 216-218, Jan. 1963.

RECEIVING SECAM

TECHNIQUES OF DECODING

By M. COX,* B.Sc.(Eng.)

A few years ago, a novel colour television system was demonstrated by engineers of the Compagnie Française de Télévision to an audience in London; the pictures originating in Paris. This system, called the SECAM system, was invented by M. Henri de France, and with Gallic logic the name is short for "*SEQ*uence *A M*émoire". The basic premise of the system is that only one piece of colour information is transmitted at any instant; and in fact, the two necessary pieces of information are transmitted on alternate lines on a subcarrier. At the receiver these may be obtained simultaneously by means of a storage or delay line of delay time equal to the line period of the television system. The original system used amplitude modulation of the subcarrier, but the need of a large-amplitude subcarrier to cope with the negative peaks of the modulating colour difference signals made the compatibility of the system poor, coupled with the necessity of maintaining the unmodulated subcarrier amplitude constant to one per cent. Accordingly, frequency modulation of the subcarrier is now employed, with all the advantages of f.m. operation, such as insensitivity to phase distortion, and amplitude/frequency distortion. The present version of the system has been evolved with the co-operation of broadcasting organizations in Europe and will now be considered in some detail.

Encoding of the Signal

The gamma-corrected primary signals are matrixed exactly as for the N.T.S.C. system to form the luminance signal and the two colour difference signals.

$$E'_Y = 0.30\ E'_R + 0.59\ E'_G + 0.11\ E'_B$$

where E'_R, E'_G and E'_B are the gamma-corrected primary colour signals.

The transmitted colour difference signals are:

$$(E'_R - E'_Y)$$
$$(E'_B - E'_Y)$$

and in the receiver, a green colour difference signal $(E'_G - E'_Y)$ is obtained from the relation:—

$$0.59\ (E'_G - E'_Y) = -0.30\ (E'_R - E'_Y) - 0.11\ (E'_B - E'_Y).$$

By adding E'_Y to the three colour signals, the original E'_R, E'_G and E'_B signals are obtained.

The two colour difference signals are used to frequency-modulate the subcarrier in a line alternation sequence such that line 1 will be modulated by $(E'_R - E'_Y)$, line 2 by $(E'_B - E'_Y)$ and line 3 by $(E'_R - E'_Y)$ again and so on. In practice, to reduce visibility of luminance components in the region of the subcarrier frequency, the colour difference signal $(E'_Y - E'_R)$ is transmitted. This merely involves reversing the polarity of the $(E'_R - E'_Y)$ signal before the sequential switching process.

After switching line by line, the colour difference signals are band-limited to approximately 1.5 Mc/s, and undergo pre-emphasis of the form shown in Fig. 1 such that the response at h.f. is increased compared with the response at l.f. The signal is then amplitude-limited and clamped to establish a black level before going into the modulator. The modulator has an undeviated frequency of 284 times the line frequency, which is 7.8125 kc/s higher than the N.T.S.C. subcarrier frequency of 4.4296875 Mc/s. A phase discriminator is used to compare the undeviated carrier frequency with the local reference frequency. The deviation used is ±350 kc/s for 75% amplitude, 100% saturation colour bars, with a peak deviation of ±750 kc/s due to the pre-emphasis mentioned above, and such that positive signals increase subcarrier frequency.

In order to achieve good compatibility, it is necessary to break up the dot pattern produced by the subcarrier. This can be achieved by reversing the phase of the subcarrier for one line in every three, and also every other field. This breaks up the pattern to the extent that SECAM is as compatible as N.T.S.C. After phase switching, the subcarrier signal is band- and amplitude-limited before being

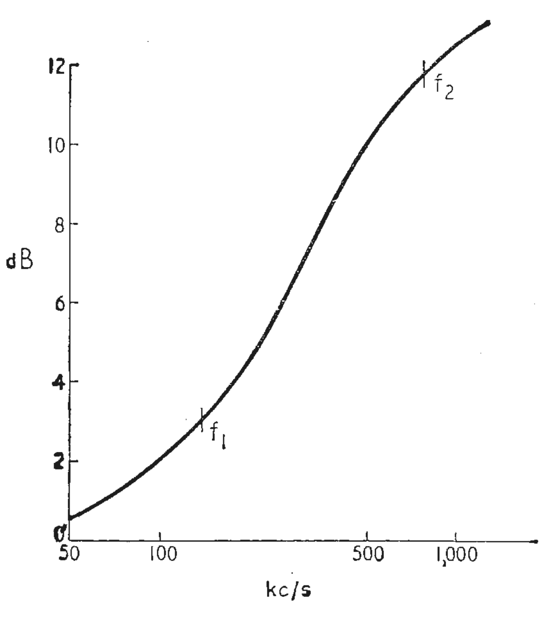


Fig. 1. Colour-difference pre-emphasis characteristic, f_1 and f_2 are inflexion points of filter.

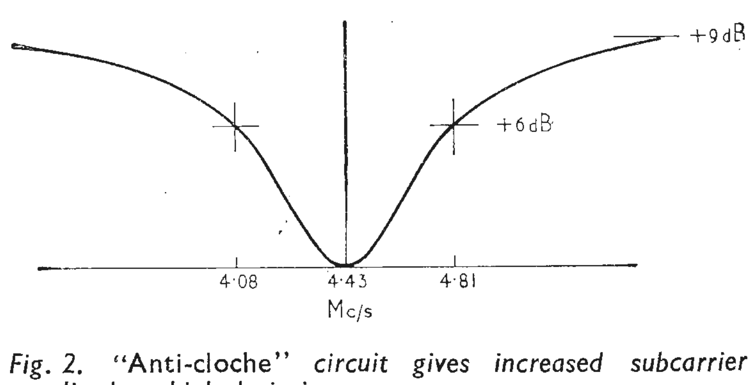


Fig. 2. "Anti-cloche" circuit gives increased subcarrier amplitude at high deviations.

* A.B.C. Television Ltd.

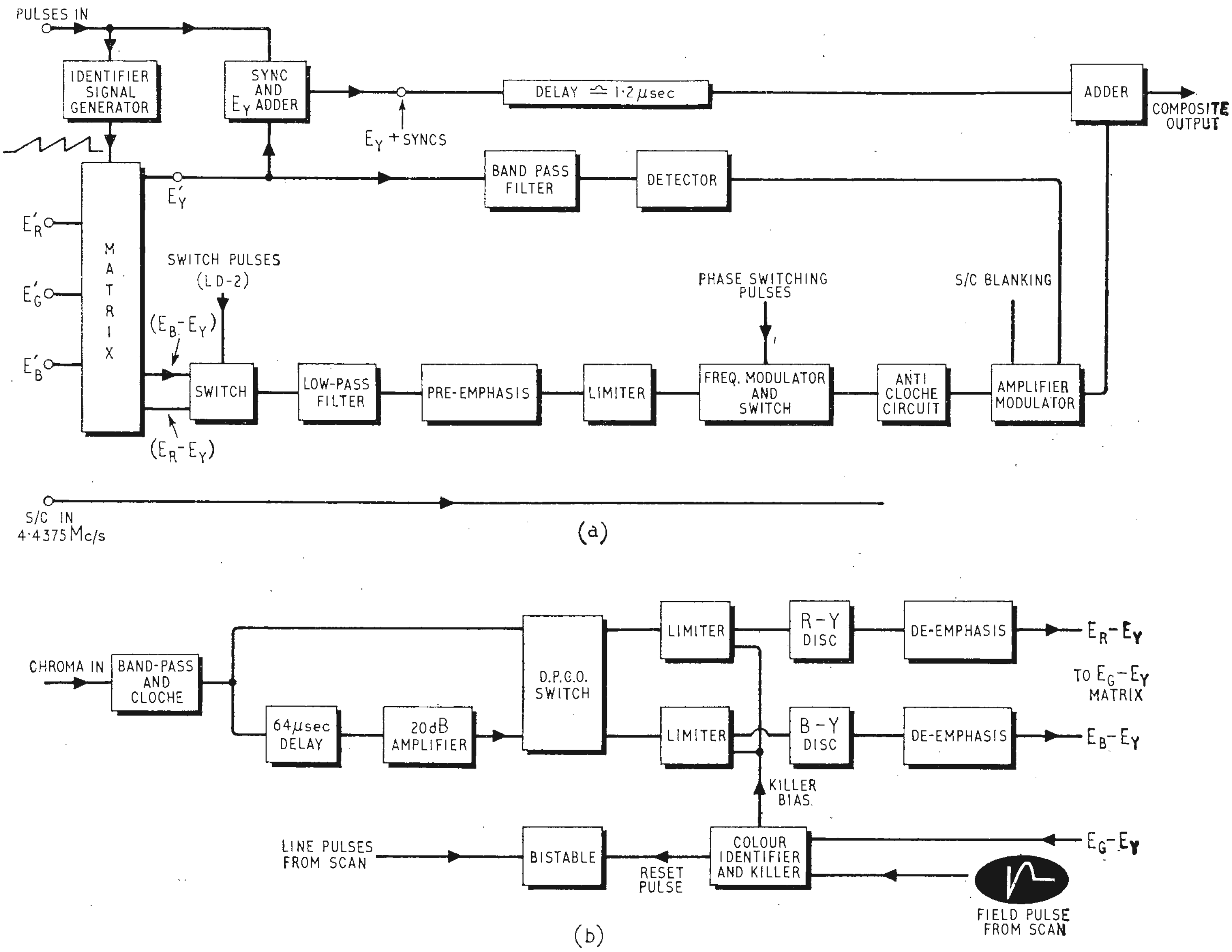


Fig. 3(a). Block diagram of SECAM encoder. (b). SECAM decoder.

amplitude-modulated to reduce " Cross Colour ", that is components of luminance within the subcarrier or chroma pass band which give spurious colour components in the output of the discriminators in the receiver. If during the presence of such a component the subcarrier level is increased, the " capture " effect in frequency modulation ensures that only the subcarrier produces any output from the discriminator and the luminance or " Cross Colour " component is suppressed. The modulating signal is derived by passing luminance signals through a chroma band-pass filter. The output consists only of luminance components within the chroma pass band. These components are rectified and filtered and the resulting envelope used to amplitude modulate the subcarrier. The order of increase of subcarrier amplitude is 6dB. It is interesting to note that no such " Cross Colour " reduction is possible with the N.T.S.C. system.

Yet another form of modification is applied to the subcarrier before it is added to the luminance signal. In order to achieve compatibility a subcarrier amplitude of only 0.14V for a video signal of 0.7V (less synchronizing signals) is added to the luminance signal, but this amplitude is not sufficient to give good noise immunity for wide deviations, that is for saturated colours. A shaping circuit, picturesquely called the "*anti-cloche*" or "*mise en forme*", increases the subcarrier amplitude as the deviation increases and the law is that for ±350 kc/s deviation either side of 4.43 Mc/s, the subcarrier amplitude increases by 6dB, rising to a maximum increase of 10dB for ±750 kc/s deviation. Fig. 2 shows this characteristic.

It now remains to blank the subcarrier before adding it to the composite luminance signal. Because of the lower bandwidth of the chroma circuits, there is a time delay through them and the luminance signal must be delayed by this amount before the subcarrier is added.

Before leaving the encoding side of the system, a word must be said about the synchronization of the line switching sequence. An identification signal is transmitted during the vertical blanking interval on lines 11-15 or 324-328 and consists of modulated subcarrier, but no corresponding luminance signal. The modulation of the subcarrier consists of a positive-going sawtooth signal during the line when blue difference is normally transmitted, and a negative-going sawtooth signal when red difference is normally transmitted. The use of this signal will be apparent later.

Fig. 3 shows the block diagram of a complete SECAM encoder, as is used in the assessment of the relative merits of SECAM and N.T.S.C. for a European colour system.

Decoding

Of more immediate practical interest to the amateur is the receiver. It is proposed only to deal with the SECAM decoding circuits, that is, circuits to deliver a volt or so of $(E_R - E_Y)$ and $(E_B - E_Y)$.

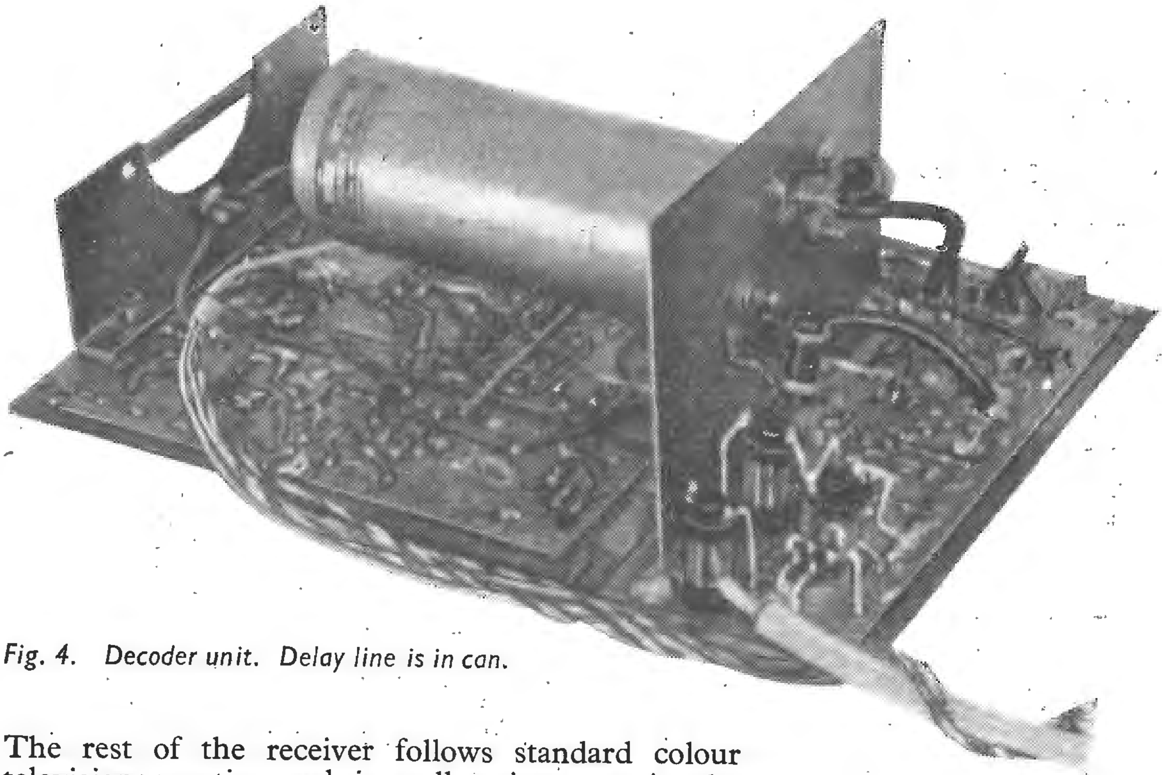


Fig. 4. Decoder unit. Delay line is in can.

The rest of the receiver follows standard colour television practice and is well written up in the literature.

A low-level composite signal is taken from the detector or first video stage of the receiver, and passes through a band-pass filter, pass band 4.43 Mc/s ± 1 Mc/s. The subcarrier signal is now subjected to the inverse of the "*mise en forme*" characteristic; this time called the "*cloche*" circuit.

After this, the subcarrier is divided into two paths. One feeds one input of a commutating diode switch, while the other path includes a 64 μS ultrasonic delay line and an amplifier to make up the loss in the delay line, terminating at the other input of the switch.

The ultrasonic delay line is an extremely simple device—a slab of quartz or glass and two transducers—usually barium titanate. Originally the lines used internal reflections in the quartz but latest developments use a straight rod with a transducer at either end. The size is some 6 inches long and $\frac{3}{4}$ inch square; the bandwidth of the line is 4.43 $\pm$ 1 Mc/s and the insertion loss 20dB between 50-ohm terminations. Development work is proceeding in many countries with a view to reducing the price of the line, which is now quoted at about £2 10s each in quantity. Fig. 4 shows a "*chroma platine*" as these decoding modules are called; the aluminium can is an early line by Quartz et Silice. The amplifier used to make up the insertion loss of the delay line consists of a grounded-emitter transistor amplifier and is consequently simple and reliable.

Consider how the direct and delayed paths are used to ensure that despite transmission of colour difference signals in sequence, they become available simultaneously at the decoder output, although the vertical resolution in *colour* is approximately halved. During the second active line, suppose that $(E'_R-E'_Y)$ is being transmitted, then by definition of the line sequence, the previous line was an $(E'_B-E'_Y)$ line. Then during line 2, $(E'_B-E'_Y)$ is emerging from the 1-line delay line. Hence at the inputs to the commutating switch, the two difference signals are present together. During the third line, $(E'_B-E'_Y)$ is being transmitted, and $(E'_R-E'_Y)$ is emerging from the line.

By operating the commutating switch at the end of every line during blanking time, each colour difference signal is fed to its appropriate limiter and discriminator. The switch is driven by a bi-stable circuit which is triggered by pulses from the receiver line time base.

Some 20 to 40dB of limiting is used on the sub-carrier signal before the discriminator, which is usually of the Travis type. Each discriminator uses germanium diodes, and is tuned to give zero output at 4.43 Mc/s, with the peaks at least 1 Mc/s either side of this. The output from the discriminator is of the order of 1 volt peak to peak.

It remains only to consider the circuit that resets the commutating switch to the correct sequence. The identification signal transmitted during the vertical interval has opposite polarity on $(E'_R-E'_Y)$ lines to that on $(E'_B-E'_Y)$ lines. Thus, should the receiver switch connect the $(E'_B-E'_Y)$ signal to the $(E'_R-E'_Y)$ discriminator, the polarity of the output during the identification period will change. This is made to operate a reset circuit, and a colour killer circuit if no identification signal is present. It is necessary to gate out the identification signal, and this is simply achieved by using the vertical flyback to ring a tuned circuit. The first peak of the ring provides the gating pulse, some 10 lines after the start of vertical synchronization. Fig. 5(a) shows the identification signal, and Fig. 5(b) the gating signals.

The gating signal and the signal from one discriminator are added together, and applied to the free base of a Schmitt trigger circuit. The bias on the Schmitt is adjusted so that the device turns over during the negative peak of the gating signal and back on the positive overswing. The output is a negative

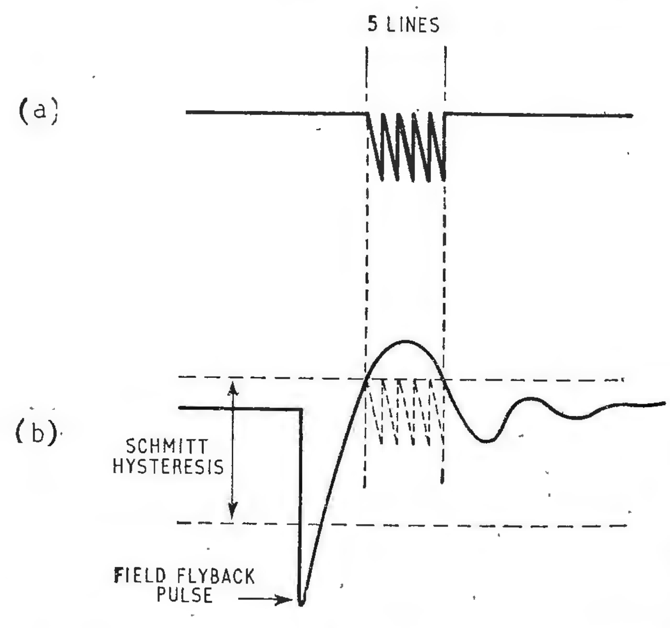


Fig. 5(a). Sawtooth identification signals after detection. (b). Composite signal applied to Schmitt trigger.

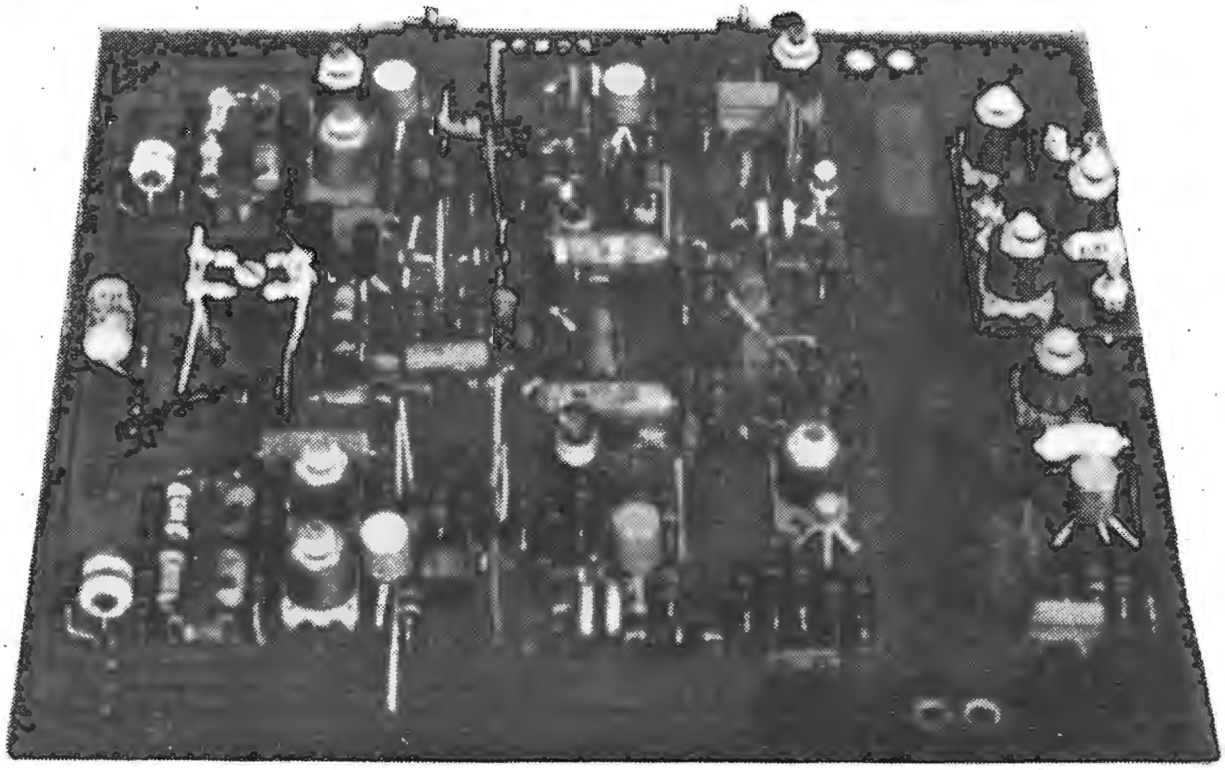
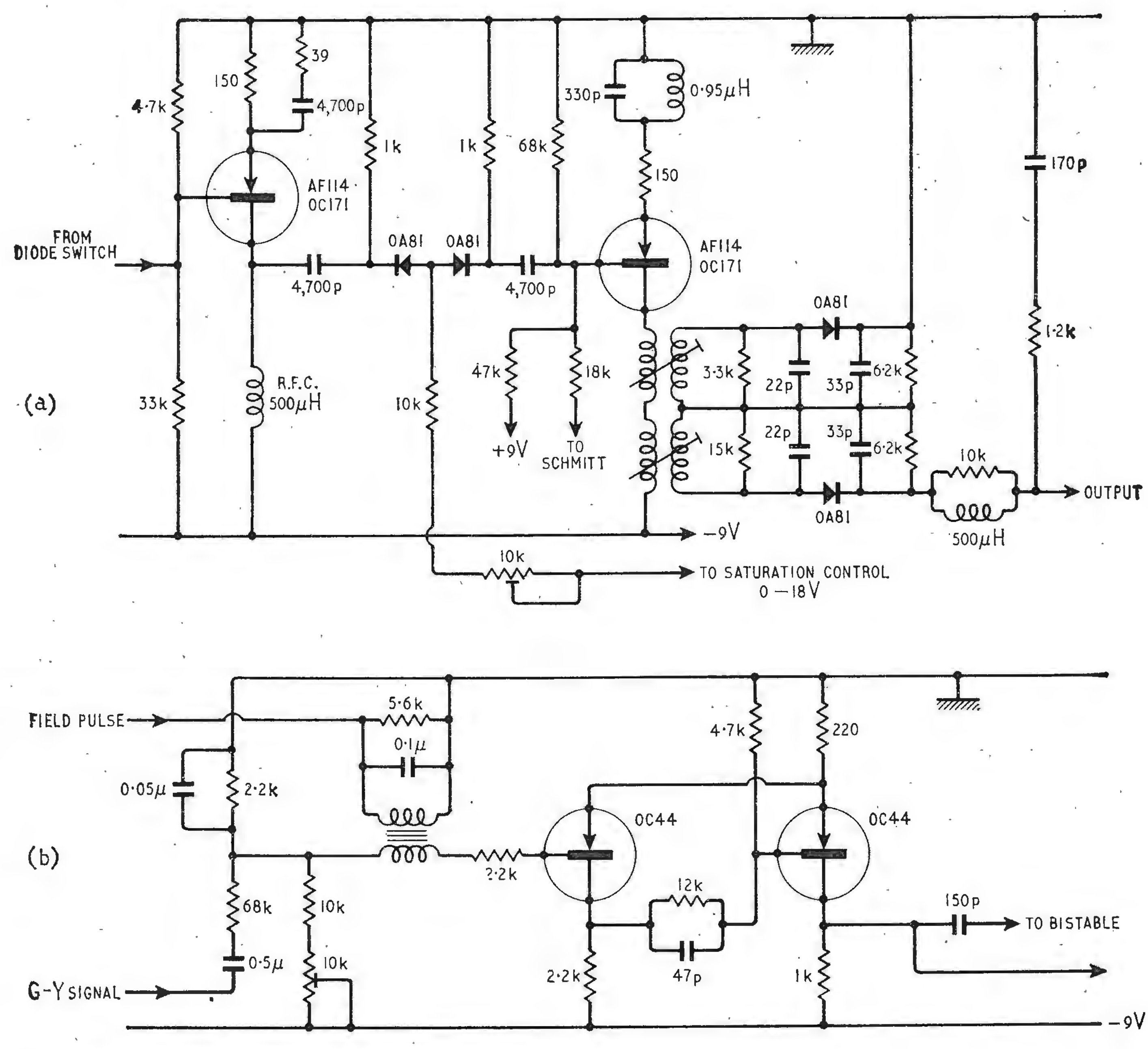


Fig. 6. Latest type of decoder.

Fig. 7(a). Circuit of limiter and discriminator. (b) Sync. trigger stage and colour killer.



pulse of duration approximately that of vertical blanking. If the identification signal is negative going, it prevents the Schmitt turning back after the negative part of the gating pulse. The potential at the output of the Schmitt remains negative, and this negative potential biases on the transistors feeding the discriminators. If, however, there is no identification signal, the Schmitt produces a negative pulse at its output, which turns on the discriminators during the vertical interval but off during the active field time. If the identification signal is positive, then the Schmitt produces its negative pulse, and the trailing edge of this pulse is passed to the bi-stable toggle which drives the commutating switch. This extra pulse switches the bi-stable over and sets the phase sequence right. On the next field, the identification signal will now be positive and the Schmidt will give a continuous negative potential output which will turn on the discriminators, and produce a coloured picture.

The description may make a SECAM receiver sound rather complicated, but the latest version of "*platine*" shown in Fig. 6, has only 11 transistors of the OC171 and OC44 type and some general-purpose crystal diodes. Fig. 7(a) shows the circuit of a limiter and discriminator, while Fig. 7(b) shows the circuit of the Schmitt identification and colour killer circuit. Fig. 8 shows the circuit of the commutating switch and bi-stable circuit, and Fig. 9 the circuit of a band-pass filter with a bandwidth of 2 Mc/s and a centre frequency of 4.43 Mc/s.

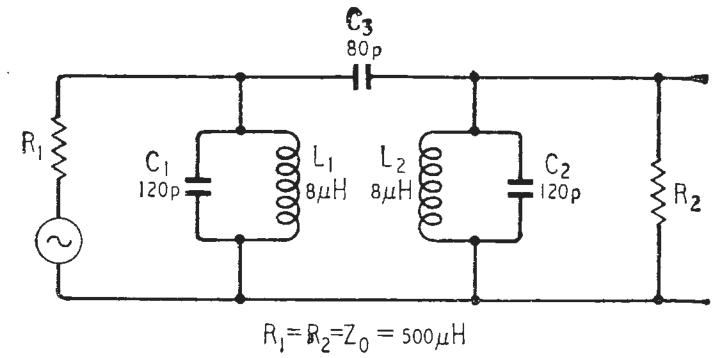


Fig. 9. Band-pass filter to give 2 Mc/s pass-band at 4.43 Mc/s.

The SECAM system is capable of giving extremely good colour pictures, and has the merit of being insensitive to differential gain and phase distortions in the transmission path. This means that standard monochrome inter-city links, transmitters and video tape machines may be used with little or no modification. Despite the apparent complication of the delay line, the receiver is a simple one, using standard techniques and the lay viewer should find it easy to tune in a good colour picture under home conditions.

This system is now under very active investigation, along with the N.T.S.C. and PAL systems, by the European Broadcasting Union who are to recommend a colour system to the C.C.I.R. for use in Europe.

Grateful thanks are extended to M. Henri Peyroles, Directeur General of C.F.T., Paris, for permission to describe the system and circuitry, to the Directors of ABC Television Limited for permission to publish this article and Mr. G. Tye for the photographs reproduced in figures 4 and 6.

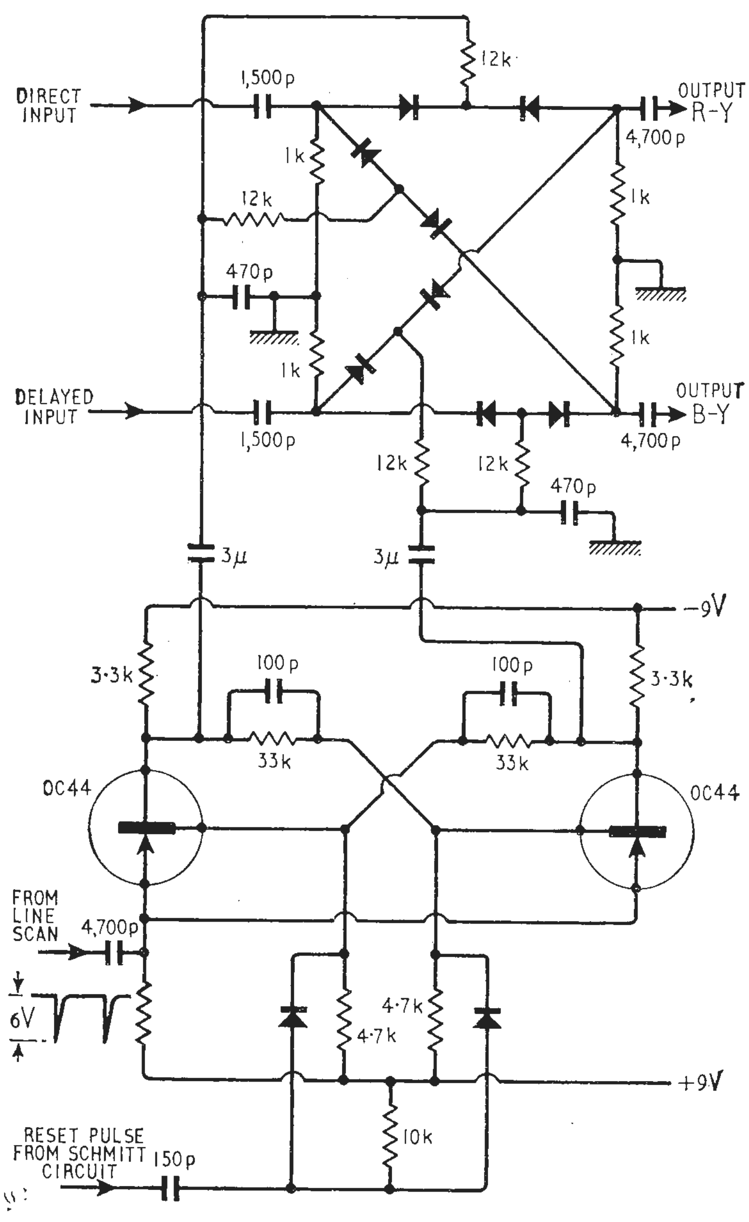


Fig. 8. Bi-stable toggle driving commutator.

CLUB NEWS

Bournemouth.—The Wessex Amateur Radio Group, which was formed last year after the dissolution of the Bournemouth Amateur Radio Society, meets each month at the "Cricketer's Arms", Windham Road, Bournemouth. At the next meeting, on September 2nd at 8.0, G. J. Fowle will speak on building communications receivers.

Dorking.—"Electrolytics" is the title of the talk to be given by S. T. Baker (G2FTB) at the September 24th meeting of the Dorking & District Radio Society at 8.0 at the Star & Garter, Dorking. The club's station G3CZU will be operated at the Model Railways and Engineering Exhibition in the town on October 3rd, 4th and 5th where members are to stage a display of equipment.

Edinburgh.—The 1963/64 session of the Lothian's Radio Society starts on 12th September with a meeting at 7.30 in the Y.M.C.A., South Saint Andrew Street, Edinburgh. Meetings are to be held on the 2nd and 4th Thursdays of each month.

Halifax.—At the September 25th meeting of the Northern Heights Amateur Radio Society K. Walton (G3IKS) will give a lecture on "Lightning—its nature and effects." The club meets on alternate Wednesdays at 7.30 at the Sportsman Inn, Ogden.

Loughton.—The recently formed Loughton & District Radio Club meets on alternate Fridays at 7.30 at the Loughton Community Centre, Debden, Essex. The next meeting is on September 6th.

The **National Mobile Rally,** organized by the R.S.G.B., will be held at Woburn Abbey, Bletchley, Bucks, on September 22nd. Talk-in station GB3RS will operate on 2 and 160 metres.

Industry Forum

NINE associations* representing manufacturers in the radio and electronics industry have jointly formed an organization to provide a forum for the discussion of common problems. It is to be known as the Conference of the Electronics Industry. So that the voice of the organization may be authoritative the members "have been chosen from the highest ranks of the electronics industry". The individual associations will continue to represent their members' interests in their own particular spheres.

The members of the Conference, and the companies they represent, are: G. S. C. Lucas (A.E.I.); John A. Clark (A.T. & E.); R. M. A. Jones (E. K. Cole); Gp. Capt. E. Fennessy (Decca); Sir Joseph Lockwood (E.M.I.); Sir Leon Bagrit (Elliott-Automation); Sir Gordon Radley (English Electric); S. Z. de Ferranti (Ferranti); O. W. Humphreys (G.E.C.); Sir Edward Playfair (I.C.T.); F. N. Sutherland (Marconi's); S. S. Eriks (Mullard); M. W. Clark (Plessey); C. O. Stanley (Pye); Dudley Saward (Rank); Paul Adorian (Redifon); F. C. Wright (S.T.C.); Jules Thorn (Thorn Electrical).

At its inaugural meeting on July 15th O. W. Humphreys was elected acting chairman. Capt. R. A. Villiers, director of the Scientific Instrument Manufacturers' Association, 20 Peel Street, London, W.8, will act as secretary of the Conference pending the setting up of a permanent secretariat.

* British Electrical & Allied Manufacturers' Association.
British Radio Equipment Manufacturers' Association.
British Radio Valve Manufacturers' Association.
Electronic Engineering Association.
Electronic Valve & Semi-conductor Manufacturers' Association.
Radio & Electronic Component Manufacturers' Federation.
Scientific Instrument Manufacturers' Association.
Society of British Aircraft Constructors.
Telecommunication Engineering & Manufacturing Association.

Television Patent Action

IN a reserved judgment given on 18th July by Mr. Justice Lloyd Jacob in the High Court of Justice, Chancery Division, the claim by John D. Burke, of Hornchurch, Essex, that Thorn Electrical Industries Ltd. had infringed his patent 877,450 was dismissed with costs.

Mr. Burke's patent covers the control of heater current in the e.h.t. rectifier by the c.r.t. beam current to compensate for cathode temperature variations in the rectifier due to the varying anode current. It was held that the impedance of the inductance used in the e.h.t. heater circuit in some Ferguson and Ultra sets to compensate for change of frequency when switching from one line standard to another was not conditioned by the state of, or changes in the current through the rectifier.

Syncom II

AFTER the abortive attempt to put Syncom I into a synchronous orbit its twin Syncom II was successfully launched on July 26th. The drum-shaped satellite, designed and built by the Hughes Aircraft Company, is 28in in diameter, 15½in deep and weighs 79lb. It is in a circular orbit, approx. 22,300 miles from the earth, and is being stabilized over the Atlantic. Syncom II, which is controlled from the *U.S.N.S. Kingsport* anchored off Lagos, Nigeria, has two travelling-wave tube transmitters each having an output of 2 watts and operating around 1800 Mc/s. In addition it carries a 1.25-watt telemetering transmitter working in the region of 136 Mc/s.

London's Radio Tower, which has reached a height of some 500ft, stands out above the surrounding buildings in this view taken from the roof of the Shell Centre on the South Bank. The cost of the 600ft tower, which will be the focal point for the G.P.O's radio links, is estimated to be £1.25M.

"**Physical Society Exhibition**".—The 1964 exhibition of scientific instruments and apparatus organized by the Institute of Physics and Physical Society will again be held in the halls of the Royal Horticultural Society, London, S.W.1, from 6th-9th January. The organizers announce that it is planned to hold the 1965 exhibition in Manchester early in April.

Instrumentation Symposium.—The Third International Flight Test Instrumentation Symposium will be held at the College of Aeronautics, Cranfield, from 13th-16th April next year. Further details are obtainable from M. A. Perry, at the College of Aeronautics.

Jamaica's commercial television service, operating on 625 lines (6 Mc/s bandwidth) came into operation on 5th August. The Jamaican government granted an exclusive television franchise to the Jamaican Broadcasting Corporation earlier this year, who in turn appointed an Anglo-American consortium of companies to be managing agents. The consortium comprises Thomson Television International (U.K.), National Broadcasting Company (U.S.A.) and Television International Enterprises (U.K.). Three transmitters, supplied by the Canadian General Electric Company, are now in operation and a number of small stations are to be built around the coastline of the island (50 miles by 150 miles) to increase the coverage of the service. The studio and control centre is located at Kingston; equipment for which has been supplied by E.M.I. Electronics Ltd. and Pye of Cambridge. The same Anglo-American consortium have also been appointed to provide the island of **Mauritius with a television service.** A Marconi 5 kW Band I 625-line (7 Mc/s bandwidth) transmitter located at the studio centre at Forest Side, near Curepipe, and a Pye 100 W transmitter at Port Louis are scheduled to open early next year. Pye are also supplying the studio equipment.

Baird Scholarship.—The first award of the John Logie Baird Travelling Scholarship, introduced by the Television Society and financed by Baird Television Ltd., is being made by Mrs. M. Baird on August 26th. The first Baird Scholar is William P. Williams, B.Sc., aged 25, of Hoylake, Cheshire, who is taking a three-year post-graduate course for his Ph.D. at Nottingham University. The monetary award is to enable the recipient to undertake a 6 to 8-week investigation abroad on some aspect of television or allied technology.

The **Association of Public Address Engineers** is holding a symposium at the Queens Hotel, Piccadilly, Manchester, on 22nd September. Admission to the symposium will be by ticket obtainable free from the A.P.A.E. at 394 Northolt Road, South Harrow, Middx.

Farnborough Show.—Next year's Farnborough air display and static exhibition, organized by the Society of British Aircraft Constructors, will be held at the Royal Aircraft Establishment from 7th-13th September.

Communications Exhibition.—This year's International Radio Communications Exhibition, the 16th in the series of shows sponsored by the Radio Society of Great Britain, will be held at Seymour Hall, Seymour Place, London, W.1, from 30th October to 2nd November. As this is the Society's Jubilee Year, a special display of "museum pieces" is planned. Offers of equipment should be sent to R. G. B. Vaughan, 9 Hawkins Road, Tilgate, Crawley, Sussex.

Nineteen British manufacturers are exhibiting their products on a combined stand at the **International Exhibition of Radio, Television and Electronic Equipment** (FIRATO), which is being held in Amsterdam this month. The stand has been organized by the Board of Trade and the Audio Manufacturers' Group of B.R.E.M.A.

Avionics.—Electronics research and development for civil aviation is the theme of a symposium being organized jointly by the Ministry of Aviation and the Electronic Engineering Association. It opens at the R.R.E., Malvern, on 23rd September and after three days transfers to the R.A.E., Farnborough, until the 30th with a final session in London on 1st October. The aim of the symposium, to which U.K. and overseas civil aviation organizations have been invited, is to exchange ideas especially on matters requiring international approval. The I.E.E. conference on the same theme opens at Savoy Place on October 2nd.

The **B.B.C.'s experimental stereo transmissions** using the Zenith-G.E. pilot-tone system have been increased from one period per week to three. Transmissions from the Wrotham station on 91.3Mc/s are now on Tuesdays, Wednesdays and Thursdays; 10.30-11.00 tone test; 11.15-11.45 programme test.

The **profits of the Post Office** have been halved in the past two years, to £12·1M, and the recently issued annual report suggests this trend is likely to continue. However, the telecommunications side of the G.P.O. is not responsible for this as in the last financial year, which ended 31st March, it made a profit of over £20M; as against a loss of over £8M by the postal services.

During the first six months of this year, the overall number of **broadcast receiving licences** increased by 207,779 to 15,788,179. The number of combined sound and television licences increased by 338,932 to 12,569,919 and sound only licences dropped by 131,153 to 3,218,260. The sound only figure includes licences issued for car radio, which, incidentally, increased by 17,411 in the first six months of this year to 543,960.

Radio Microphones.—The American Federal Communications Commission is relaxing Part 15 of its rules and regulations to allow radio microphones to be operated in the f.m. broadcasting band 88-108Mc/s without a licence. The radio microphones will have to be type-approved and operate within a 200kc/s bandwidth. The radiated field strength at a distance of 50ft must not exceed 50μV/m.

The Hendon College of Technology, London, W.4, is holding a number of **short courses of evening lectures,** starting between 23rd September and 16th October. These include: Digital computers and their industrial applications; A design course for electronic engineers; Transistors and transistor circuit design; An introduction to microwaves; Global communications; and High-fidelity sound reproduction.

The **Wandsworth Technical College,** London, S.W.18, is starting two one-year transistor courses in September; one for post H.N.C. level students and the other for O.N.C. level students. The College is also running a ten-week course on transistors, starting in October.

The Wesley Evening Institute, London, N.W.10, have informed us that they are starting a series of **radio and television courses** this month covering theory and practice.

Day-time and evening **courses on v.h.f. and microwave engineering** are to be held at the Borough Polytechnic, Borough Road, London, S.E.1. These begin in September and will extend over three college terms.

RADIO AMATEURS' COURSES

We have been notified of the following institutes conducting evening courses during the coming session in preparation for the P.M.G.'s radio amateurs' examination. Some are arranged in collaboration with local amateur organizations.

Birmingham.—Central Evening Institute, Lea Mason Centre, Bell Barn Road, Birmingham, Mondays and Wednesdays at 7.0.

Bradford Technical College, Great Horton Road, Bradford 7, Wednesdays at 7.0.

East Ham Technical College, High Street South, London, E.6, Wednesdays at 7.0 with morse on Mondays.

Glasgow.—Allan Glens School, Montrose Street, Glasgow, Tuesdays at 7.0. Morse on Thursdays at 7.0.

Holloway.—Montem School, Hornsey Road, London, N.7, Mondays and Wednesdays at 7.0 with morse classes at 9.0.

Wembley Evening Institute, Copland School, High Road, Wembley, Mondays at 8.0 with morse at 7.0.

Northwood Evening Institute, Potter Street, Northwood Hills, Middx., Mondays 7.15 with morse on Tuesdays.

SEPTEMBER MEETINGS

LONDON

3rd. Institute of Service Management.—Demonstration of radio and television fault-finding at 7.30 at Telesurance Club, Windmill Street, W.1.

20th. Television Society.—"America and television" by L. C. Jesty at 7.0 at Cinematograph Exhibitors' Association, 164 Shaftesbury Avenue, W.C.2.

LEICESTER

24th. Television Society.—"Basic principles of colour television" by I. Macwhirter at 7.30 at Vaughan College, St. Nicolas Street.

SOUTHAMPTON

24th. Brit.I.R.E.—"Principles of industrial computing" by K. J. McCarthy at 6.30 at the Lanchester Theatre, Southampton University.

Personalities

L. W. Hayes, who became adviser to the director of the International Radio Consultative Committee (C.C.I.R.) on 1st March, has been appointed acting director of the Committee following the death of Dr. Ernst Metzler. The new director will be appointed at the next session of the I.T.U.'s administrative council next April. Mr. Hayes was appointed vice-director of the C.C.I.R. at the Vth Plenary Assembly in Stockholm in 1948, prior to which he had been with the B.B.C.'s Engineering Division for 25 years and on many occasions had represented the U.K. at international conferences. When he left the B.B.C. he was head of the Overseas Engineering and Information Department.

Professor E. E. Zepler, D.Phil., has retired from the chair of electronics at the University of Southampton which he has occupied since it was established in 1949. Dr. Zepler, who was president of the Brit.I.R.E. in 1958-60, obtained his doctorate at the University of Wurzburg and joined Telefunken in Berlin where he was eventually head of the receiver development laboratories. He came to this country in 1935 at the age of 37 and was with Marconi's for four years before starting his academic career. After two years as a lecturer at Southampton he spent three years at the Cavendish Laboratory, Cambridge, before returning to Southampton in 1946 as head of the department of electronics, telecommunications and radio engineering.

Professor Maurice G. Say, Ph. D., M.Sc., M.I.E.E., M.Brit.I.R.E., is retiring from the chair of electrical engineering at Heriot-Watt College, Edinburgh, at the end of the scholastic year after spending thirty years at the College. Professor Say, who gave the 1959-60 Faraday lecture "Electrical Machines," became a research assistant to Professor S. Parker Smith in 1924 and a lecturer at the Royal Technical College, Glasgow, in 1928.

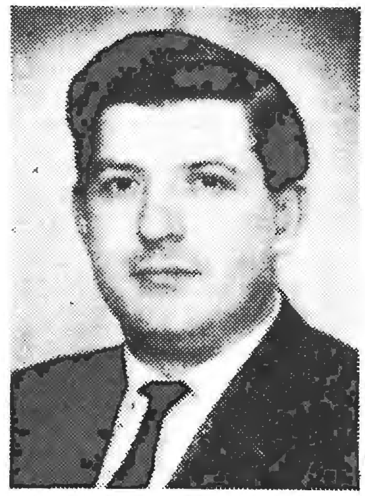
Following the appointment of **Dr. R. L. Beurle** to the chair of electronic engineering at Nottingham University, which was reported in our June issue, **Dr. J. C. Firmin** has been appointed his successor as manager of camera tube research at the English Electric Valve Company. Dr. Firmin, who received his Ph.D. following research in mechanical sciences at Cambridge in 1953, has been with E.E.V. for the past ten years. His previous position with the company, as assistant manager in charge of display and storage tubes, is being filled by **Dr. P. C. Bailey,** who is a graduate of Alford University, New York.

Major M. J. Squire, M.I.E.E., who for the past ten years has been a chief experimental officer at S.R.D.E., has been appointed chief technical sales executive of the British Physical Laboratories at Radlett. Major Squire was head of the radio production technical section of the Ministry of Aircraft Production during the war, and was concerned with liaison between the design and production staffs. At the end of the war he joined N.S.F. Limited as technical sales manager, and in 1950 he rejoined the Civil Service at the Signals Research and Development Establishment, Christchurch, Hants, and was subsequently in charge of the Test and Measurement Group.

Arthur C. Clarke is to receive, on October 16th, the 1963 Stuart Ballantine Medal of the Franklin Institute of Philadelphia for "his soundly based and prophetic early concept of the application of satellites in the primary human endeavour of communication." It will be recalled that Mr. Clarke's article "Extra-Terrestrial Relays" outlining the basic principles of "stationary" satellites was published in *Wireless World* in 1945. The gold medal was introduced by the Franklin Institute in 1946 "in recognition of outstanding achievements in the fields of communication and reconnaissance which employ electro-magnetic radiation."

James T. Kendall, M.A.(Cantab.), Ph.D., F.Inst.P., A.M.I.E.E., formerly general manager of SGS Fairchild Ltd., has been appointed managing director of Edwards High Vacuum Ltd. Dr. Kendall is succeeded by **Peter G. Tagg,** B.Sc.(Eng.), Grad.I.E.E., who has been sales manager since June of last year. Mr. Tagg spent two years with Hughes International (UK) Ltd. as a sales engineer before joining SGS Fairchild. His earlier positions include five years with Lintronic Ltd. and five years with E.M.I. Electronics Ltd.

Dr. J. T. Kendall



P. G. Tagg

Kennyth E. Harris, B.Sc., M.I.E.E., M.Brit.I.R.E., who for the past ten years has been a director of Cossor's, has joined Redifon Ltd. of Wandsworth as divisional manager. Mr. Harris joined the Post Office Engineering Department in 1934 and at the outbreak of war went to the Telecommunications Research Establishment at Malvern as a technical officer. He left Malvern in 1947, as principal scientific officer in charge of the ground radar division, to join Sir Robert Watson-Watt & Partners. Two years later he transferred to the Cossor Company as research manager.

Andrew G. Stirling, M.Sc., A.M.I.E.E., has been appointed divisional manager of the Control and Instrumentation Division of Ultra Electronics Ltd. Mr. Stirling is a former lecturer on servo mechanisms in the engineering department of Edinburgh University, and undertook ionospheric research under Sir Edward Appleton for three years. Mr. Stirling was previously with R.C.A. (Great Britain) as chief engineer.

D. Edmundson, B.Sc., M.I.E.E., formerly manufacturing manager of the A.E.I. Electronic Apparatus Division, has been appointed director of manufacture of the same Division. Mr. Edmundson, after graduating from the Rugby College of Technology and Arts, served an engineering apprenticeship with B.T.H. and joined A.E.I. as a design engineer in 1934.

K. P. Wood, B.Sc., A.M.I.E.E., who joined Standard Telephones & Cables last year as head of the Radio Division, has been appointed a director of its subsidiary, the International Marine Radio Company, following the recent retirement of its managing director, **H. Thorpe-Woods.** Mr. Wood was at one time head of the electrical engineering department at the Medway

College of Technology, Rochester, and was from 1956 until 1961 with Cossors (latterly as an executive director). Mr. Thorpe-Woods was managing director of I.M.R.C. for 29 years.

UNIVERSITY APPOINTMENTS

A. F. Gibson, Ph.D., B.Sc., A.Inst.P., deputy chief scientific officer at the Royal Radar Establishment, Malvern, has been appointed to the chair of physics at the University of Essex. Dr. Gibson is to take up his appointment in the autumn of this year to enable him to plan the new laboratories required for the first intake of students in October, 1964.

Henry A. Prime, M.Sc., B.Sc., A.M.I.E.E., manager of the applications division of the Brush Electrical Engineering Company, is to occupy the newly established third chair of electrical engineering at Birmingham University.

E. Openshaw Taylor, B.Sc., M.I.E.E., assistant professor of electrical engineering at Heriot-Watt College, Edinburgh, is to occupy the chair of electrical engineering following the retirement of Professor M. G. Say.

Geoffrey D. Sims, Ph.D., M.Sc., D.I.C., A.M.I.E.E., senior lecturer at University College, London, is to take the chair of electronics at Southampton University on 1st October, following the retirement of Dr. E. E. Zepler.

William A. Gambling, Ph.D., B.Sc.(Eng.), A.M.I.E.E., senior lecturer in the department of electronics at Southampton University, has been appointed a reader.

Fredrick J. Hyde, M.Sc., A.M.I.E.E., senior lecturer in the department of electronic engineering at University College, Bangor, has been appointed a reader.

P. J. Spreadbury, M.A., M.Sc. (Cantab.), has been appointed a lecturer in the electrical engineering department of Sheffield University.

OUR AUTHORS

Michael Cox, B.Sc.(Eng.), author of the article in this issue on receiving the SECAM television system, has been a senior engineer in the Planning and Installation Department of A.B.C. Television since 1961 and for the past year has been working on a SECAM investigation. Educated at Dulwich College and University College, London, he was a graduate apprentice with Marconi's W/T Company and for several months with Solartron before joining Associated Rediffusion as a maintenance engineer in 1959.

G. C. Peel, who describes in this issue the channel diplexers used at two of the Eire stations, has been with the Pye organization since 1944. He was one of the team of engineers which formed the nucleus of the present transmitter design section of Pye T.V.T. Ltd. when that company was formed. He is 38.

D. N. Tilsley, B.Sc., Grad.Inst.P., A.M.Brit.I.R.E., a senior lecturer in the department of electrical engineering at the Borough Polytechnic, London, contributes an article on transistor cut-off frequencies in this issue. Mr. Tilsley, who graduated at the University of Glasgow in 1944, after reading mathematics and natural philosophy, was for some time at the Royal Aircraft Establishment, Farnborough, working on radar before taking up teaching. He has taught in West Africa and has been on the staff of the Borough Polytechnic for ten years.

OBITUARY

John Keir, at one time assistant general manager of Marconi International and, at the time of his retirement three years ago, personal assistant to the company's managing director, died on the 5th August. He joined Marconi's as a radio officer in 1915 and had held many technical and administrative posts including that of managing director of the Brazilian subsidiary.

Industry News

The board of **The Plessey Company** have announced that the profit, before taxation, for the year ended 30th June will exceed £10,000,000. This represents an increase of over £3·5M on the previous year (which included only eight months trading in respect of Automatic Telephone & Electric Co. and Ericsson Telephones Ltd.). The telecommunications side of the Plessey group accounts for 48% of the year's turnover, electronics and electrical products 20%, radio, TV and domestic equipment 18%, aircraft equipment 8% and hydraulics and nucleonics 6%.

The group profits of **Thorn Electrical Industries Ltd.** for the year ended 31st March amounted to £6,528,298, representing an increase of £1,466,259 on the previous year's results. After deducting all charges, including depreciation of £1,498,543 and taxation of £1,371,848, the net profit this year amounted to £2,847,845 as against £2,154,737 in 1961/62.

General Electric Company.—Profit, before taxation, for the year ended 31st March amounted to £6,121,676, showing an increase of £1,993,897 on the previous year's results. Taxation this year took £3,150,228, as against £1,996,157 in the previous year, leaving a group profit of £2,769,988 compared with £1,839,420 in 1961/2.

Pye of Cambridge Ltd., the holding company of the Pye-Ekco group and formerly known as British Electronic Industries Ltd., record a trading profit for the year ended 31st March of £4,346,983. Total group profit, after taxation, was £1,014,133, an increase of £864,440 on the previous year.

Profits of **Cable and Wireless Ltd.** for the year ended 31st March totalled £4,130,678. Compared with the previous year's results, this represents a drop of £444,604. After taxation of £1,500,222 and making reserves and appropriations for special contingencies, the net balance for the year was £27,956.

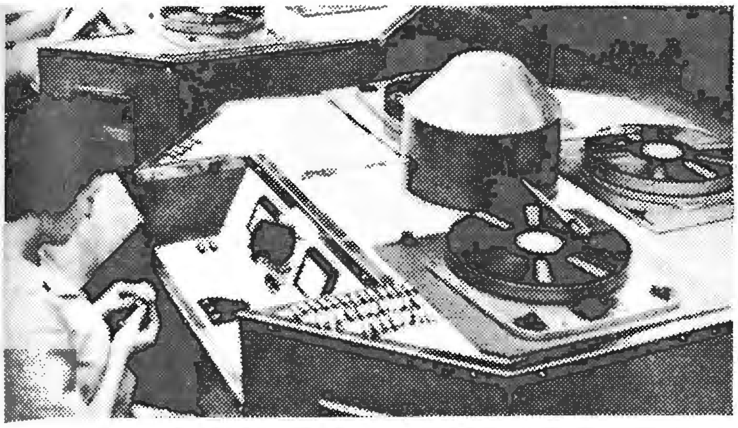
The **Metal Industries** group profit, after taxation, for the year ended 31st March amounted to £1,231,103, representing an increase of £29,957 on the previous year's results. Member companies of this group include Avo, International Rectifier, and Taylor Electrical Instruments.

The **Antiference** group pre-tax profits for the year ended 31st March amounted to £221,896 and showed an increase of £35,546 on the previous year. Net profit, after tax, showed an increase of over £20,000 on the previous year and totalled £109,324.

The trading profit of **British Relay Wireless and Television Ltd.** and its subsidiaries amounted to £4,605,723 for the year ended 30th April, representing a £670,925 increase on the previous year's results. After writing off £3,696,884 (depreciation) and taking into account other charges, including £3,646 taxation, the group net profit totalled £688,640; an increase of £329,837 on the previous year.

Profits of **Telefusion Ltd.** for the year ended 24th April, after taxation, amounted to £438,247; representing an increase of £68,160 on the previous year's results. Depreciation this year was £1,003,333 as against £921,802 in 1961/2.

B.A.C.-Marconi Agreement.—The British Aircraft Corporation and Marconi's W/T Company (to be known in future as the Marconi Company) are to collaborate in the design and manufacture of satellite communication systems. The B.A.C. was awarded the contract for constructing U.K.3, the first all British satellite.



This machine, which has four radial arms, simultaneously tests three pickup cartridges; each for a different performance characteristic. It was produced by the development laboratory of the Garrard Engineering & Manufacturing Company which is to be known in future as Garrard Engineering Ltd.

Negretti and Zambra have acquired a controlling interest in **Visual Engineers Ltd.** which was formed three years ago by F. N. W. Ernst (who will continue as managing director) to manufacture closed-circuit television equipment. Visual Engineers recently acquired manufacturing facilities at Stocklake Works, Aylesbury, Bucks, and will continue to be the sole U.K. agents for the industrial television equipment manufactured by Grundig of West Germany.

The International Telephone and Telegraph Corporation of America has acquired the **Cannon Electric Company** of Los Angeles, California. In addition to its headquarters and factory in Los Angeles, Cannon has associated organizations in Toronto, London, Paris, Antwerp, Melbourne, Milan and Tokyo.

The **International Marine Radio Company** of Croydon, Surrey, has become a subsidiary of Standard Telephones and Cables Limited and will now operate within the Radio Division of S.T.C. Both I.M.R.C. and S.T.C. are British subsidiaries of the International Telephone and Telegraph Corporation of America; I.M.R.C. having previously operated as a direct subsidiary of I.T.T.

A new 14,000 sq ft wing is to be built on to **Standard Telecommunication Laboratories** at Harlow, Essex, to provide more facilities for basic and advanced research projects. S.T.L. and its parent company, Standard Telephones and Cables Ltd., are spending over £3,000,000 on research this year—of which less than 10% is being financed by the Government.

Philips Electrical Ltd. have installed a sound distribution system in the Shell Centre on the South Bank of the Thames. Eight individual sound sources plus 18 different microphone points are all controlled from a single console the inputs from which can be distributed to any, or all, of 23 areas where loudspeakers have been sited. An induction, simultaneous interpretation system has been installed in the theatre of the Shell Centre. This has four separate channels and can be fed from microphones or multi-lingual sound tracks on films, etc.

Decca have installed a 30-watt (per channel) stereo outfit in the theatre of the American Embassy at Grosvenor Square. The two special loudspeaker enclosures each contain two bass units and 24 treble units.

R.C.A. (Great Britain) Ltd. are to supply ten of their TR-22 transistorized multi-standard television tape recorders to the B.B.C.

Kolectric Ltd., manufacturers of coil winding machinery, have moved their offices to Sinclair House, The Avenue, London, W.13. (Tel.: PERivale 9066.)

Cannon Electric have asked us to point out that only the mains connectors of the XLR series described in our July Manufacturers' Products columns meet the conditions of BS415. Also that the pin insulator material of the mains connector is nylon.

Standard Telephones and Cables Ltd. are overhauling the sound reinforcement system fitted into St. Paul's Cathedral. The original time delay mechanism, fitted to reduce interference between the direct and reinforced sound, is to be replaced by a new delay mechanism using a magnetically loaded neoprene belt, stretched around a metal drum. The original line-source loudspeakers are being retained, but transistor amplifiers are to replace the existing valve amplifiers.

OVERSEAS TRADE

Three British companies, Imperial Chemical Industries, Formica and Morgan Crucible Group, have just held (29th July to 11th August) an **exhibition of their goods in Peking.** The Chinese Ministry of Trade has recently announced that it would welcome small technical exhibitions by British companies.

The English Electric Valve Company has received an order from the **Italian broadcasting authority,** Radio televisone Italiana, for 250 4½in image orthicon television camera tubes. E.E.V. has been supplying image orthicons to Italy for several years and this new order is expected to meet the operating requirements of Radiotelevisione Italiana for the next two years.

The M-O Valve Company has received a substantial order from the **National Aeronautics and Space Administration of America** for a number of high-power travelling-wave tubes for use in satellite communication systems. The tubes to be supplied are rated at 6kW and are designed for c.w. operation in the 6,500Mc/s range.

The special products division of Ultra Electronics Ltd. has received its **first American order** from the Bureau of Rehabilitation Services in Kentucky for the ultrasonic aid they are producing to assist the blind. The aid consists of a transistor transmitter-receiver and a hand-held "torch," which emits an ultrasonic beam to locate objects and their distance.

Toshiba of Tokio have signed an agreement with Garrard Engineering Ltd. to fit Garrard "Autoslim" record changers exclusively to their radiograms.

South Midlands Construction Ltd. of Cadnam, Southampton, have recently supplied aerial mast equipment valued at £15,000 to the **Ethopian government** and a further £7,000 worth to the Sudan government.

Televisao Excelcior of Brazil have ordered a 3in image orthicon colour television channel from the Marconi Company. This order brings the value of equipment supplied by Marconi's to Televisao Excelcior in the past six months to about £250,000.

The Automatic Telephone and Electric Co. has received an order, valued at £150,000, from the **Finnish Posts and Telegraphs Department** to supply a number of 300-channel transistor repeaters for use with small core coaxial cables.

OUR COVER

A colour test card after transmission to Telstar and back to the G.P.O. station at Goonhilly, where it was photographed by T. N. J. Archer of the B.B.C. Research Department, is reproduced on our front cover. It is interesting to note that as many as eight reproduction processes have been involved. The original transparency was transmitted from Goonhilly to Telstar, re-transmitted from Telstar to Goonhilly, received on an R.C.A. Victor receiver, photographed on Ektachrome EH120 film, a transparency was produced, copies of this were made from which the colour blocks were prepared and the cover printed.

Channel Diplexers

By G. C. PEEL*

TWO-CHANNEL COMBINING UNITS FOR RADIO EIREANN

IN the early days of television, sound and vision transmissions were radiated from separate aerials but it was soon realized as being economically advantageous to combine the two transmissions before radiating them from a common aerial. With this arrangement for a given aerial gain per transmission the size of the aerial may be approximately halved, thus effecting great economies in size and cost of the supporting structure. Constant impedance combining units and wide band aerials were developed for this purpose.

As the number of programmes in any area increases the question of co-siting the transmitters inevitably arises. Obviously the same economic advantages then apply to the use of a common aerial system for both programmes, provided that combining units and high-gain aerials with sufficient bandwidth are available.

Broadband high-gain aerials are now in fairly common use although generally only one transmission is radiated. For instance aerials covering the whole of Band III (approximately 174-223 Mc/s) are readily available. However, combining units capable of handling television transmissions on two different channels have not so far been required in this country.

* Pye T.V.T., Ltd.

When television was introduced into Eire, using a 625-line system in Band III it was found necessary in some parts of the country to provide an additional service on 405 lines for those viewers who already had receivers for the reception of programmes originating in England and Northern Ireland.

This called for the simultaneous radiation from the same site of a 625-line and a 405-line service on two channels in Band III. For this purpose a two-channel combining unit, or channel diplexer, was developed for the Radio Eireann transmitting stations at Dublin and Sligo.

At each site there is a 5kW peak white 405-line vision transmitter with its associated $1\frac{1}{4}$kW a.m. sound transmitter and a 5kW peak sync 625-line vision transmitter with a 1kW f.m. sound transmitter. Each pair of transmitters has its own conventional single channel combining unit feeding the combined transmission to the channel diplexer which combines the two transmissions and passes them into the coaxial aerial feeder system. The channel diplexer presents a constant matched impedance to both input transmission lines over the whole working channel and provides a separation of at least 34 dB between the two transmitters.

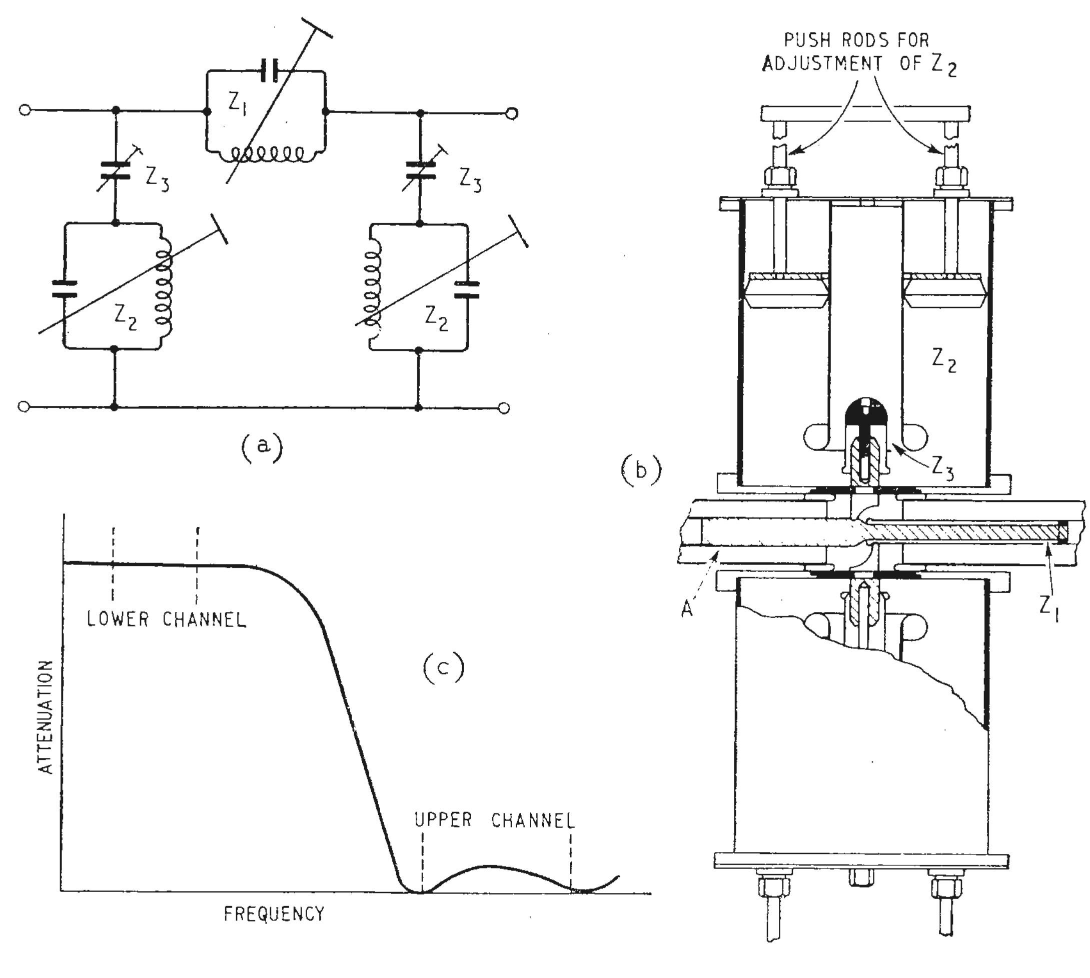
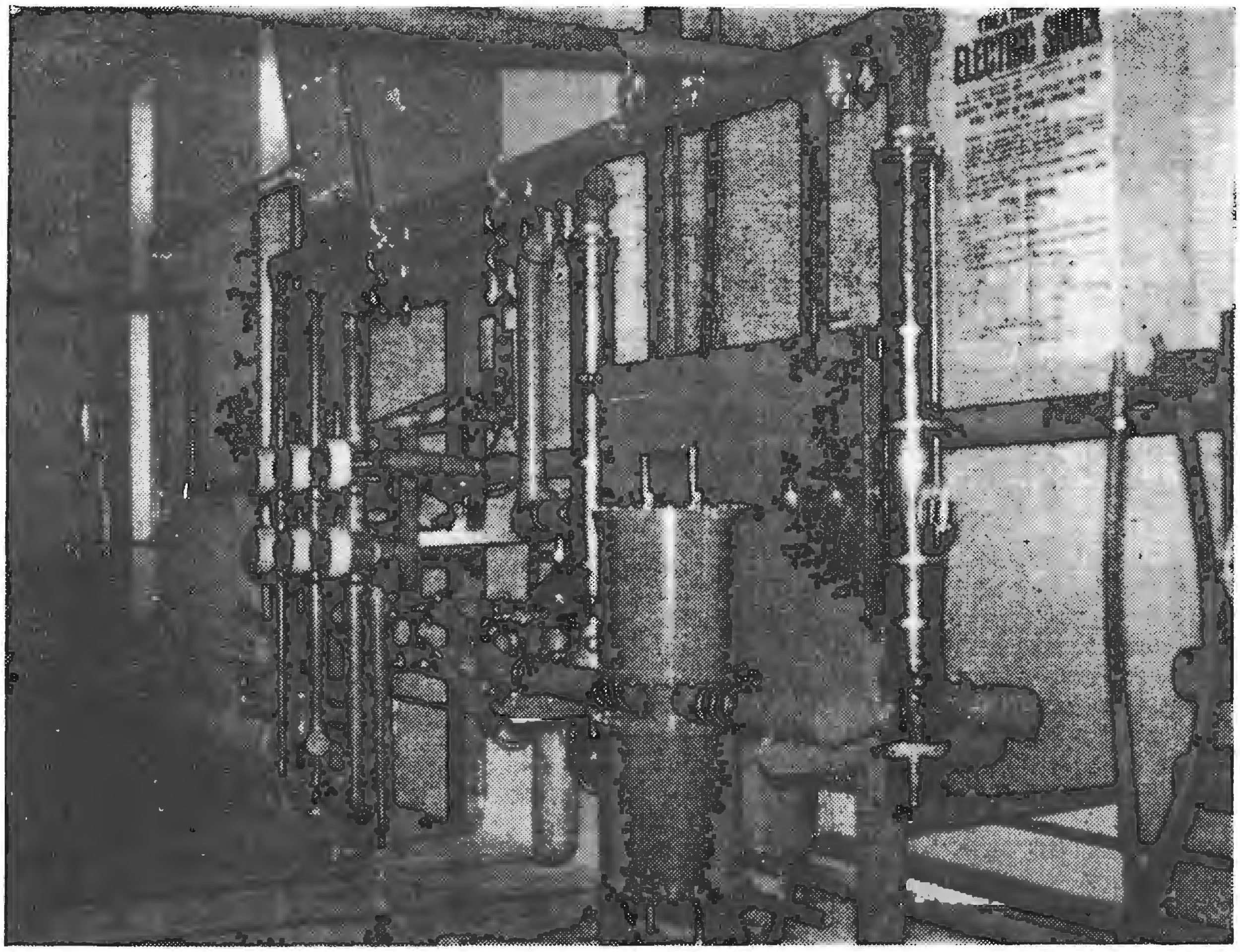


Fig. 1. Circuit diagram, response curve and cut-away drawing of the coaxial filter.

The channel diplexer is of the well known double bridge type[1] in which two slotted-tube bridges[2] are connected back-to-back by means of two coaxial transmission lines on each of which is mounted a filter. In the normal single channel diplexer these filters, which are identical, have a "notch" in their frequency-attenuation response which allows the whole wideband spectrum of vision frequencies to pass unattenuated but produces a virtual short circuit across the line at sound frequency. This causes the sound transmission to be totally rejected to one of the bridges whose balance-to-unbalance action directs it into the aerial feeder. The action is thus dependent upon the filter having sufficient rejection (usually 20-30 dB) at one of the transmitter frequencies.

The main difference in applying the same prin-



Channel diplexer installed at the Truskmore, Sligo, station. The coaxial switches and feeders are also shown.

ciple to the combination of two complete channels is the much larger band of frequencies, up to 8 M/cs, which has to be reflected by the filter. A simple notch filter is obviously not suitable since it only exhibits high attenuation over a range of frequencies of the order of kilocycles.

If the programmes to be combined lie in adjacent or very slightly separated channels a sharp cut off is essential and a band-stop filter, possibly consisting of a number of stagger-tuned notch filters, is required. Where the frequency separation is greater, as was the case at the two Irish stations, it is advantageous to use a low- or high-pass filter which must have a good impedance match over the relevant portion of the pass band together with sufficient rejection over all the upper channel frequencies. It must also lend itself to coaxial construction with physically realizable component valves. These requirements are very suitably met by an MM′ derived low-pass filter and a coaxial embodiment of such a filter was used for these combining units.

Fig. 1 (a) shows the low-frequency circuit of an MM′ low-pass filter. It consists of a series-connected tuned circuit Z_1 and two shunt-connected tuned circuits Z_2, the latter being fed through series capacitors Z_3. The component values are so arranged that when the filter is terminated by a resistance Z_0 equal to the design characteristic impedance of the filter, the input impedance Z_{in} is also Z_0 throughout the pass band. The point of maximum attenuation is designed to fall within the upper of the two channels to be combined, the lower channel lying within the pass band.

The coaxial construction of the filter is shown in Fig. 1 (b). The transmission line A is the line of characteristic impedance Z_0 into which the filter has to be inserted. The resonant circuit Z_1 is represented by a short-circuited section of coaxial line contained within the normal transmission line inner conductor. The length and characteristic impedance of this line section are such that over the relevant range of frequencies its input impedance, which appears in series with the main line, is the same as that of the distributed constant equivalent.

In a similar manner the resonant circuits Z_2 are represented by short-circuited line sections, which again present the same impedance over the working range. These circuits Z_2 are connected to the inner conductor, one on either side of the impedance

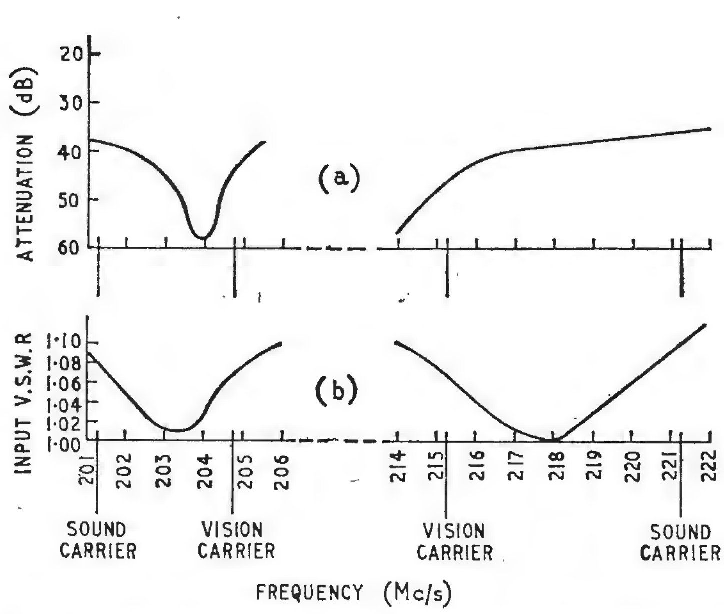


Fig. 2. Cross-insertion losses (a) and standing wave ratios (b) on the two channels used by the Sligo, Eire, transmitters.

Z_1, through the capacitance Z_3 formed by a short section of coaxial line within the inner conductor of circuit Z_2. The relatively large size of the resonators Z_2 is occasioned by the large voltages appearing across their input impedance.

Fig. 2(a) shows the cross-insertion losses between the upper and lower channel inputs of one of the combining units. A loss of 40 dB means that for every kilowatt of power entering the unit from one transmitter, only one tenth of a watt reaches the other transmitter. Fig. 2(b) shows the standing wave ratios on the two input feeders when the unit is correctly terminated.

BIBLIOGRAPHY

[1] G. Schaffer: "Frequenzweichen zum Betrieb von Fernseh-Bild-und-Tonsendern an gemeinsamer Antenne," *Rohde & Schwarz Mitteilungen*, 4, 1953.

[2] C. Gillam: "The Diplexer," *Wireless World* (Overseas Supplement), March, 1950.

LETTERS TO THE EDITOR

The Editor does not necessarily endorse opinions expressed by his correspondents

Lasers

MAY I make two small comments on the question of coherence in lasers? The first relates to Fig. 1(c) of Mr. Harris's article in your August issue, with the caption "output contains components of varying phase." Now the sum of a number of sinusoids of the same frequency but varied phases is just a single sinusoid, so that it is implicit in Fig. 1(c) and 2(c) that "output" is in some sense a collective term; and it will then be seen that the other properties of the laser are a direct consequence of the coherence. For there is, firstly, *coherence in space.* If the vertical axis in the diagrams is regarded as distance along a diameter (or chord) of the aperture, then coherence means equality of phase over the whole aperture, and this is the condition for non-divergent or parallel-beam propagation. Diffraction effects cause disturbances to an extent depending on the ratio of wavelength to aperture, but the laser aperture is at least thousands of wavelengths. Hence space coherence is the cause of the parallel-beam radiation. Secondly, there is *coherence in time*, to study which one should image the several traces in the sinusoid placed end-to-end. In the coherent case, constant phase, we have the equivalent of a c.w. radio transmission, but the incoherent wave is more like a spark transmission. So without going into the niceties of the bandwidth of random phase modulation, we can realize at once that the incoherent radiation of ordinary light sources cannot have so narrow a spectral line as the coherent radiation of a laser.

A most interesting point is the way in which the laser illustrates the essential duality of wave and quantum aspects of radiation. For the stimulated emission is described in terms of quantum phenomena, while the coherence is a wave aspect of the radiation. This illustrates nicely the point that the quantum description of radiation supplements but does not supersede the wave description.

Sonning Common, Berks.

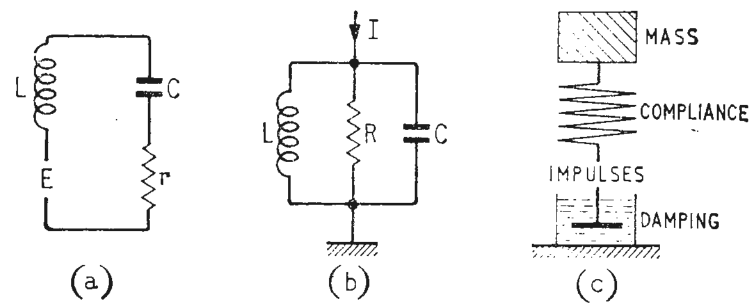
D. A. BELL,
Director of Research,
AMF British Research Laboratory.

Class C Oscillators and Pendulum Clocks

I HAVE just been reading Thomas Roddam's interesting articles on oscillators in the January, February and March issues.

It seems to me that in discussing the frequency stability of a class C oscillator (March issue, p. 139), he is wrong in regarding it as analogous to a bad pendulum clock in which the impulse is supplied at the moment of maximum displacement of the pendulum from its central position.

When a short duration impulse force is applied to the pendulum bob, the reaction to this applied force comes almost entirely from the inertia of the bob, the effect of gravity being relatively insignificant during the impulse.



Thus, when we consider the equivalent electrical circuit, the e.m.f., E, representing the impulse force, must come in *series* with the tuned circuit, as shown in (a). Then the impulse voltage will virtually all appear across L, and hardly at all across C—which is equivalent to nearly all the force going to accelerating the bob.

If the pendulum receives impulses at the centre of its swing, as it should do in a good clock, this means the impulse occurs at maximum bob velocity, i.e. at maximum current in the equivalent electrical circuit. Now the positive peaks of the fundamental component of a regular series of positive pulses occur coincidentally with the pulses, so that the fundamental component of E is in phase with the current in the tuned circuit. Thus no reactance is introduced and oscillation is at the true series-resonant frequency.

The relevant electrical circuit, when it comes to considering a class C oscillator, however, is not (a) but (b). Here we have a *parallel* tuned circuit fed with *current* impulses, I. These impulses occur at the moment of maximum *voltage* across the tuned circuit, i.e. the fundamental component of the current fed to the tuned circuit is in phase with the voltage across it, so that once again no reactive effect is introduced.

A practical class C oscillator is usually not quite as simple as this, but I think it will never be as bad as is implied by comparing it with a pendulum impulsed at the extremes of its swing.

The correct mechanical analogy for a class C oscillator is evidently something more like (c).

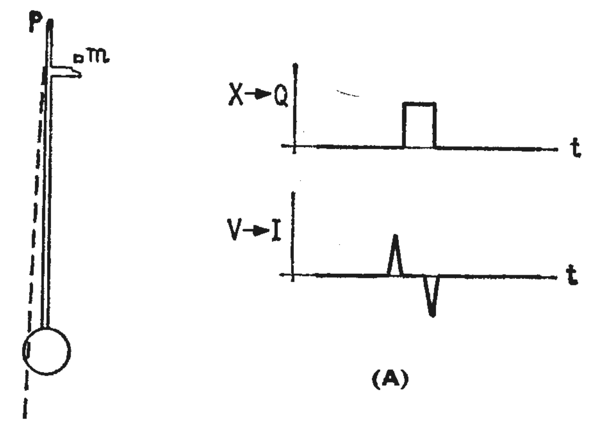
Great Malvern. PETER J. BAXANDALL.

The author replies:

There is no doubt that I was reckless in my comment, but it was so closely related in my mind to the problem of pulsing a crystal at a sub-harmonic rate that I did not explore the relationship properly. Mr. Baxandall has also taken a rather limited view.

First of all, I agree that we can draw the mechanical equivalent of the pendulum in the form shown in his (a), but equally well we can draw it as his (b). The starting point is easily found if the maintaining force is produced by a transducer: for (a) we use the piezoelectric effect and for (b) the electromagnetic effect. The only way of evading this duality is by introducing a gyrator.

One way of driving a pendulum is by dropping a small



(A)

NEUTRAL POSITION WITH m ON SIDE-ARM

weight on a side arm. This is shown in diagram (A) and the weight m is released by a relay which snatches it up again once it falls free of the arm. When m is resting on the side arm we can say that the neutral position of the pendulum is displaced a little. At the point $X=0$ we have introduced a perturbation ΔX which lasts for a short time. Using the analogy $X \rightarrow Q$, $dX/dt = V \rightarrow I$ we see that the relevant waveforms are those shown in (A).

Mr. Baxandall gets his pulse from a current source, and his reasoning applies to this: I have been thinking in terms of Franklin's circuit, using a voltage source and a very small capacitance as the energy supply path. My drive is thus the curbed pulse.

To buttress my own stupidity I have dug into some dusty bundles for Tillman's paper (*Wireless Engineer*, Dec. 1947) and I hold P. J. B. responsible for the resulting dirt and muddle. I find that my memory had played me false, and that the drive is limited on one half-cycle only. This is in fact a class B system. It would be interesting to know whether complete squaring has been used.

I do not think that we should allow it to be said that a class C circuit must use an anti-resonant circuit. We can operate a circuit using a resonant circuit in class C if we wish.

An alternative approach (see diagram B below) suggests that it really does not matter when the circuit is impulsed. Because I happen to be at this point on some other work, let us take the circuit of P. J. B. (a) and connect the maintaining circuit across r. When the active elements are *on* we have a negative value for r. E, of course, is zero. During the *off* period the circuit has roots in the left-hand side of the plane and we need only look at one of these, R_1. When r goes negative this root moves round into the right-hand half of the plane, to R_1'. The circuit thus oscillates at the frequency ω for much of the cycle, and at ω' during the active epoch. The shorter the conduction period the larger the value of α we shall need to maintain the average oscillation level constant.

The analysis looks like taking up too much space, but it would appear that there would be some advantage in placing the active root at R_2 and this, of course, is what we do if the system operates in class B. Here, of course, we still have the problem that R_2 must shift slightly to compensate for any errors in the values of the two α terms.

I wrote the articles because I thought we were all getting a bit complacent about oscillators. May I suggest as a conclusion that here, at least, you can be certain that if you simplify you just can't go right.

THOMAS RODDAM.

Overload Protection

THE labour of constructing a regulated and protected power supply unit is such that many readers would wish to go beyond the 1.2A described by Mr. Butler in his article in the August issue. Indeed for this kind of current an automobile battery on trickle charge is convenient and the very simple current limiter shown in the accompanying Fig. 1 (*Audio*, Dec. 1961, p. 40, Fig. 4)

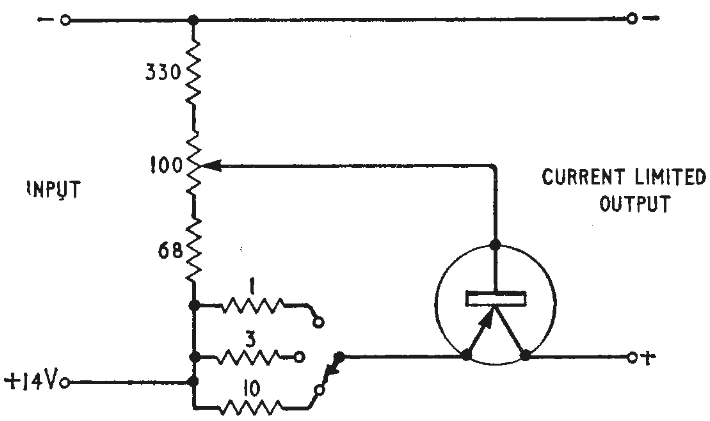


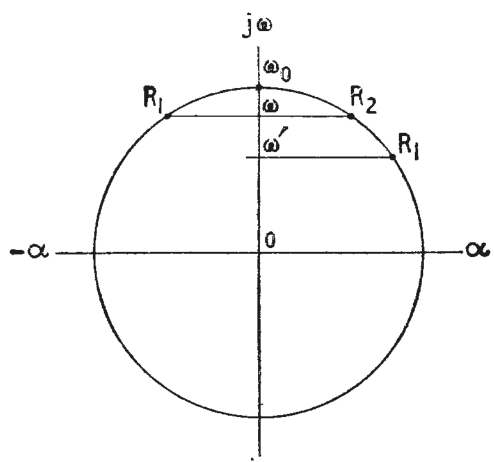
Fig. 1.

will do the job. This circuit will have the transistor bottomed until the drop across the range selecting resistance is about 1 volt—the variable tap is used to allow for variations in V_{be}. If the circuit demands a higher current the transistor is moved into the high source impedance region of its characteristic.

R. and p. supply units giving 10A or more are extremely useful and are worth the effort required to build them. It is then reasonable to consider whether they cannot be arranged to give either current limiting or total switch off. Without exploring the matter in detail it would appear that some modification to Mr. Butler's Fig. 3 would convert the circuit into a snap circuit. The changes are indicated in Fig. 2. Here R_3 is returned to the other side of R, a resistance R_B is added in the base lead of Q1 and a feedback resistance R_F has been added. The feedback is positive, so that if Q1 starts to come on it will drive Q2 to increase the base current in Q1.

Ideally we should transform the system so that there is no drop across R_F until movement begins. R_F can then be switched in without altering the threshold.

An interesting variant is to make R_F a resistance and thermistor in parallel and to mount the thermistor on



(B)

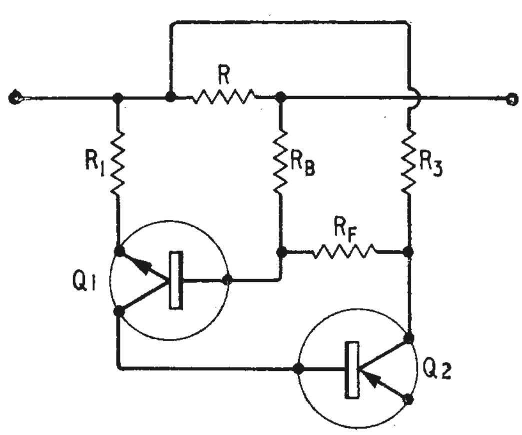


Fig. 2.

the control transistor Q5. This will provide thermal protection.

The rather high internal impedance of Mr. Butler's raw power supply may lead to difficulty and will certainly lead to excessive control transistor dissipation. The latter cannot be helped but if switching is needed a Schmitt trigger can be interposed between Q1 and Q2. A circuit of this kind was described by the writer in *Audio*, June 1962, and appears there as Fig. 5, p. 29. The regulation system described in this article also contains refinements in the amplifier which appear to be worth while.

London, W.8. GEORGE FLETCHER COOPER.

The author replies:

The protective circuits I described are applicable to power supply units giving any desired output current. For use with a 10A supply, instead of the 1.2A unit I described, the only change required is a reduction in value of the sensing resistance R from 1.5 ohm to 0.18 ohm. Naturally, the higher current will cause extra dissipation in the series regulator transistor and paralleled banks must be used to cope with this.

On Mr. Cooper's second point, the use of a pnp-npn pair of transistors to give snap-action switch-off instead of current limiting, I am quite sure that this can be done and his arrangement looks as if it would work. I have used such a transistor pair as the discharge device of a timebase generator, in frequency dividers and even as a linear regenerative amplifier. It is no more than a form of bi-stable circuit which has the useful property that, in one of its two states, both transistors are cut off.

I like his suggestion for providing thermal protection for the regulator transistor. It could be applied to my three circuits by making R from some material having a strong positive temperature coefficient of resistance. Semiconductor elements are commercially available with this property.

I shall have something to say about high power switching-type regulators in a later article in *Wireless World*. As regards error-signal amplifiers it is almost standard practice to start with a differential pair instead of the single stage used in my circuits. However, my paper was concerned with protective devices and did not profess to cover the wider field. This is well documented by published papers and in manufacturers' application reports.

F. BUTLER.

Non-linearity Distortion Measurement

I WOULD like to comment upon the article by Murray and Richards on distortion in your April issue, and on the subsequent correspondence.

(1) A very large proportion of the music heard today reaches the listener via a class B transistor stage, and measurements show that a major part of the audible distortion here is of high order. Many authors have shown the rapid increase in audibility and annoyance value of distortion with increase in the order of the harmonic. So M. & R. have no justification for regarding high-order distortion as unimportant.

(2) M. & R. argue that if high-order distortion were present, it would increase rapidly with signal power. This idea presumably arises from their over-simplified analysis including only one or two distortion terms. In fact, in most class B amplifiers, the high-harmonic percentage is actually greatest at low outputs. This can be explained most easily by regarding the characteristics as discontinuous, and analysing the waveforms on Fourier lines. If a serious analysis were attempted using a continuous power series, many terms having interrelated amplitudes would have to be included; the amplitude of any given harmonic is then determined not by any one, but by the resultant of a number of components (in or out of phase) arising from different terms.

(3) The total power in the intermodulation tones is not, in fact, usually much greater than that in the harmonics. The "astronomical ratio" quoted by M. & R. is obtained partly by ignoring the large increase which occurs in the harmonic from one tone when the total signal level is increased by adding other tones, and partly by taking an unrealistically large number of equal tones. An analysis of this question (for two tones, up to the 6th harmonic) is given in an early paper by the writer (*Electronic Engineering*, June, 1951).

(4) It could, however, still be argued that the audibility of the intermodulation tones is greater than that of the harmonics. This is a difficult question since it involves subjective effects—masking by the fundamentals and production of harmonics and difference tones in the ear. It has been investigated to a limited degree by Lazenby (*Wireless World*, Sept. 1957) whose figures suggest that there should not be, on the average, any great difference in the audibility of harmonic and intermodulation components even when only 2nd and 3rd harmonics are considered.

(5) It is, I think, only when we take the matter a further stage, and consider the annoyance value of the distortion, that it can seriously be argued that intermodulation products are much more important (as introducing a greater degree of disharmony) than the harmonics. But even here we have the fact that if numerous fundamentals are present, aural masking ensures a large rise in the minimum level at which a single distortion product is audible and an even larger rise on the *total* distortion power required to reach this level of audibility.

(6) The results of M. & R.'s test with a distorter giving an infinite percentage of harmonic do not seem to have much practical relevance, since we are here concerned with the level of distortion which is just audible. This distortion will comprise say 1% to 5% of low harmonic, either (a) without or (b) with a significant amount of high harmonics. In case (a), the intermodulation products can be easily estimated if required from the measured harmonics, while in case (b), both the conventional 2-tone intermodulation test and M & R.'s "slotted noise" test fail to allow for the great differences in audibility (> 100 times in terms of power) between the different components.

(7) In conclusion, the method proposed is interesting but I feel that much more evidence would have to be forthcoming before it could be accepted as valid, except perhaps for class A amplifiers operated with automatic control to exclude overload. A measurement of harmonics with suitable weighting and for several fundamental frequencies, still seems to me a more universally reliable criterion

Southend-on-Sea. M. V. CALLENDAR.

Tape Guides

YOUR correspondent Mr. W. P. Skinner who advocates (August issue) the use of a p.t.f.e. surfaced pressure pad on tape recorders may be interested in my experience. The sight of tape-abrading brass tape guides was more than I could stand, and I removed all tape guides, skimmed them down in the lathe, and fitted short pieces of p.t.f.e. sleeves to them.

Imagine my disappointment when trying the recorder after the modification, when I found that in the fast-spooling modes, after some few seconds of operation, the take-up motor began to slow up, with subsequent over-run by the "trailing" spool. I found that even a single surface of p.t.f.e. would cause this excessive drag. It seems possible that friction between p.t.f.e. and recording tape is higher than might be expected from its characteristics in association with other materials.

Since this experience I have fitted glass surfaced tape guides, and have been very satisfied with their performance.

Brampton, Cumb. RAYMOND E. ROSS.

1-6

H.F. WAVE ANALYSER TYPE 853 =

1. **An Analyser**
2. **A field strength and interference measuring set**
3. **A Selective Voltmeter**
4. **A Heterodyne Wavemeter**
5. **Transmission measuring set**
6. **A Bridge detector**

30kc/s — 30Mc/s — and highly versatile

The Airmec H.F. Wave Analyser Type 853 is a selective measuring set of great versatility, suitable for use in the frequency range 30 kc/s—30 Mc/s. The sensitivity of the amplifier enables measurements to be made from 1 microvolt to 1 volt up to a frequency of 20 Mc/s and from 4 microvolts to 4 volts above this frequency. This instrument has many uses as an Analyser, Selective Voltmeter, Transmission Measuring Set, Field Strength and Interference Measuring Set, Bridge Detector and Heterodyne Wavemeter.
Above 30 Mc/s we recommend the use of an Airmec V.H.F. Wave Analyser Type 248 (range 5 to 300 Mc/s). Full details of either of these two instruments, which form part of the comprehensive range of high quality electronic instruments produced by Airmec for use in Laboratories and Workshops, will be forwarded to you upon request.

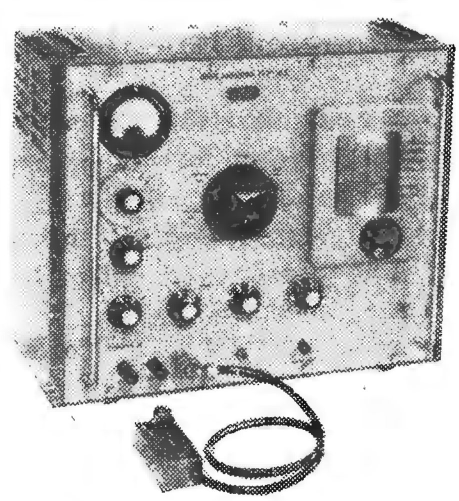
FREQUENCY RANGE:
30 kc/s — 30 Mc/s in 7 bands

SIGNAL INPUT RANGE:
$1\mu V$ — 1V up to 20 Mc/s
$4\mu V$ — 4V from 20 — 30 Mc/s

ATTENUATOR RANGE:
H.F. Attenuator:—
0, 10, 20, 40 and 60 dB
L.F. Coarse Attenuator:—
0 — 60 in 10 dB steps
L.F. Fine Attenuator:—
3 — 10 dB variable

ATTENUATOR ACCURACY:
$\pm$ 0.1dB over 105dB range
$\pm$ 0.5dB over 120dB range

INPUT IMPEDANCE:
75 ohms. A high impedance probe also provided.



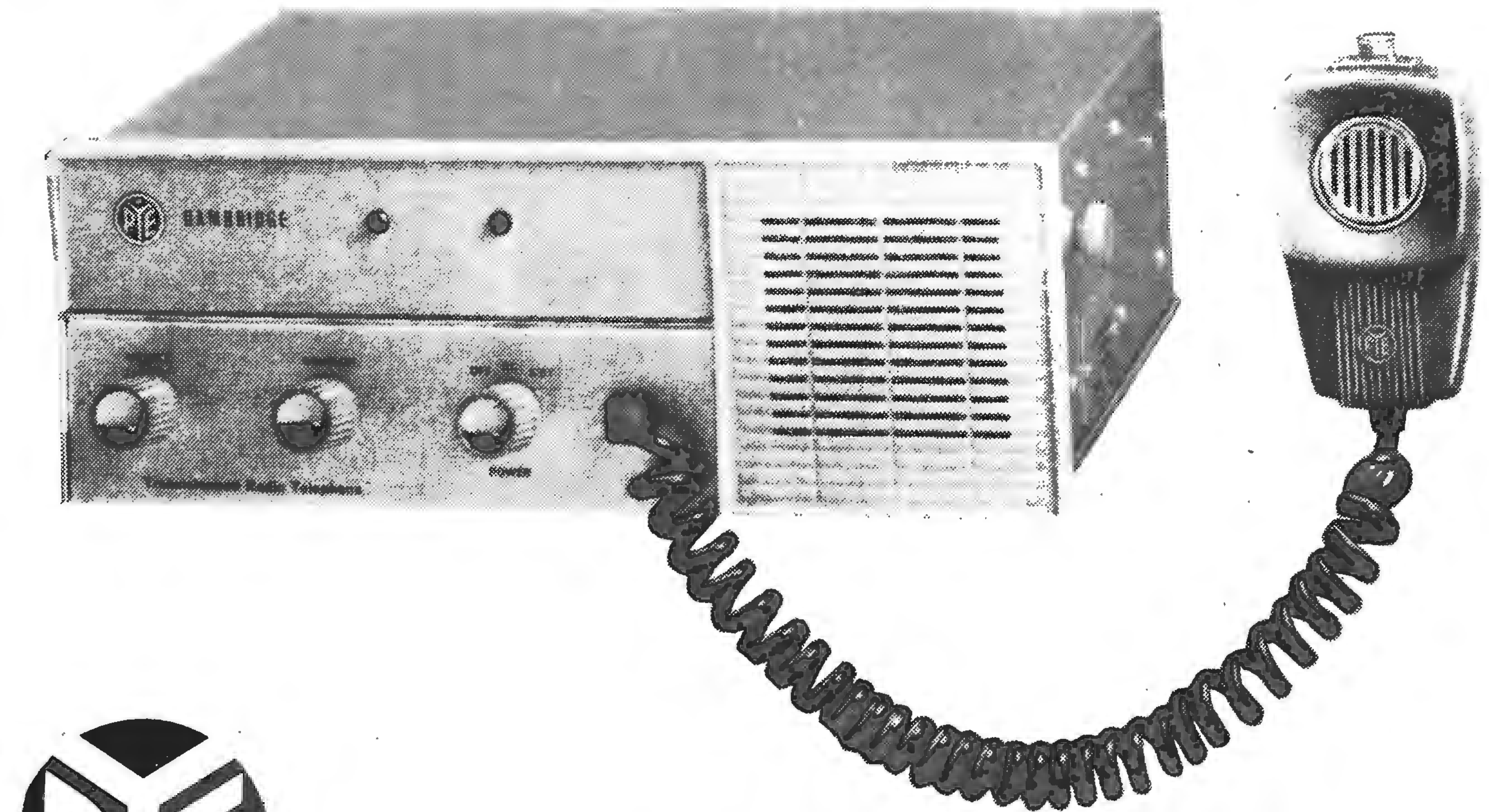
Airmec for peak performance consistently

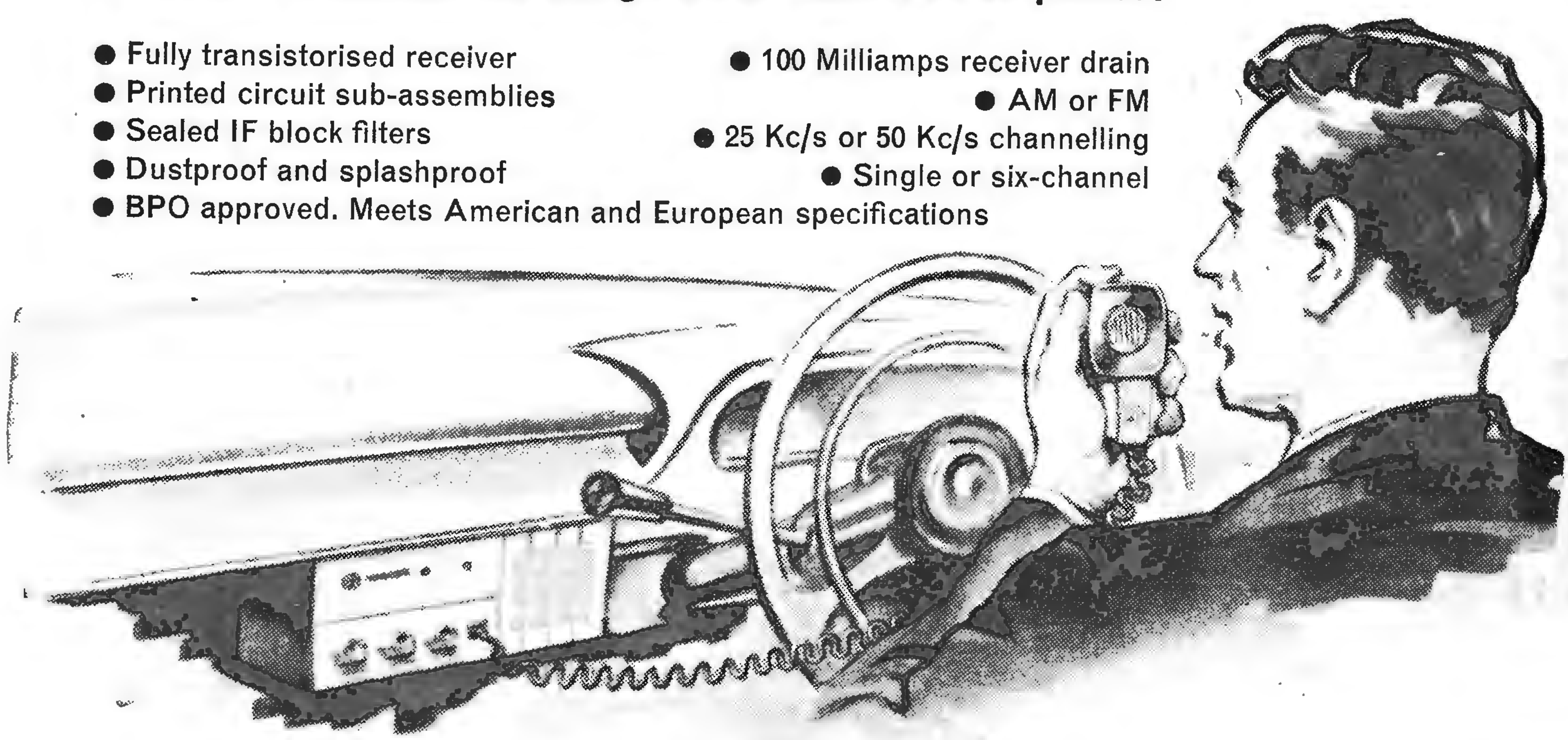
LABORATORY INSTRUMENTS DIVISION

Wave Analysers, Signal Generators, Oscilloscopes, Valve Voltmeters, Phase Meters, High Speed Counters, Ohmmeters, etc.

AIRMEC LIMITED HIGH WYCOMBE BUCKS ENGLAND
TELEPHONE: HIGH WYCOMBE 2501 (10 LINES)

AP 277a





NOISE IN AUDIO AMPLIFIERS

ANALYSIS APPLIED TO DESIGN OF TAPE PRE-AMPLIFIERS

By P. THARMA,* B.Sc.(Hons.)

THE sources of noise and a method of calculating the total noise of an amplifier are described in this article. From the noise spectrum of the valve or transistor, the noise spectrum of the amplifier can be derived. This can then be compared with the spectra of other sources of noise to obtain the subjective effect of noise under practical listening conditions.

Wide-band measurement of noise (with or without weighting) has very little value in assessing the subjective effect of noise. A narrow-band measurement in the 2-3 kc/s region can be more useful. This measurement can, in most cases, establish whether the noise is of any subjective significance.

The noise in pre-amplifiers for tape playback heads is considered in detail. It is shown that pre-amplifiers with the AC107 transistor and any tape head (irrespective of inductance) have noise spectra well below tape noise or room noise. The AC107 transistor with low inductance heads (50-100 mH) compares favourably with the EF86 valve and a 2 H tape head.

Sources of Noise

Thermal Noise (Nyquist's Theorem, ref. 1 chapter 2):—The noise in any circuit kept at a uniform temperature T can be described by a noise e.m.f. V in series with each resistance R of the circuit such that for a small frequency interval d*f*

$$V^2 = 4kTR\,df$$

where V is the noise voltage in volts
- k, Boltzmann's constant = 1.38. 10^{-23} joule per degree
- T, temperature in °K
- R is the resistance in ohms
- d*f* is in cycles per sec.

Alternatively, the noise can also be described by a current generator *i* of infinite impedance connected in parallel with R such that if $g = \frac{1}{R}$ then,

$$i^2 = 4kTg\,df$$

The above theorem is also valid for other passive electric, electroacoustic and electromechanical systems (such as microphones, pickups, etc.) as these can be completely defined by their electrical equivalent circuits.

Noise in Resistors.—Carbon resistors may have noise considerably greater than the values given by the above equations. This noise, due to the granular nature of the carbon, has a 1/*f* spectrum and is directly proportional to the current in the resistor. The magnitude of this noise depends on the manufacturing process, and commercially available resistors show a wide variation.

* Mullard Radio Valve Company, Applications Research Laboratory.

Typically the noise voltage from a 1/2 W 1 kΩ resistor with 5 mA d.c. is 7μV in the bandwidth 10 c/s to 10 kc/s. The thermal noise in the same bandwidth is 0.4μV. The noise voltage from a 100 kΩ 1/2 W resistor with 1 mA d.c. is 250μV in the bandwidth 10 c/s to 10 kc/s. The corresponding thermal noise is 4μV.

Wirewound resistors and certain metal film resistors do not have this " excess " noise.

Noise in Valves (Reference 1).—The noise in valves, in the audio frequency range, may be divided into three categories: shot, partition and flicker. Shot noise is due to the discrete nature of the electron stream, partition noise is caused by the random division of the stream between electrodes, and random emission from the cathode gives rise to flicker noise. Shot and partition noise have a uniform spectrum, i.e. the noise power in a unit bandwidth is independent of frequency. In flicker noise the power is inversely proportional to frequency and for this reason is often known as 1/*f* noise.

The noise can be represented by a voltage generator at the input of the valve. For calculation of the signal-to-noise ratio of an amplifier it is necessary to know the variation of the noise voltage per cycle with frequency. Typical curves for an EF86 are given in Fig. 1.

If a complex impedance is connected to the input of the valve, the noise due to the resistive component of the impedance will add (r.m.s. addition) to the valve noise. A curve of the total noise per cycle *versus* frequency can thus be drawn. Allowance can then be made for any frequency-dependent processes and the result gives the frequency spectrum of the noise of the pre-amplifier.

Noise in Transistors (Reference 1).—Transistors may show three types of noise:

(1) Thermal noise, caused by random motion of current carriers.

(2) Shot effect resulting from the " drift " of the

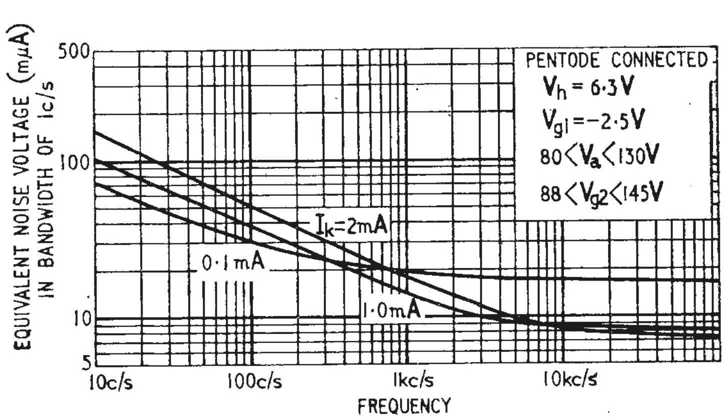


Fig. 1. Equivalent noise voltage curves for the EF86 valve.

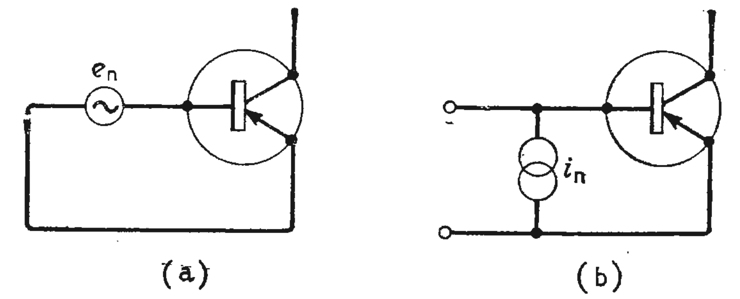


Fig. 2. Equivalent current and voltage noise generators of transistor.

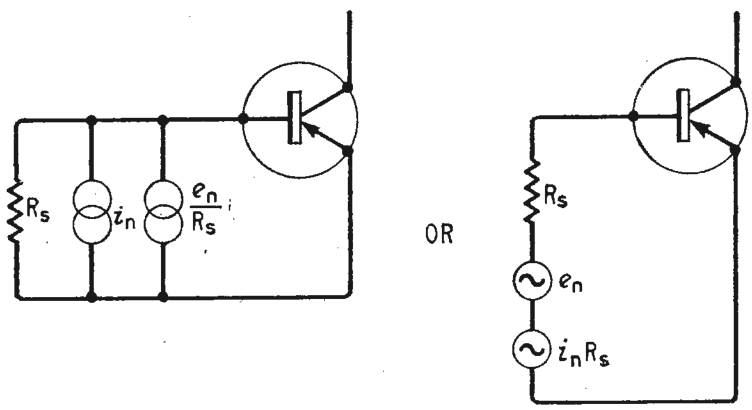


Fig. 3. Alternative equivalent noise generators with source resistance R_s.

current carriers caused by the applied electric field.

(3) Excess noise or flicker effect resulting from slow fluctuations in conductivity.

Thermal and shot noise have constant frequency spectra whilst the excess noise has a $1/f$ power spectrum. The turnover frequency, which is somewhat dependent on source resistance, is of the order of 3 kc/s for the AC107 low-noise transistor. Above this frequency the noise per cycle is constant, whilst below this frequency the noise is inversely proportional to the frequency.

Unlike the valve noise, the noise contributed by the transistor in circuit depends on the source resistance. The transistor thus requires at least two generators to define the noise completely. Several combinations of voltage and current generators are possible. The simplest is to assume the two generators (Fig. 2) which can be measured easily.

(1) With the input short circuited for a.c. the noise in the output can be referred back to the input to give an equivalent voltage generator e_n.

(2) With the input open circuit for a.c. the noise in the output can be referred back to the input to give an equivalent current generator i_n.

These two generators can, to a close approximation, be considered to be independent of each other.

For any specified source resistance R_s connected across the input of the transistor, the above generators can be replaced (Fig. 3) by a single generator which can either be:

(1) a current generator $\sqrt{i_n^2 + (e_n/R_s)^2}$ in parallel with R_s, or

(2) a voltage generator $\sqrt{e_n^2 + (i_n R_s)^2}$ in series with R_s.

Typical curves of noise current and noise voltage per cycle *versus* frequency, for the AC107 transistor, are shown in Fig. 4. The noise current generated increases with increase of current whilst the noise voltage generated decreases with increasing current.

The noise does not vary appreciably with collector voltage, provided the collector voltage is well below the collector-emitter softening voltage. As the softening voltage is approached, the noise increases considerably. Due to this, operation of the AC107 at collector-emitter voltage greater than 8 V is not recommended.

It can be shown that there exists an optimum source resistance for maximum signal/noise ratio.

For a resistive source giving constant signal power the equivalent signal current generated increases with decrease of source resistance. But as the source resistance decreases, the noise contribution due to the noise voltage generator increases, whilst the contribution due to the noise current generator remains unaffected. An optimum source resistance exists for which the signal-to-noise ratio is a maximum. The value of this resistance which equals e_n/i_n is usually lower than the source resistance for maximum power transfer. The matching for optimum noise involves a sacrifice in gain which is often, but not always, fairly small. For example, at $I_c = 0.3$mA and at a frequency of 2kc/s, $e_n = 2$mμV, $i_n = 1.6\mu\mu$A, R_s optimum = 1.25kΩ. Input resistance of transistor, $h_{fe} = 50$ at 0.3mA is 4.2kΩ.

The optimum signal-to-noise ratio is given by a 1.2kΩ source whereas maximum power transfer is obtained with a source resistance of 4.2kΩ.

With a finite source impedance connected across the input of the transistor, both the current and voltage generators will contribute to the noise. Also, there will be some noise due to the resistive component of the impedance. It is often convenient to consider the various noise generators as current generators in parallel as shown in Fig. 5. The source impedance is replaced by the admittance $Y_s = g + jb$ and the source generator is represented by a current generator i_s in parallel with Y_s.

The three noise generators are:

i_s. equivalent current noise generator of transistor

$e_n Y_s$. noise contribution due to voltage generator e_n

i_{th}. thermal noise due to resistive component of source impedance = 4kTg df.

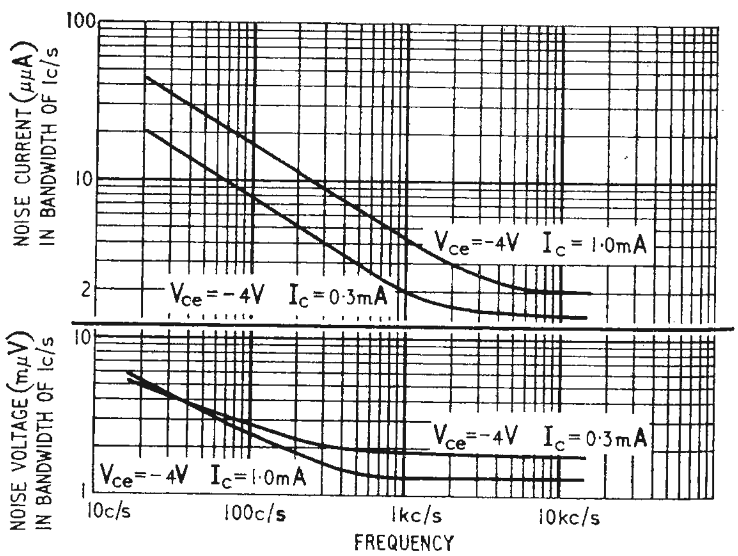


Fig. 4. Equivalent noise voltage and noise current curves for the AC107 transistor.

The total noise at any frequency is given by the r.m.s. addition of the above three components.

$$i_n^2 \text{ total} = i_n^2 + (e_n Y_s)^2 + i_{th}^2$$

The frequency spectrum of the noise of the pre-amplifier can thus be determined.

Over a frequency band f_2 to f_1 this becomes (see appendix):

$$i_n^2 (\text{total } f_2 - f_1) = \int_{f_1}^{f_2} (i_n^2 + (e_n Y_s)^2 + i_{th}^2)$$

Assessment of Noise

It is common practice to make a single measurement of the total hum and noise of an amplifier. Such a measurement has very little value in making a realistic assessment of the performance of the amplifier. Periodic components such as hum should be evaluated separately, as these have subjective effects which are different from noise. These and other problems are now discussed.

Methods of Measuring Noise.—The various methods of measuring noise are discussed in ref. 2. The most commonly used methods are:

(1) *Wide-band noise measurement*

In this method the total noise is measured using an r.m.s. reading voltmeter. The measurement will, of course, depend on the bandwidth, and this should be specified. The result has very little value in showing the subjective effect of noise, and comparison of amplifiers based on this measurement can be misleading.

(2) *Weighted noise measurement*

In this measurement, a "weighting" network with a response similar to Fig. 6, which simulates the frequency response of the ear at low sound levels, is placed between the amplifier and the r.m.s. reading meter. This method in effect measures the mid-band noise and is somewhat more useful than an unweighted measurement in assessing the subjective effect of noise, although either of these methods can be used for comparing amplifiers of similar basic structure.

(3) *Noise spectrum analysis*

The noise spectrum is analysed using narrow bandpass filters and a graph of noise per cycle *versus* frequency is plotted. The noise spectrum analysis gives complete data on the noise, as it can be compared directly with the spectra of other noises present in the system. Also the subjective effect of noise can be estimated from the spectrum. These are discussed in later sections.

Realistic Assessment of Amplifier Noise.—The noise in a reproducing system may be due to:

(1) Amplifier noise.
(2) Noise in the reproducing medium, e.g. tape noise.
(3) Room noise.

In practice, for the amplifier noise to be inaudible its spectrum should be everywhere a few dB below the medium noise or the room noise, whichever is higher.

It is common practice to give information on noise and sound levels in terms of sound pressures with reference to 10^{-16} watt per sq. cm. To convert from electrical quantities to sound pressures it is necessary to know the relation between the power output and sound pressure. The maximum preferred listening level is 90dB (page 80, reference 4) and the maximum power output is assumed to correspond to this level.

Much higher levels can be generated in many practical systems. But the maximum level at which one would prefer to listen is seldom likely to exceed 90dB, and the volume control will be turned down to give this maximum level. In properly designed systems, the noise contribution due to amplifier stages after the volume control should be negligible. Therefore the 90dB figure for maximum listening level can be taken as realistic.

In general, amplifiers using low-noise devices such as EF86 valves or AC107 transistors will in use have noise spectra well below room noise or medium noise. In exceptional circumstances, the amplifier noise may predominate. In this case the subjective effect of noise can be evaluated by comparison with the ear sensitivity characteristic, as discussed earlier.

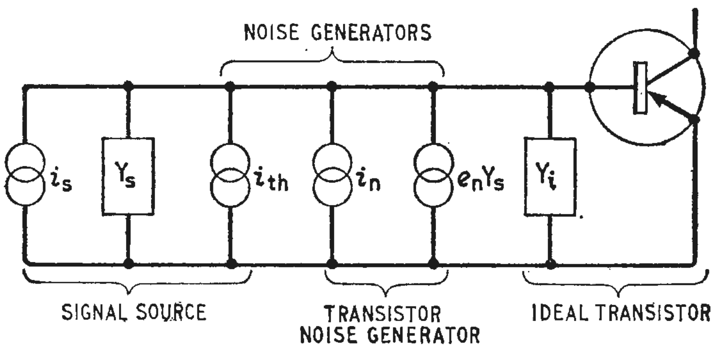


Fig. 5. Equivalent noise circuit of input stage.

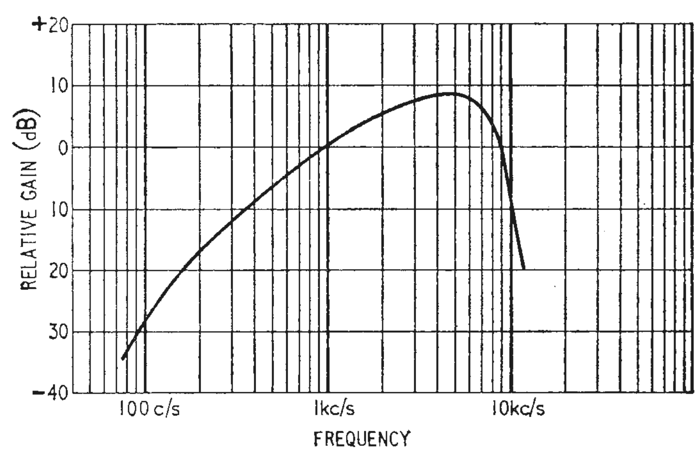


Fig. 6. Weighting curve simulating the sensitivity of the ear.

At low levels the ear is most sensitive to frequencies in the region of 2 to 3kc/s and it is the noise in this frequency band which has the greatest effect subjectively. A narrow band measurement at 2.5kc/s can in most cases predict the subjective effect of noise. If the noise in 1c/s bandwidth at 2.5kc/s is more than 100dB below maximum output, then it will not have any subjective effect, even in the absence of room noise. The equivalent wide-band (50c/s-15kc/s) signal-to-noise ratio can be anywhere from 50 to 60dB unweighted and 50 to 65dB weighted.

Assessment of Hum.—The subjective effect of single frequency components is different from that of purely random noise. In a sound reproducing system, components at mains frequency and multiples of mains frequency are likely to be present due to a variety of causes such as insufficient smoothing on d.c. supplies or induced hum. Single tones of this kind are likely to produce standing waves in a room, resulting in the accentuation of the hum levels over parts of the room. The local increase of sound level due to standing waves may be as much as 15dB (page 85, ref. 4). The intensities of these single tones should therefore be at least 15dB below the threshold levels given by the ear sensitivity characteristic.

The components at mains frequency and multiples of mains frequency should be measured separately. These components, to be inaudible under all circumstances, should preferably have the following values below maximum output:

50 c/s	42dB
100 c/s	59dB
150 c/s	66dB
200 c/s	71dB

This assumes that the loudspeaker in its enclosure does not resonate at any of these frequencies.

Pre-amplifiers for Tape Playback Heads

The study of the noise in input stages for tape playback heads of different inductances given in this section shows the various calculations in the assessment of noise. The following cases are considered.

A 2H tape head with EF86 pre-amplifier.
A 70mH tape head with AC107 pre-amplifier.
A 2H tape head with AC107 pre-amplifier.

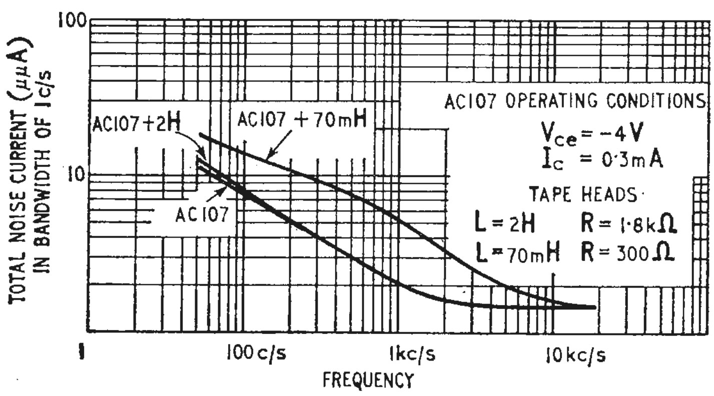


Fig. 7. Total noise current calculated for two values of head inductance with the AC107 transistor.

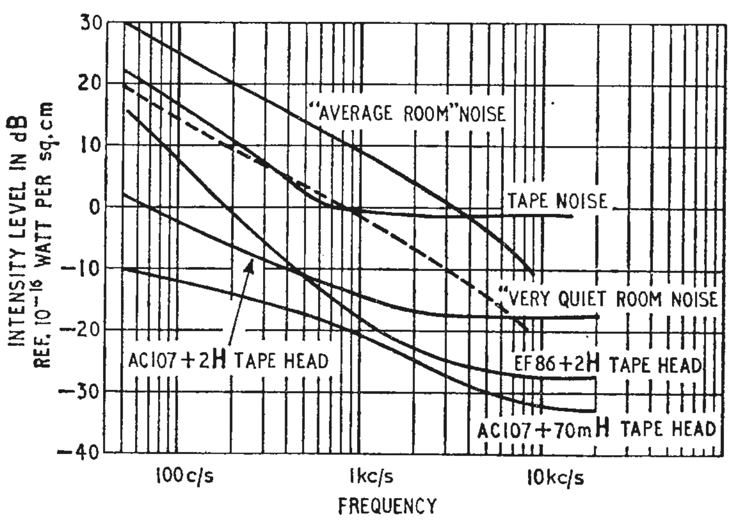


Fig. 8. Spectrum of room noise from pre-amplifiers for tape heads. Tape noise is for 9.5cm/sec. quarter track.

It is assumed that the magnetic circuits of the tape heads are identical. The open circuit voltage v_s of the heads is then proportional to $f\sqrt{L_s}$. For the particular heads used, at full modulation on tape.

$$v_s = 3\sqrt{L_s} \text{ mV at 1kc/s}$$

and $i_s = \dfrac{0.48}{\sqrt{L_s}}$ μA at all frequencies.

where L_s is the inductance of the head in henries. The above values are for a tape speed of $3\frac{3}{4}$ in/sec. and the heads are designed for quarter track working.

For constant magnetic induction in tape, the current i_s is independent of frequency. It is assumed that gap losses are negligible. It will be seen later that treble boost to equalize for gap losses has negligible influence on the subjective effect of amplifier noise, as this is well below the tape noise.

2H tape head + EF86

The operating conditions chosen for the EF86 are:

$Vg_1 = -2.5V$
$80 < V_a < 130V$
$88 < Vg_2 < 145V$
$I_k = 1.0mA$

The d.c. resistance of the 2H head was measured to be 1.8 kΩ. The thermal noise in one cycle bandwidth due to this resistance is given by:

$$V_{th}^2 = 4kTR = 29.10^{-18}$$

This noise is added (r.m.s. addition) to the equivalent noise of the valve, Fig. 1.

The signal output from the 2H head at 1 kc/s is $3\sqrt{L_s} = 4.2$ mV.

Assuming 4.2 mV = 90 dB on the intensity scale, the noise voltage can be plotted on the intensity scale. The equalization required (in dB) is now added to give the noise spectrum for the pre-amplifier stage including equalization.

Typical calculations:

at 10 kc/s: $e_n = 9\ m\mu V$
$(V_{th})^2 = 29.10^{-18}$
e_n (total) $= (\sqrt{9^2 + 29})\ 10^{-9}$
$= 10.5\ m\mu V$

$$\text{S/N ratio} = 20 \log_{10} \frac{4.2 \text{ mV}}{10.5\ m\mu V} = 112 \text{ dB}$$

This on the intensity scale becomes − 22 dB, assuming that the signal corresponds to + 90 dB on the intensity scale. Equalization required (R.I.A.A. characteristic, referred to 1 kc/s) at 10 kc/s is − 5.3 dB.

∴Noise at 10 kc/s, in 1 c/s bandwidth, corresponds to − 27.3 dB on the intensity scale.

The spectrum thus calculated is shown in Fig. 8, curve labelled " EF86 + 2H tape head."

Tape Heads Feeding the AC107 Transistor.— The tape head is represented by its equivalent current generator i_s in shunt with its admittance Y_s. For constant recorded flux, the generator i_s is independent of frequency.

The input admittance of the transistor Y_i is in shunt with Y_s and the current into the transistor will be frequency dependent due to the frequency dependence of Y_s and Y_i. Equalization is applied to compensate for this frequency-dependence so that the output is independent of frequency. If the noise is also represented by a current generator in shunt with Y_s, then this current will also suffer the same frequency-dependent losses due to Y_s and Y_i and the subsequent equalization. Therefore the signal-to-noise ratio can be calculated by considering the noise and signal current generators disregarding the losses and the equalization.

70mH Tape Head + AC107

The calculation of the equivalent noise current generator was discussed earlier. The following example illustrates the method. The operating conditions of the transistor are:

$I_c = 0.3$ mA

$V_{ce} < 8$V

$L_s = 70$ mH $R = 300\,\Omega$ i (signal) $= 1.8\mu$A for full modulation.

At a frequency of 1 kc/s,

$(\omega L)^2 = 20.10^4$

$Z^2 = R^2 + (\omega L)^2 = 29.10^4$

$g = R/Z^2 = 10.10^{-4}$ ohm^{-1}

$i_{th}^2 = 4\,kTg = 16.10^{-24}$

From Fig. 4, e_n at 1 kc/s = 1.8 mμV. The equivalent current due to e_n is e_n/Z.

$$\left(\frac{e_n}{Z}\right)^2 = 11.10^{-24}$$

Also from Fig. 4, i_n at 1 kc/s = 2.0$\mu\mu$A

$$i_n\,(\text{total}) = \sqrt{i_{th}^2 + \left(\frac{e_n}{Z}\right)^2 + i_n^2}$$

$= 5.5\ \mu\mu$A/cycle.

A plot of i_n (total) versus frequency calculated in this way is given in Fig. 7.

Assuming that the signal current of 1.8μA corresponds to 90dB on the intensity scale, the noise current can be connected to its equivalent intensity level. This graph is shown in Fig. 8, curve ' AC107 + 70mH tape head '.

2H *tape head + AC*107

$L_h = 2$H

$R = 1.8$kΩ

$i_s = 0.34\mu$A

As the source impedance is increased, the contribution due to the voltage generator of the transistor (e_n/Z) becomes small compared with the current generator i_n. Also the thermal noise contribution becomes negligible. The total noise current is therefore very nearly equal to the noise current generator of the transistor. This is shown in Fig. 7 which shows the graphs for the 2H and 70mH tape heads and the noise current generator of the transistor. The signal current with the 2H head is, of course, much lower than with the 70mH head, giving a poorer signal-to-noise ratio. This is illustrated in Fig. 8, curve ' AC107 + 2H head ', which shows the noise currents replotted on the sound intensity scale.

Comparison of Amplifier Noise with Tape Noise and Room Noise.—In order to obtain a realistic assessment of the pre-amplifier performance, the noise from the pre-amplifiers should be compared with room noise and tape noise. Data on the spectrum of room noise is given in references 3 and 6. Exceptionally quiet rooms are about 10dB lower than

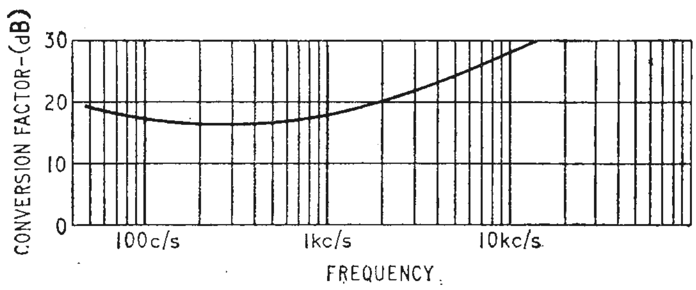


Fig. 9. Conversion from noise per cycle to masking level

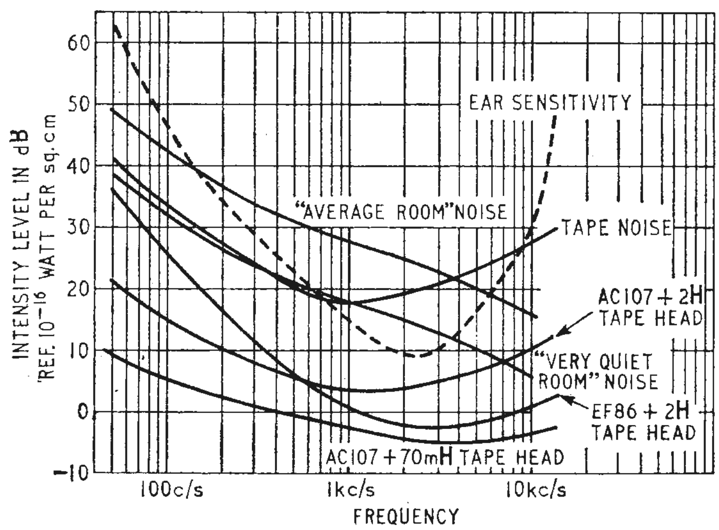


Fig. 10. Masking levels calculated from Figs. 8 and 9.

the average and the spectral distribution does not vary appreciably with local conditions. Spectra of noise of ' average ' and ' quiet ' rooms are shown in Fig. 8.

The spectrum of tape noise is given in reference 2. The data given there is for full track (¼in tape) at 15 in/sec. The signal-to-noise ratio for quarter track working at 3¾ in/sec will be worse by approximately 10dB. After allowing for this difference the spectrum is replotted in Fig. 8, curve ' **Tape Noise** '.

The following conclusions can be drawn from the graphs of Fig. 8.

(1) All three pre-amplifier designs considered have noise spectra well below the tape noise or room noise.

(2) With the AC107 transistor, the 70mH tape head is better than the 2H tape head. Detailed calculations show that the region of 50 to 100mH is optimum.

(3) The AC107 with 70mH is slightly better than the EF86 with 2H. The large difference in low frequency noise is not significant subjectively, as will be discussed in the next section.

The above conclusions relate to quarter track working at 3¾in/sec. With half track working at 7½ in/sec the results will be better.

The output from the head will be 10dB higher so that the amplifier noise will be 10dB lower than in Figure 8. The signal to tape noise ratio will be better by 5dB so that the tape noise spectrum will be 5dB lower than in Fig. 8. Therefore the difference between the tape noise and pre-amplifier noise will be greater by 5dB.

The effect of tone controls is to modify the spectrum by the amount of " boost " or " cut ". In the examples considered, the noise spectrum is so low

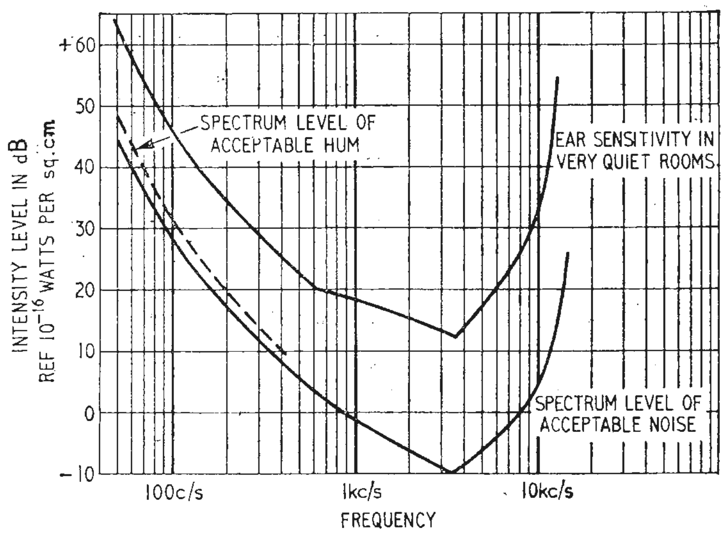


Fig. 11. Spectrum levels of acceptable noise and hum.

that a 10dB boost of treble or bass has negligible subjective effects.

Subjective Effects of Noise

In the absence of noise, the threshold of hearing is determined by the ear sensitivity characteristic. Noise increases the threshold by "masking". The masking level can be calculated from the spectrum level as discussed in references 3, 5 and 7. The conversion factor is given in Fig. 9. The masking curves for the noise spectra of Fig. 8 and the ear sensitivity curve are given in Fig. 10. Several conclusions can be drawn from these curves.

(1) The threshold of hearing is determined by the ear sensitivity characteristic for the low and high ends of the frequency range and by room noise for the middle of the range.

(2) In the absence of room noise, the ear is most sensitive in the frequency region of 2-3 kc/s. The noise in this frequency region is therefore subjectively more important than the low and high frequency ends. Room noise shifts the emphasis to the 3 to 6 kc/s region.

(3) The very poor sensitivity of the ear to low frequencies implies that considerable amount of low-frequency noise, e.g. flicker noise, can be present without any significant subjective effect.

(4) In most cases measurement of the noise in the 2-3 kc/s band is sufficient to assess the subjective effect of noise.

Using the data of Fig. 8 and the ear sensitivity curve of Fig. 10, it is possible to deduce the spectrum level (intensity in 1 cycle bandwidth) of acceptable noise. Such a curve for very quiet rooms (ignoring room and speaker resonances) is given in Fig. 11. The acceptable spectrum level of hum is also shown.

REFERENCES

1. "Noise," by A. van der Ziel (Chapman and Hall, 1955).

2. "A Comparison of Several Methods of Measuring Noise in Magnetic Recorders for Audio Applications," John G. McKnight, *I.R.E. Transactions on Audio*, March-April 1960.

3. "Hearing, the Determining Factor for High Fidelity Transmission," Harvey Fletcher. *Proc. I.R.E.*, June 1942.

4. "High Quality Sound Reproduction," by James Moir (Chapman and Hall, 1961).

5. "Auditory Patterns, Harvey Fletcher. *Rev. Mod. Phys.* Vol. 12, January 1940.

6. "Room Noise Spectra at Subscribers Telephone Locations," D. F. Hoth. *J. Acous. Soc. Amer.*, Vol. 12, No. 4, April 1941.

7. "Masking of Pure Tones and Speech by White Noise," J. F. Hawkins and S. S. Stevens. *J. Acous. Soc. Amer.*, Vol. 22, 1950.

APPENDIX

Some of the basic processes in calculations with noise expressed as voltages is given below. Similar considerations apply to noise expressed as currents.

Addition of Noise Voltages

Noise voltages are summed up by r.m.s. addition, e.g. if V_1, V_2, V_3 are three noise voltages in series, then the total noise, V_T is given by:

$$V_T \sqrt{V_1^2 + V_2^2 + V_3^2} \quad .. \quad .. \quad .. \quad .. \quad (1)$$

Noise in a Frequency Band $f_2 - f_1$

The total noise in a frequency band $f_2 - f_1$ in which the noise voltage per cycle is constant at V_1 is:

$$\sqrt{V_1^2 (f_2 - f_1)}$$

If the noise voltage per cycle, V_f, varies with frequency, then the total noise V_T in the frequency band $f_2 - f_1$ is given by:

$$V_T^2 = \int_{f_1}^{f_2} V_f^2 df \quad .. \quad .. \quad .. \quad .. \quad (2)$$

Noise Subject to Frequency-dependent Amplification

If the noise voltage V_f passes through an amplifier whose gain G_f varies with frequency, then the noise in the output $V_{n,o}$ is, for bandwidth $f_2 - f_1$.

$$V^2_{n,o} = \int_{f_1}^{f_2} (V_f G_f)^2 df \quad .. \quad .. \quad .. \quad (3)$$

Equivalent Noise Voltage and Signal/Noise Ratios

In practical applications it is more useful to express the total noise with reference to an input signal of specified frequency. If the gain of the amplifier at the signal frequency is G_s then the equivalent noise at the input is:

$$V^2_{n,i} = \frac{1}{G_s^2} \int_{f_1}^{f_2} (V_f G_f)^2 df \quad .. \quad .. \quad (4)$$

This equation can be re-written in the form:

$$V^2_{n,i} = \int_{f_1}^{f_2} \left(V_f \frac{G_f}{G_s}\right)^2 df \quad .. \quad .. \quad .. \quad (5)$$

In the above equation V_f is multiplied by the ratio of gains G_f/G_s and the actual values of gains need not be known.

If the signal input voltage is V_s, then the signal to noise ratio is given by:

$$\text{S/N ratio} = \frac{V_s}{V_{n,i}} \quad .. \quad .. \quad .. \quad .. \quad (6)$$

The equivalent noise voltage $V_{n,i}$ given by equation (5) can be evaluated numerically as discussed below.

Calculation of $V_{n,i}$ and S/N Ratio

Given the graphs showing the variation of V_f and G_f with frequency, then a graph of $V_f \frac{G_f}{G_s}$ *versus* frequency can be drawn. Using this graph, $V_{n,i}$ and S/N ratio are calculated as follows:

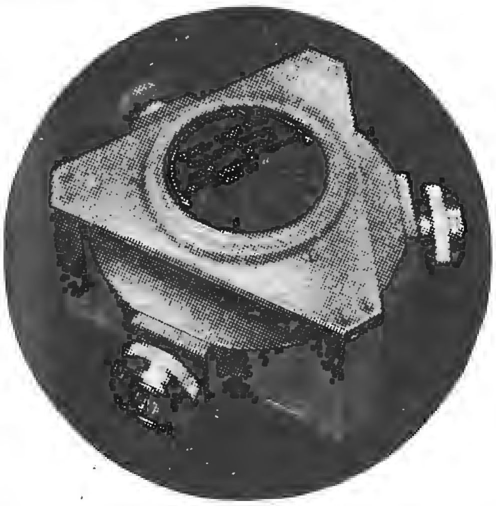
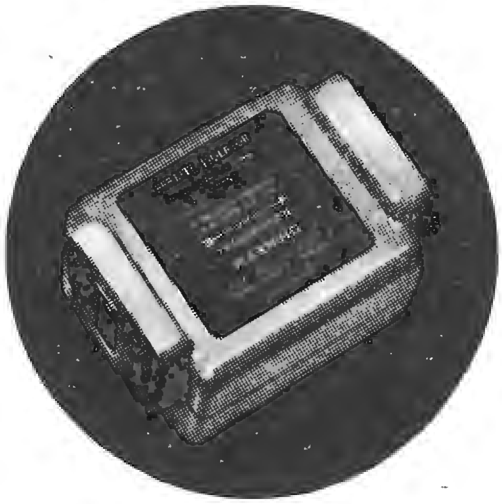
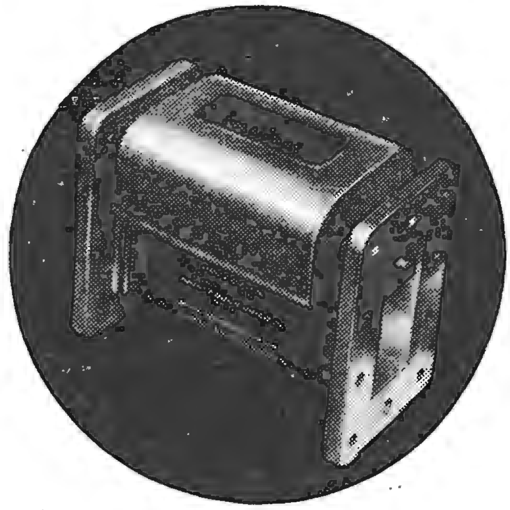
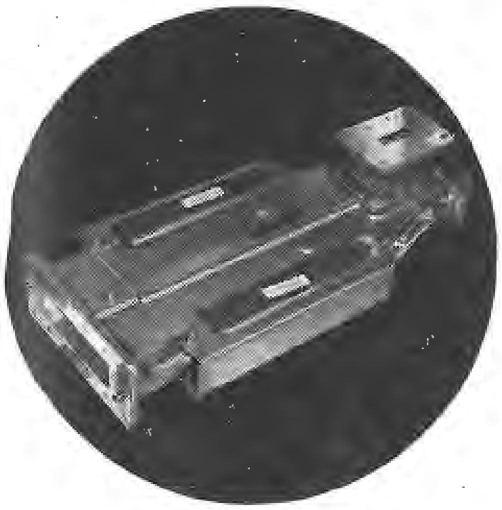
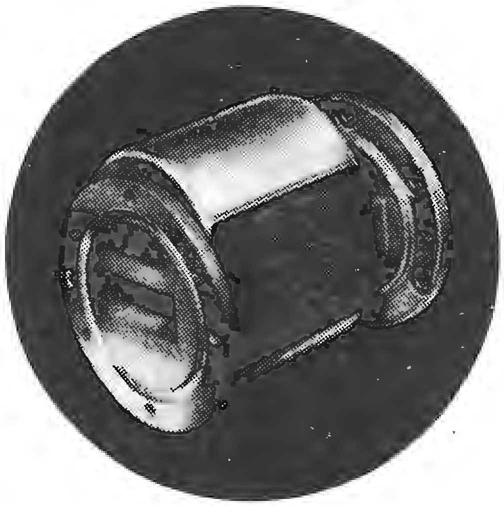
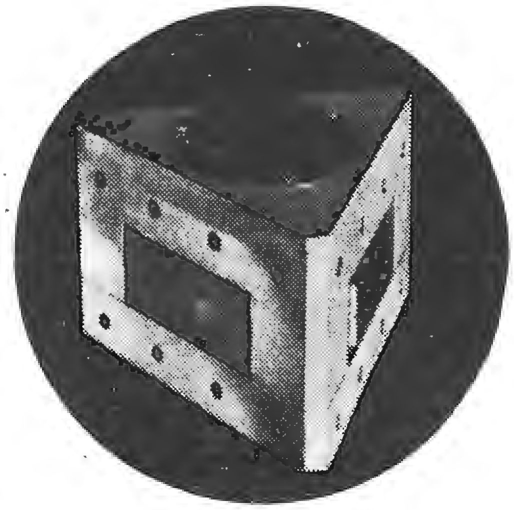
(1) Divide the frequency range $f_2 - f_1$ into suitable intervals of bandwidth B_1, B_2, B_3 . . . .

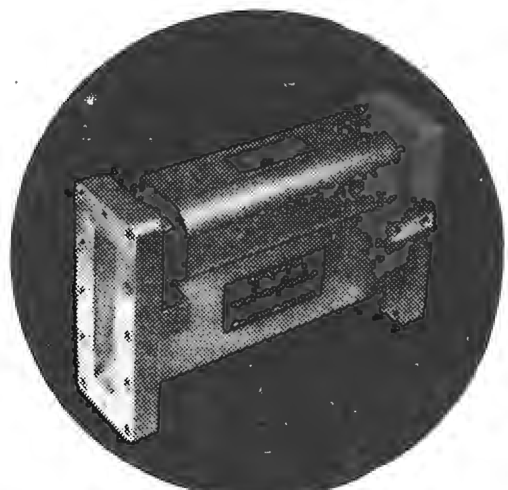
(2) Determine the ordinates V_1, V_2, V_3 . . . . at the centre of frequencies of B_1, B_2, B_3 . . .

(3) Calculate the sum:
$$(V_1^2 B_1 + V_2^2 B_2 + V_3^2 B_3 \ldots)$$

(4) $V_{n,i}$ is given by the square root of the above sum

(5) S/N ratio is $V_s/V_{n,i}$



TRANSISTOR CUT-OFF FREQUENCIES

FREQUENCY SYMBOLS EXPLAINED

By D. N. TILSLEY B.Sc., Grad.Inst.P., A.M.Brit.I.R.E.

A QUESTION often asked about a transistor is " What is its cut-off frequency?" The implication is that it will work fairly satisfactorily up to this frequency, but at higher frequencies its performance will be poor.

When the manufacturer's published data is read to find this very useful frequency, symbols such as f_1, f_T or f_α are found but they all seem too high.

f_1, f_T or f_α are all roughly the same, and for the commonest type of transistor would be about half a megacycle. But this same transistor is described as an Audio Frequency transistor, and as usually employed its current gain falls off rapidly above about 10kc/s. I have heard it said that the really important parts of a contract are not the initial words like WHEREAS in capitals, but the clauses at the end in tiny print. In our case the f is not very important (anyone can see that it is a frequency since it is specified in kc/s), but the little subscripts, as in f_1, f_α, f_β or f_T must be looked at very closely.

f_α.—Let us first consider a transistor in the common-base configuration. At low frequencies its current gain is α, which is very close to 1. At high frequencies this current gain decreases, and at a certain frequency it has dropped to $1/\sqrt{2}$ or 0.707 of its low frequency value. The frequency is called the "alpha cut-off frequency," and it is denoted by the symbol of f_α This is shown in Fig. 1.

If the current has fallen by the ratio $1/\sqrt{2}$, then since the power which would be available in a load is proportional to the square of the current, then the output power will be halved. This could also be specified as a loss of 3dB. f_α could therefore alternatively be defined as the "3dB frequency" or the "half-power frequency." But it is very important to realize that this refers to the common-base configuration only, and the subscript α is a useful reminder of this. For an audio transistor, 500kc/s is a common figure for f_α, but radio-frequency transistors are available with an f_α of over 300Mc/s.

f_β.—Transistors are more generally used in the common-emitter connection, and here a current gain of β is obtained, where numerically $\beta = \alpha/(1-\alpha)$. We will assume a typical value of 80 for β, but in fact variations of between 20 and 150 are not unusual in the same type of transistor. Let us consider our audio transistor of f_α = 500kc/s and β = 80 being used in the common-emitter configuration. The current gain of 80 at low frequencies falls off as the frequency increases, and at a certain frequency it has dropped by 3dB to $80/\sqrt{2}$ or 80 × 0.707 or approximately 57. This frequency is called f_β, and it is usually this which is required rather than f_α.

The f_β and f_α of a transistor are related by $f_\beta = f_\alpha/\beta$. In our case f_β = 500/80kc/s = 6.3kc/s and it is obvious why the manufacturer regards it as suitable for only audio frequencies. Later this important relation will be proved: here it will merely be shown to be reasonable. As we said earlier, β, the common-emitter current gain, and α are related by $\beta = \alpha/1-\alpha$. The variation in β as α varies from 0.99 down to 0.95 are shown below:

α	0.99	0.98	0.97	0.96	0.95
β	99	49	32	24	19

A small change in α will be seen to cause a large change in β. At f_α the current gain has fallen to 0.707 of its low frequency value of about 0.98 to 0.99, and at this frequency will give a current gain very close to 0.70. When α has fallen to 0.70, the common-emitter current gain β has fallen to $0.7/1-0.7 = 0.7/0.3 = 2\frac{1}{3}$.

At f_α the common-emitter current gain has fallen from about 80 down to about 2, and so the frequency f_β at which it would have fallen down to 80 × 0.707 = 57 will be much lower than f_α.

Conversely, over the range of frequencies in which β has fallen from 80 to 57, the α changes from 0.988 to 0.983, and so again f_β must be very much less than f_α, over which range α would drop to about 0.7.

At frequencies considerably above f_β, the common-emitter current gain falls off at 6dB per octave. Since a fall of 6dB means that the voltage or current has halved, and an interval of an octave means that the frequency has been doubled, a fall of 6dB per octave merely states that the current gain is inversely proportional to frequency.

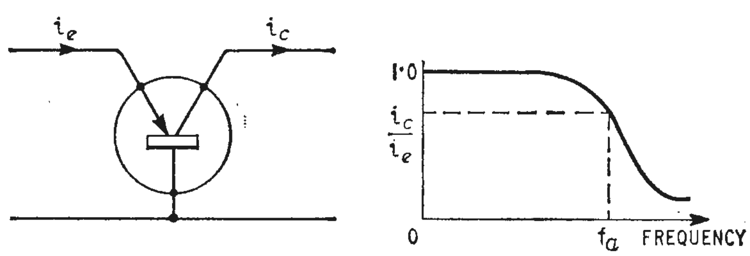


Fig. 1. Derivation of the term "alpha cut-off frequency".

f_1.— So far we have considered f_α and f_β, but the most frequently quoted frequency is neither of these: it is f_1. This is the frequency at which the common-emitter current gain has fallen to unity. One way of finding f_1 is to short circuit the transistor of a common-emitter amplifier by a short piece of wire between its base and collector. If this piece of wire gives more output than the transistor, then the frequency applied is above f_1. The frequency at which the transistor gives neither current gain nor loss is found, and then the same output will be obtained when either the transistor or the piece of wire is connected, and this frequency is f_1. (In practice changing from the transistor to the short circuiting link may cause a change in the impedance presented to the signal generator, which may vary the input current and thus invalidate the result. A " swamping " resistor of about 100kΩ connected in series with the signal generator should reduce this error to negligible proportions.)

f_T.—There should be little difficulty in measuring f_α, f_β or f_1 up to a few megacycles per second, but above 50Mc/s the difficulties and errors increase rapidly. It is therefore usual to plot the curve of current gain in dB, against frequency on a logarithmic scale for frequencies well above f_β, and then to extrapolate it as a straight line falling at 6dB per octave. The frequency at which this line, shown dotted in Fig. 2(a) cuts the $\beta = 1$ or 0dB axis is sometimes called f_T.

The frequencies f_1 and f_T should be the same for a fall of 6dB per octave, but in practice some transistors show the "tail" at extreme high frequencies shown in Fig. 2(b). Here f_1 is considerably higher than f_T, but it would be unfair to quote this high value just because the transistor still gives a trace of gain at these frequencies. Apart from ease of measurement this is an additional advantage which f_T possesses over f_1.

Going back to f_α, we see that when $\alpha = 0.7$, β is a little over 2. At f_1, β has fallen to 1. There is not a very great difference in frequency between f_α and f_1, and as a rough guide we may take f_1, f_T and f_α as all being the same, and here this frequency will be called f_1.

For the common-base connection we have a low-frequency current gain of about 1, and a bandwidth of f_1. The same transistor as a common-emitter amplifier has a low-frequency current gain of β, and a bandwidth of $f_\beta = f_1/\beta$. So f_1 is really a gain $\times$ bandwidth product. If f_1 is 500 kc/s and a current gain of 5 is required, then a bandwidth of 100kc/s is possible: increasing the current gain to 100 will decrease the bandwidth to 5kc/s. Change from common emitter to common base—apply negative feedback—do what you will, the product of the current gain and the bandwidth will be approximately f_1.

It is not always realized that the common-

Fig. 2. Although f_1 can be higher than f_T, for practical purposes, f_T is considered as gain cut-off frequency.

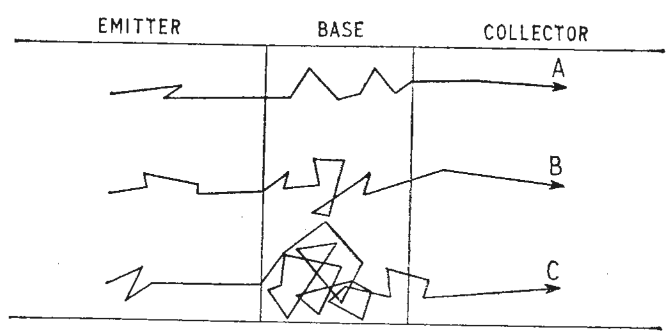


Fig. 3. Paths of holes through base region.

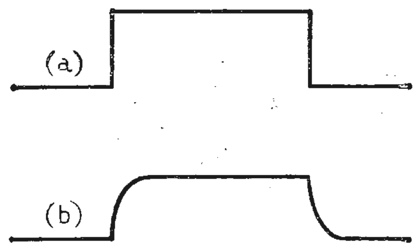


Fig. 4. Different transit times of holes give exponential rise and fall times.

collector amplifier or emitter follower has a bandwidth similar to that of the common-emitter amplifier, since both connections give a current gain of approximately β. Because of its similarity to the cathode follower, many expect it to function satisfactorily up to about f_α, instead of f_β.

f_{osc}.—There is yet one more frequency symbol, f_{osc}, to be considered: this is the highest frequency at which oscillation may be obtained. At f_1 the current gain is unity, but there may still be a power gain since the output impedance is probably higher than the input impedance. And if there is a power gain then oscillation is possible. A skilled experimenter with plenty of time on his hands may sometimes manage to make a transistor oscillate at remarkably high frequencies. Since f_{osc} is to some extent a measure of the ability and patience of the tester, the use of f_{osc} is declining and f_1 or f_T are now the most popular frequencies to be specified.

So far we have defined f_α, f_1 and f_T and said that they are roughly the same; we have defined f_β and stated that $f_\beta = f_\alpha/\beta$; we have defined f_{osc} and then immediately dismissed it.

Transit Time.—We will now attempt to demonstrate the truth of these relationships, but firstly the reason for the deterioration of transistor performance at high frequencies must be considered.

Suppose that the current into the emitter is suddenly switched on. For a p-n-p transistor this means that a large number of holes is injected from the emitter into the base. These holes diffuse in a random and purposeless fashion through the narrow base and into the collector, and Fig. 3 shows the paths of three.

Hole B wanders about considerably before finally arriving at the base-collector junction where the negatively-biased collector captures it.

Hole C is even less direct, but A follows a moderately direct path. If the input current were represented in Fig. 4(a), then the output current would be as shown in Fig. 4(b).

The start of the output current rise is almost coincident with the input rise, since holes such as A take a fairly direct path, and their transit time is quite negligible. Most holes, however, are somewhat like B, but the full output current will be attained only when the slow coaches like C have arrived. When the input current suddenly ceases, the output current does not fall to zero until all the errant holes have ceased their wanderings and finally reached the base-collector junction.

The shape of the output pulse therefore depends on the transit time of holes through the base region: if all the holes had the same transit time then the output current waveform would be merely the input current waveform delayed by the transit time, but it is the differing transit times which account for the output current shape. Now this shape is very reminiscent of the "exponential" waveform which would be obtained for the current flowing through the

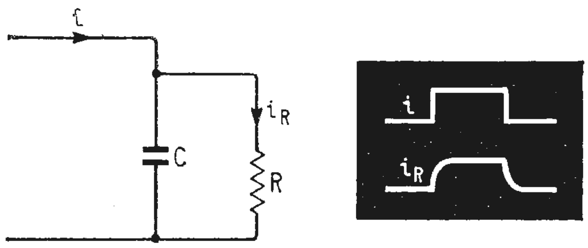


Fig. 5. C represents diffusion capacitance.

resistor when a step of current is made to flow into the parallel combination of resistor and capacitor.

The resemblance is more than a superficial likeness—the equations governing the diffusion of the holes through the base are very similar to the rise and fall of the resistor current in Fig. 5. (Had a lossy R and C transmission line been taken instead of the simple R-C combination, the similarity to hole diffusion would have been much more exact. But I, for one, cannot easily solve problems connected with such a line, and so no useful purpose is served in transforming one difficult problem into another.)

This representation of hole diffusion is very useful, and the high-frequency behaviour of transistors is often simulated by including such a capacitance in the equivalent circuit, called the "diffusion capacitance."

Derivations: In this article we are primarily concerned with the response of transistors to sine waves, and for these we can use the j notation.

The impedance of R and C in parallel is

$$\frac{R\left(\frac{1}{j\omega C}\right)}{R+\frac{1}{j\omega C}}$$

multiplying above and below by $j\omega C$ gives

$$\frac{R}{1+j\omega CR}\ .$$

therefore, $V = i\,\frac{R}{1+j\omega CR}$ and $i_R = \frac{V}{R} = \frac{i}{1+j\omega CR}\ .$

At low frequencies $\omega = 0$ and then $i_R = i$.

When $\omega CR = 1$, the modulus of i_R is $i/\sqrt{1+1} = i/\sqrt{2}$. Therefore $i_R = i/\sqrt{2}$ or 0.707 of its low-frequency value when $\omega = 1/CR$. If we call this value ω' then $CR = 1/\omega'$ and we could write:

$$i_R = \frac{i}{1+j\frac{\omega}{\omega'}} \text{ or } \frac{i}{1+j\frac{f}{f'}}$$

This would enable us to find the current flowing through R at a frequency f in terms of the frequency f' at which the "current gain" i_R/i has fallen to $1/\sqrt{2}$ of its low-frequency value. The corresponding expression for the transistor is $\alpha = \alpha_o/(1+jf/f'_\alpha)$ where α_o is the low-frequency current gain. At frequencies much greater than f_α, f/f_α is much greater than 1, and so numerically

$$\alpha = \frac{\alpha_o}{\frac{f}{f_\alpha}} = \frac{\alpha_o f_\alpha}{f}$$

which shows that the current gain will be inversely proportional to frequency, and so will fall at 6dB per octave.

In the common-emitter connection $\beta = \alpha/(1-\alpha)$ and at high frequencies $\alpha = \alpha_o/(1+jf/f_\alpha)$.

Therefore,

$$\beta = \frac{\frac{\alpha_o}{1+j\frac{f}{f_\alpha}}}{1-\frac{\alpha_o}{1+j\frac{f}{f_\alpha}}}$$

Multiplying above and below by $1+jf/f_\alpha$ we obtain

$$\beta = \frac{\alpha_o}{1+j\frac{f}{f_\alpha}-\alpha_o}$$

$$= \frac{\alpha_o}{(1-\alpha_o)+j\frac{f}{f_\alpha}}$$

$$= \frac{\frac{\alpha_o}{1-\alpha_o}}{1+j\frac{f}{f_\alpha(1-\alpha_o)}}$$

Now $\alpha_o/(1-\alpha_o) = \beta_o$, the low-frequency value of β

therefore $$\beta = \frac{\beta_o}{1+j\frac{f}{f_\alpha(1-\alpha_o)}}$$

This will be 3dB down when the denominator is $1+j$, and this will be when $f = f_\alpha(1-\alpha_o)$. By definition this frequency is f_β,

therefore $f_\beta = f_\alpha(1-\alpha_o)$.

Since $\beta_o = \alpha_o/(1-\alpha_o)$, therefore $1-\alpha_o = \alpha_o/\beta_o = 1/\beta_o$ (approximately, for α_o is between 0.95 and 1.00). Therefore, $f_\beta = f_\alpha/\beta_o$, and a convenient expression is $\beta = \beta_o/(1+jf/f_\beta)$. A few lines above we had

$$\beta = \frac{\alpha_o}{(1-\alpha_o)+j\frac{f}{f_\alpha}}$$

This can be used to find f_1, the frequency at which β, or more accurately the modulus of β, is unity.

If $|\beta| = 1$ then

$$\alpha_o = \sqrt{(1-\alpha_o)^2+\left(\frac{f_1}{f_\alpha}\right)^2}$$

therefore $\alpha_o^2 = 1+\alpha_o^2-2\alpha_0+\left(\frac{f_1}{f_\alpha}\right)^2$

therefore $\left(\frac{f_1}{f_\alpha}\right)^2 = 2\alpha_0-1$, and $f_1 = f_\alpha\sqrt{2\alpha_0-1}$

Now since α_o is very nearly unity, f_1 is approximately equal to f_α.

Finally it should be noted that since

$$\beta = \frac{\beta_o}{1+j\frac{f}{f_\beta}}\ ,$$

then at frequencies well above f_β the modulus (or magnitude) of β is inversely proportional to frequency and so the 6dB per octave rule is justified in obtaining f_1 by extrapolation.

So it has been shown that f_α, f_1 and f_T are all virtually the same frequency, but the common-emitter current gain will be 3dB down at f_β, where

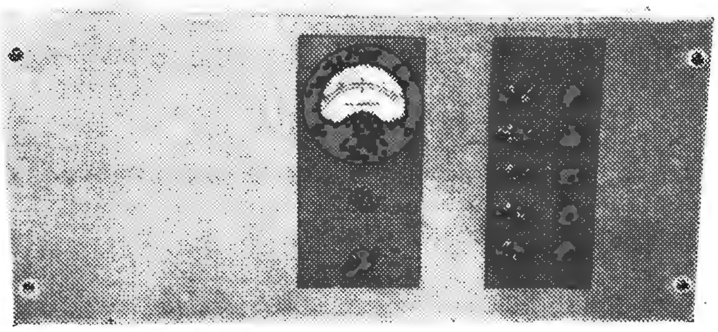
$$f_\beta = \frac{f_\alpha}{\beta}.$$

MANUFACTURERS' PRODUCTS

NEW ELECTRONIC EQUIPMENT AND ACCESSORIES

Teleprinter Drive Unit

UP TO five teleprinters can be driven from a low-level input signal by the Westrex teleprinter distribution unit TRDU MODEL 2411-A. Each of the five outputs is individually adjustable and the essential characteristics of each may be monitored by a meter on the front panel of the equipment. The relay used was designed specifically for the unit, the radio interference suppression being such that the complete equipment can be installed adjacent to radio reception apparatus. Keying speeds of up to 400 bauds are possible. The equipment will operate from a 110/230 V, 50/60 c/s mains supply. It is supplied to be mounted in a 19-in rack but a cabinet for bench use can be supplied. The address of the Westrex Co. Ltd., a division of Litton Industries, is Coles Green Road, London, N.W.2.



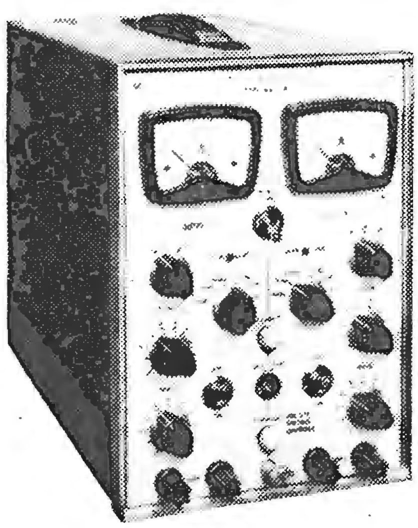
Westrex teleprinter distribution unit TRDU Model 2411-A.

For further information circle 301 on Service Sheet.

Power Supply

THE FIRST of a range of new-style Solartron instruments is a twin power supply Type AS1164.2. Each of the outputs is independently variable from 0-30V d.v. Output voltage control settings are made by decade switches used in conjunction with the range switches; the setting error is quoted as ±2%. The outputs are arranged to give 2×0-30V at 1A, 0-30V at 2A or 0-60V at 1A. When used in parallel operation the output current is read on the right-hand meter. Floating outputs provide negative and positive supplies. The overload protection system has visual indicators and the load current can be limited to any one of six preselected values. Other features include a stability factor greater than a 1,000:1, a ripple figure of 1mV, p-p, regulation better than 0.1% at maximum output and an output impedance of less than 0.35Ω up to 100kc/s. The instrument weighs 25lb and its dimensions are approximately 11×7×14in. The address of the manufacturers is Victoria Road, Farnborough, Hants.

For further information circle 302 on Service Sheet.



Solartron twin transistor power supply, Type A.S.1164.2.

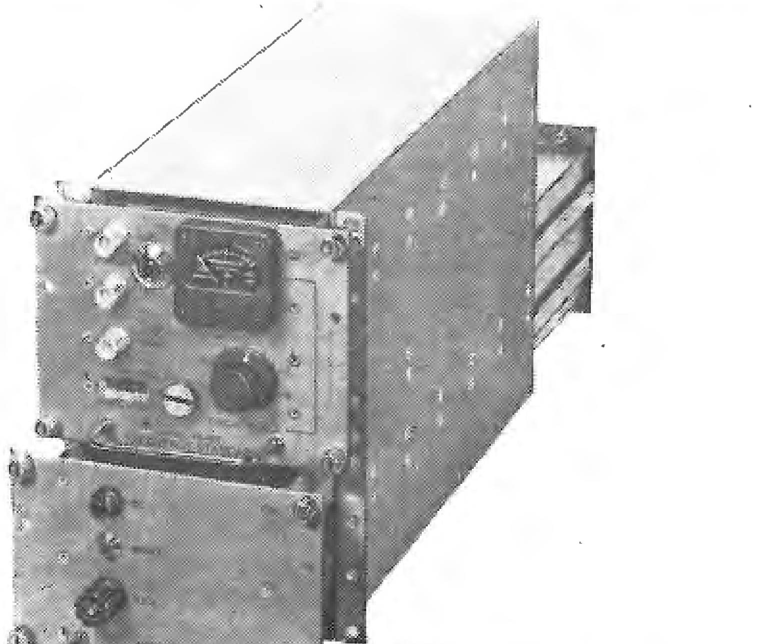
Instrument Cases

EIGHT SIZES of instrument case are being manufactured by Olsen Electronic Ltd., 54 Myddleton Street, London, E.C.1. The smallest of the range is $6\frac{1}{2}\times4\frac{1}{2}\times4\frac{1}{2}$in, the largest being $14\times10\frac{1}{2}\times8\frac{1}{2}$in. The cases are manufactured from 20 s.w.g. mild steel, with a silver-grey hammer finish. The steel front panel is made from 16 or 18 s.w.g. (dependent on size), and has a light grey, high-gloss enamel finish. Rubber feet are fitted to all cases and vent panels are available at extra cost.

For further information circle 303 on Service Sheet.

High Stability Frequency Standard

THE USE of solid-state techniques by Frequency Electronics Inc. of 22/60 46th Street, Astoria, N.Y., has enabled them to manufacture a lightweight portable frequency standard weighing less than 18lb. The equipment, modular in construction, meets all the requirements of the MIL-E-16400 specification. Three outputs, 5Mc/s, 1Mc/s and 100kc/s are available; the drift rate is 2 parts in 10^{10} per day while the short-term drift, less than one second, is better than 5 parts in 10^{11}. The output levels are quoted as IV r.m.s. minimum into 50Ω. The instrument has a built-in circuit checking system; it also has an automatic cross-over network so

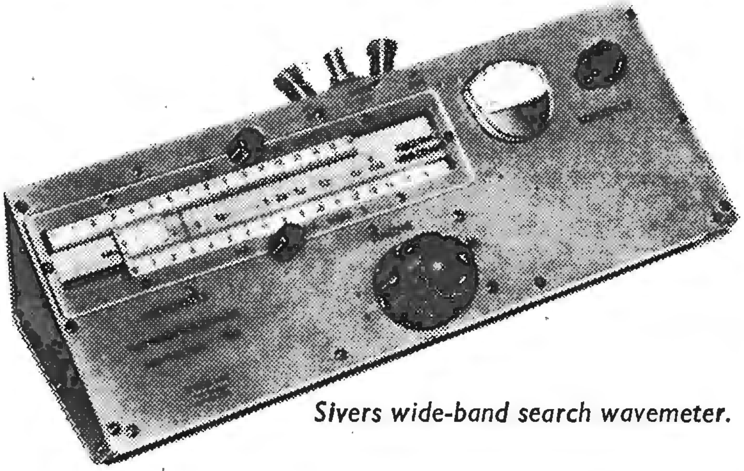


Frequency Electronics high-stability frequency standard.

that in the event of a mains power failure or the equipment being removed from a mains supply, it can be driven for 20 hours from its battery pack without interruption of stability or phase.
For further information circle 304 on Service Sheet.

Microwave Wavemeter

OF PARTICULAR value for testing in microwave laboratories, a new wavemeter manufactured by Sivers Laboratories and distributed by Research and Control Instruments Ltd., Kings Cross Road, London, W.C.1, exhibits a range of 550 to 12,000 Mc/s. This wide range is especially useful when the frequency of the signal is not known. High-order spurious oscillations may also be detected. The instrument, Type number SL7591, consists of a coaxial resonator with a crystal detector, the output being displayed on either a built-in meter or an external indicator. The tuning error lies within 0.2% at the lower end of the range to 5% at the highest frequencies.



Sivers wide-band search wavemeter.

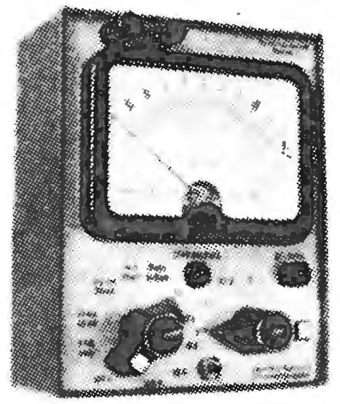
For further information circle 305 on Service Sheet.

Laser Mirror

AN ELLIPTICAL cylindrical mirror together with a linear flash-tube mounted along one axis provide a high-efficiency pumping source in lasers. A reflecting cylinder of this type introduced recently by L. Light & Co. Ltd., Colnebrook, Bucks is constructed from heat-resistant "Duran" glass. The construction is such that the undesired radiation of the lamp can pass through multi-layer coatings without reflection but the pumping frequency is reflected on to the laser rod with an efficiency of about 90%. The lateral cover plates of the cylinder can be constructed in a similar fashion to obtain maximum output of the exciting light source. The manufacturers claim that the reflector, because it enables laser emission at minimum thresholds of the exciting energy, prolongs the life of the lamp and that the temperature of the laser rod is kept as low as possible.
For further information circle 306 on Service Sheet.

Indicator Switch

A FEATURE of the "Press-Lite" push-button switch introduced by Diamond H Controls Ltd., Gunnersbury Avenue, London, W.4, is that the bulb circuit is independent of the controlled circuit. Single-pole changeover models are available to switch 2 A, 125 V a.c. and 15 A, 125 V a.c. or $7\frac{1}{2}$ A, 250V a.c. Cap assemblies, which can be provided with a legend, are available in white or coloured plastic. Low-voltage bulbs are available and neons for mains voltages will be introduced shortly. The switch mechanisms are completely enclosed, and the diameters are $\frac{9}{16}$in for the 2 amp and $\frac{3}{4}$in for the 15 amp switch.
For further information circle 307 on Service Sheet.



Comark d.v. millivoltmeter, Type 120.

"Press-Lite" illuminated switch.

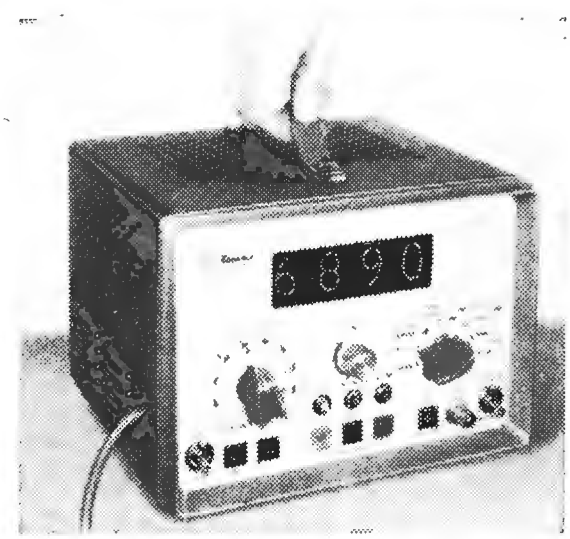
Millivoltmeter

DESIGNED for low-level, high-impedance working, the Comark Type 120 d.v. millivoltmeter has a maximum sensitivity of 1 mV full scale and a 1 Mω/V input resistance. The instrument, which uses transistors, is of the chopper amplifier type with linearizing negative feedback. Transistor noise is of a sufficiently low level to allow an input of 10 μV to be detected. A centre-zero facility is provided and the meter movement is of the taut-wire suspension type. Maximum voltage measurement is 100 V full scale with an accuracy of 2% of f.s.d. at 20°C, zero drift being less than 0.2% per degree Centigrade.

Resistance measurements can be carried out on a linear scale up to a maximum of 10 Mω at an accuracy better than 5% of f.s.d. The instrument is powered by three internal mercury cells. The price is £36 and the address of the manufacturers is Comark Electronics Ltd., Gloucester Road, Littlehampton, Sussex.
For further information circle 308 on Service Sheet.

Timer/Counter

A SIMPLE, general purpose counter from Advance Components Ltd., Hainault, Essex, Model TC2 uses transistors and measures frequency up to 1 Mc/s, at a sensitivity of 200 mV. Single and multiple periodic-time measurements may be carried out together with single- or two-line gate control. The clock pulse generator is accurate to 1 part in 10^6. The gate is



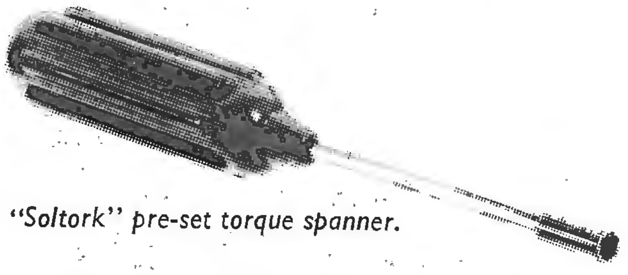
Advance timer/counter Type TC2.

automatically reset after a continuously-adjustable display time. The price of the instrument is £180.

For further information circle 309 on Service Sheet.

Pre-set Torque Tools

TO ELIMINATE the possibility of stripped threads, Solstrand Industries of High Wycombe, Bucks, have introduced a range of "Soltork" pre-set torque spanners and screwdrivers. Box spanners are available in the even sizes from 2 to 8 B.A. and both Phillips and conventional screwdriver heads can be supplied. Moulded handles contain the sealed torque mechanism and are colour-coded to indicate size and torque loading. "Specials" can be made to individual requirements.



"Soltork" pre-set torque spanner.

For further information circle 310 on Service Sheet.

Conductive Paint

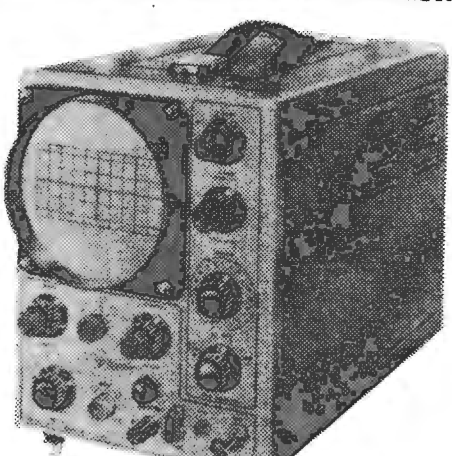
AN ELECTRICALLY conductive paint, containing metallic silver, introduced by Detel Products Ltd., Ruislip, Middlesex, can be used to repair printed boards which have been mechanically damaged. The paint can also be brushed to form a conductive strip, patch or area. Adhesion to the substrate can be maintained up to about 200 °C. The resistance of a brush-applied strip $\frac{3}{8}$in wide and 3in long is not more than 2 Ω when dry.

For further information circle 311 on Service Sheet.

Measuring Oscilloscope

A NEW oscilloscope, the Dartronic Model 510, has a bandwidth of z.f. to 10 Mc/s. The basic sensitivity is 10 mV/cm with an input impedance of 1 MΩ (40 pF). A frequency-compensated, 9-position attenuator permits adjustment of sensitivity. For convenience in the measurement of larger amplitude waveforms, the sensitivity can be reduced by a factor of 10 by a panel control. The rise-time of the y amplifier is 35 nsec. Sweep speeds from 1 μsec/cm to 0.5 sec/cm are covered in 18 ranges. The timebase may be triggered internally or externally in a number of modes, namely, line frequency, a.c. slow (up to 1 kc/s), a.c. fast (above 1 kc/s) and auto. A trigger level control is provided.

The x amplifier bandwidth extends from z.f. to 150 kc/s and has an input impedance of 500 Ω (100 pF). The expansion can be continuously varied up to x10. Z-modulation facilities are available.



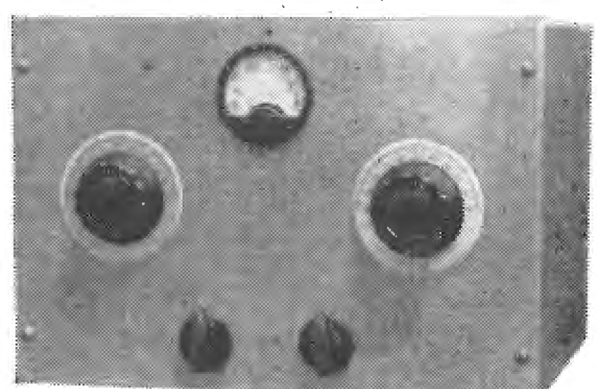
Dartronic measuring oscilloscope Model 510.

Calibration is achieved by an internally-generated square wave with an amplitude of 20 mV ±1 % and a frequency of 1 kc/s ±1 %. No external leads are required since depression of the "Calibrator" push-button connects the calibrating waveform. The 5-in helical p.d.a. cathode-ray tube is operated at 3 kV. The price of the oscilloscope is £85 and its dimensions are 8 × 10 × 15in. The manufacturer's address is Dartronic Ltd., 3-7 Windmill Lane, London, E.15.

For further information circle 312 on Service Sheet.

Aerial Coupler

THE "OLYMPIC" Z-match aerial coupler can be used over the range 160 to 10 metres. From 80 to 10 metres the equipment may be used to match into low-impedance feeders (50-1000 Ω). Its main function is to load any length of wire used as an end-fed aerial on the 160-40 metre bands, though 33 feet or multiples of this length are recommended. An r.f. meter is included, this monitors true aerial current. The coupler is manufactured by Southern Radiocraft (Tx) Ltd., Bournemouth. The 250 W version costs £10 10s, 150 W £9 10s and the 75 W £8 10s.



Southern Radiocraft "Olympic" aerial coupler.

For further information circle 313 on Service Sheet.

Silver Preparation

AN AIR-DRYING, silver metallizing preparation, designated FSP51 and produced by Johnson, Matthey and Co., 78-83 Hatton Garden, London, E.C.1, produces a strong, electrically-conductive film that can be applied without heat treatment to plastics, ceramics, graphites and metals. The preparation can be brushed or sprayed on to the substrate and will dry in 24 hours in air at room temperatures. When in use the maximum continuous service temperature should not exceed 120°C. The use of a silver-plated spring clip is advised when it is necessary to make connection to the film.

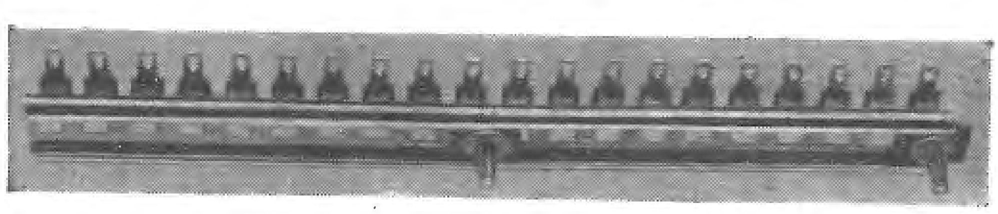
For further information circle 314 on Service Sheet.

Terminal Strip

A FEATURE of the "Adup" terminal strip manufactured by Jackson Brothers Ltd., Kingsway, Croydon, is that two or more strips may be locked together by special nuts and bolts. The strips are available with groups of 3 to 8 terminals mounted at $\frac{1}{4}$-in centres, the width being $\frac{1}{2}$in. The terminals are mounted by ceramic pillars to steel channelling, which in turn can be bolted to the chassis.

For further information circle 315 on Service Sheet.

Jackson Brothers "Adup" terminal strip.



INITIAL CHARGE of £2 MAZDA DESIGN DATA SERVICE
provides new subscribers with both volumes completely up-to-date and includes packing and postage. It also entitles subscribers to "follow-up" data to 30th June following the date of joining.

An ANNUAL RENEWAL CHARGE of £1
covers subsequent amendments and new issues and is made every 12 months on 1st July.

SPECIAL OVERSEAS EDITION
covering components under the EDISWAN brand by our Export Division in which precedence is given to European type numbers is available. The price is the same as for U.K. publications.

To: PUBLICITY DEPARTMENT,
THORN-AEI RADIO VALVES & TUBES LTD.,
155 Charing Cross Road, London W.C.2

Please send me.............. sets of the new handbooks;
I enclose £2 in payment for each set.

☐ **MAZDA** handbooks ☐ **EDISWAN** handbooks
(Please tick whichever edition you require)

NAME..

FIRM..

ADDRESS..

....

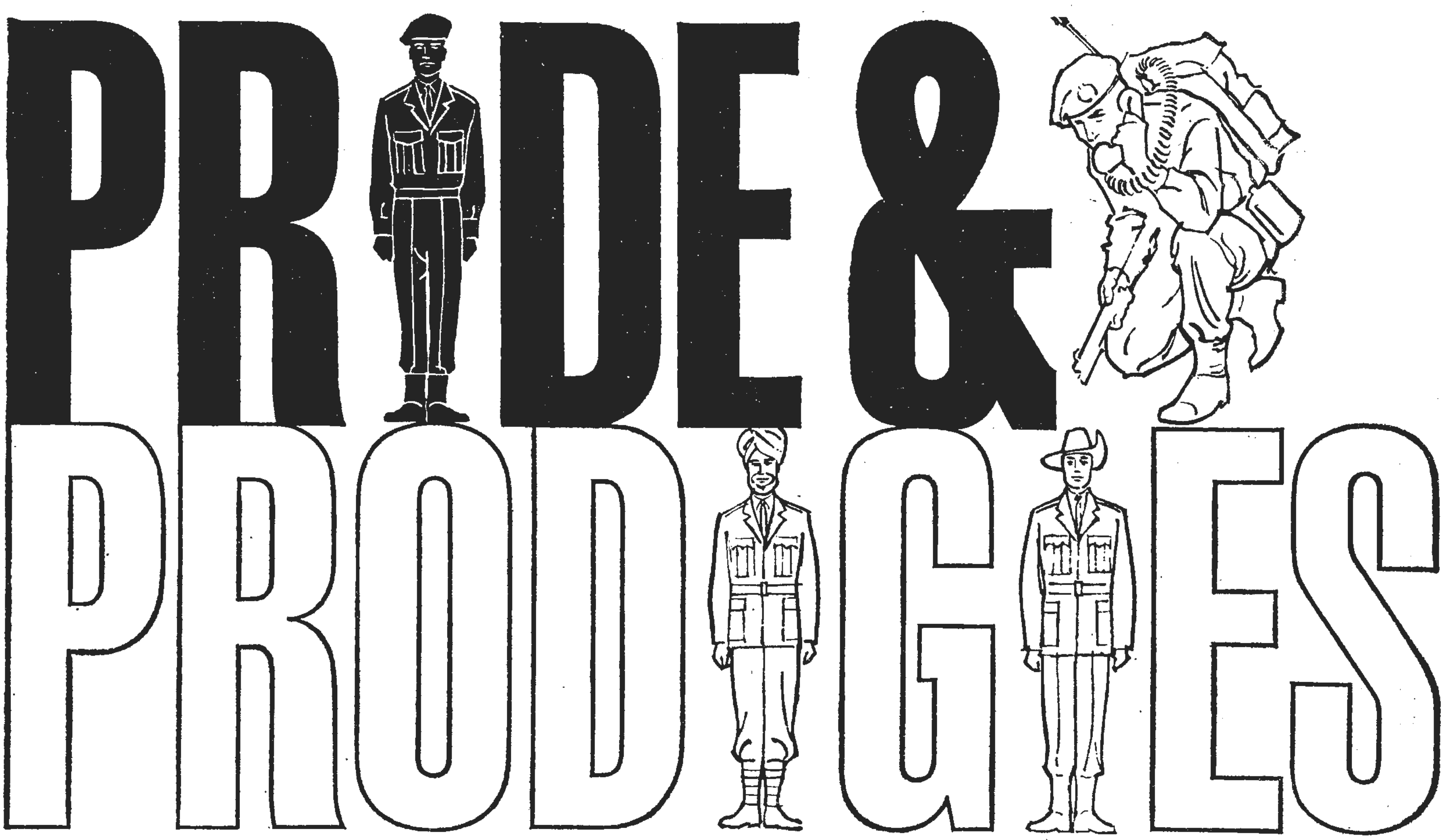
SIGNED..
BLOCK LETTERS PLEASE

MAZDA

Thorn-AEI Radio Valves & Tubes Ltd.

HEAD OFFICE: 155 CHARING CROSS ROAD · LONDON, W.C.2 · Telephone: GERrard 9797

EXPORT DIVISION: THORN HOUSE · UPPER ST. MARTIN'S LANE · LONDON, W.C.2

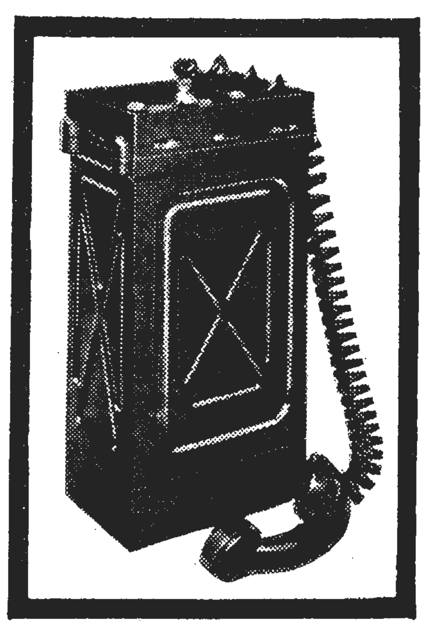


Is there any other single equipment . . . that . . . is being used as a man-pack set during drops by **paratroops** for *ground-to-air* communications and as a *homing beacon* for follow-up support, and . . . by **marine commandos** during beach assaults for *beach-to-air* and *beach-to-ship* communications, and . . . is fitted in **vehicles, tanks, fixed** and **mobile guns** for *fire-control* and *air-support* communications, and . . . is fitted in **naval launches, landing craft** and **mine-sweepers** for short-range *ship-to-ship, ship-to-shore* working? From the arctic to the tropics, Land, Sea and Air Forces have proved that this is the most versatile, smallest, lightest, toughest, self-contained U.H.F. pack-set in existence.

After exhaustive trials, this equipment is in quantity production for the War Office, Admiralty, Air Ministry, NATO, Commonwealth and other armed Forces. Full details are available.

Redifon

WAR OFFICE : TYPE A43R
ADMIRALTY : TYPE 634
NATO : REF. NO. 5820-99-949-1359



REDIFON LIMITED Communications Division Broomhill Road, London, S.W.18 Tel: VANdyke 7281: Cables: Redifon, London

Silicon Controlled Rectifiers

AN EXPLANATION IN TERMS OF TRANSISTOR ACTION

By THOMAS RODDAM

I FIND this article curiously difficult to begin. You may wonder why this is not something I hush up, or why, indeed, I do not just shut up. I suspect that the real difficulty is associated with my reluctance to *use* silicon controlled rectifiers and I hope that by exploring the reasons for this reluctance I may help some readers to break through a similar barrier.

The properties of s.c.rs. are in many respects similar to those of point-contact transistors except that in place of milliamps we now have amps. In the conditioning years the cost of the s.c.r. was high. There will not be very many readers who remember the days when half-a-dozen A1698 transistors, fresh from North America, were the total company stock, but in those days some of us learned just how fast a triggered solid-state device could be destroyed. The same lesson had to be learned again, when we began to drive power transistors up into the negative resistance region. And again, when we found that silicon rectifiers could be destroyed by transients on the incoming mains.

For many applications the advantages of the s.c.r. appear to be marginal. Mr. Butler, in the February issue of *Wireless World*, described some power unit circuits based on s.c.rs., but the end results can be obtained by using variable toroidal transformers, regulating transformers and other iron-cored techniques. These on balance, have been cheaper, although the end product is much bulkier and very much heavier than the circuits using s.c.rs. We can now consider the destruction barrier. Before we achieve a satisfactory design using s.c.rs., or any new device of this kind, we expect to destroy n devices each costing some price p. This is true even if " destruction " implies merely returning a transformer to have a change made in one winding. I think that most of us have expected to obtain a high value of $n.p$ in the development of our first unit using s.c.rs. We have studied the career of Icarus and sat back to wait for the Wright Brothers; and you will remember that no one believed *them*.

The years roll on. The cost of the devices, p, falls but our reflexes are conditioned and we cannot see that the destruction barrier is much lower than it was. We must see how we can reduce n, to make the barrier even lower. In this article I want to explore ways of thinking about the silicon controlled rectifier which will help to destroy the irrational fears which I suspect are still limiting its use.

The external behaviour of the s.c.r. is usually described in something like the following manner. The unit has two main terminals, an anode and a cathode. If an alternating voltage is applied there will be no current through the device, unless the voltage reaches a level which is regarded as the rating limit and which will cause failure. However if when the anode is positive a small current is fed into a third terminal, the device instantly, that is within a few microseconds, converts itself into a conventional diode and remains a diode, passing current freely in the forward direction, even though the trigger current is stopped. By reducing the anode current to zero the diode is re-set to the non-conducting state again. The third electrode is conventionally known as the gate electrode, although it might show its action more clearly if it were called the toggle, or the trigger.

Most descriptions of s.c.r. action point out that this behaviour is very similar to the behaviour of a hot-cathode gas triode. This comparison is no doubt very useful for the power engineer but very few light-current engineers have ever used thyratrons at all and it seems to me that it does not really help to tell the reader that the scenery in Siberia is very much like that in Alaska.

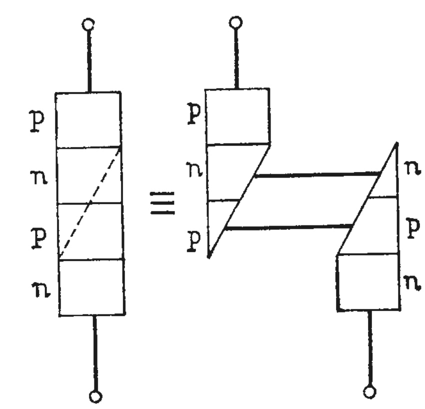


Fig. 1 A four-layer device can be regarded as two three-layer devices connected together.

It is more to the point to consider why the s.c.r. behaves as it does. An examination of the literature reveals that the s.c.r. as we know it is only one of a large family of devices, most of which have not yet been brought into commercial production. The basic configuration is a four-layer construction. Instead of having the three regions, say p-n-p, of a conventional transistor, we have four regions, n-p-n-p. The theory of this kind of arrangement, the transistor with a hook collector, was discussed by Shockley, Sparks and Teal in *Physical Review*, Vol. 83, pp. 151-162, July 1, 1951, and they showed that a transistor of this kind could have an α which was considerably greater than unity.

Instead of working towards this conclusion by discussing the energy levels we can work in terms of familiar devices. Suppose that we have a p-n-p-n structure, as shown in Fig. 1(a), and that we make a diagonal cut, pull the two parts away from each other, and join them in the way shown in Fig. 1(b). The next point is one which seems to need rather

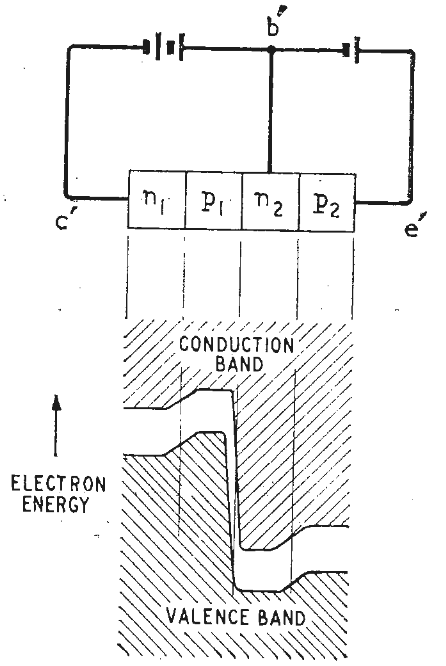


Fig. 2. Energy diagram for a hook-collector system.

careful thought. In Fig. 2 we have the diagram for a p-n-p transistor with an n-p hook at the collector. The energy diagram shows the downward hook at the collector, c′, which gives the system its name. If you cover up the left-hand part of the diagram you will see the diagram for an ordinary p-n-p transistor with the emitter junction between n_2 and p_2. Now cover up the p_2 region and you see the energy diagram for an n-p-n transistor. The p_1 layer floats at a potential which makes the net current into it equal zero. The diagram is that of an n-p-n transistor but the emitter junction is undoubtedly the junction between n_1 and p_1.

This is the tricky point of the two transistor analysis. It is very tempting to forget about the d.c. requirements and to assume that a collector is a collector. In fact the collector is an emitter. Of course, once you see this at all you look back to Fig. 1 and say it is obvious, because the junction which does the blocking must be the control n-p junction, the only one common to the two transistors.

In the conventional s.c.r. the hook collector is called an anode, and the n-region emitter is called a cathode. I do not know whether this is because the god-parents were thyratron men or because they wanted to avoid calling an emitter a collector. We can, however, proceed now to analyse the circuit in the simplest possible form.

We begin by drawing Fig. 3, and it is noteworthy that my automatic reaction was to draw the p-n-p transistor the wrong way up. Let us put in first the p-n-p emitter current of unity, giving us a hook collector current of α_0 and a current into the composite transistor base, G, of $1-\alpha_0$. Notice that this is not the arrangement shown in Fig. 2. Now if the p-n-p transistor has a current gain of α_2 we shall get a collector current in this transistor of $\alpha_0\alpha_2$, for this transistor has an emitter current of α_0. The base current of the p-n-p transistor will be $\alpha_0(1-\alpha_2)$. This base current must be the collector current of the n-p-n transistor, which is α_1, and so

$$\alpha_1=\alpha_0\ (1-\alpha_2)$$

from which $\alpha_0=\alpha_1/(1-\alpha_2)$

Provided that the gate current is small we may expect the two transistors to take about the same current and to have about the same value of α. This is an extremely crude approximation but it gives us $\alpha_0=\alpha/(1-\alpha)$. Our assumption of small gate current requires that $\alpha_0=1$, so that we must have $\alpha=0.5$. We may reasonably expect that this condition will be satisfied only if either the current is very small or the voltage across the transistors is so low that they are bottomed. Although it is unlikely that the two values, α_1 and α_2, will approach these regions in step the general argument is still valid. The current can only flow from anode to cathode without escaping if it is either very small or its producers bottoming.

The next logical step is to use a reasonably complete equivalent circuit for the composite unit or for the two transistors and to determine the input resistance at either cathode or anode when a resistive load is provided at the other electrode. It we treat the device as a transistor which can have $\alpha_0>1$ we find that the input resistance will be negative. Indeed, if we add a few resistors we find that the circuit becomes Yanagisawa's current-inversion type negative impedance converter shown in Fig. 4. I do not propose to carry through the analysis of the circuit but it is not difficult, although it is tedious, to show that the characteristics will be of the form shown in Fig. 5. This is, of course, the form we associate with an open-circuit-stable negative resistance system and it must be noted that although no scales are given the current region shown would normally cover only a few milliamps for a device meant to handle as many amps, while the voltage scale may cover anything from 25 volts to several hundred volts. It is more usual to draw the curves in the coarse form of Fig. 6.

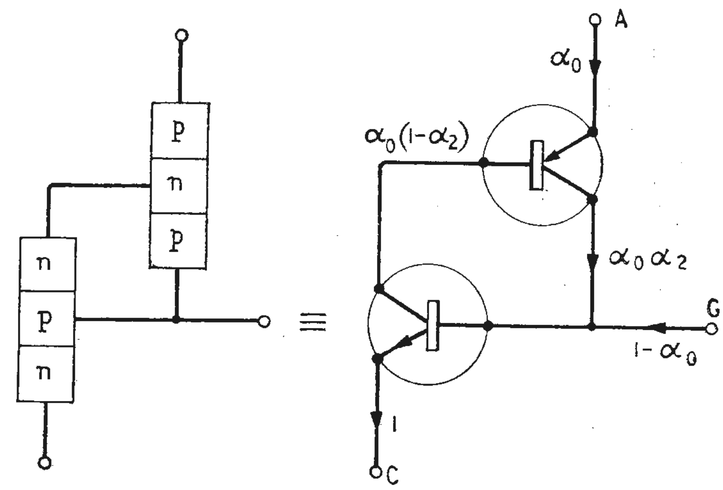


Fig. 3. Currents in the twin three-layer devices.

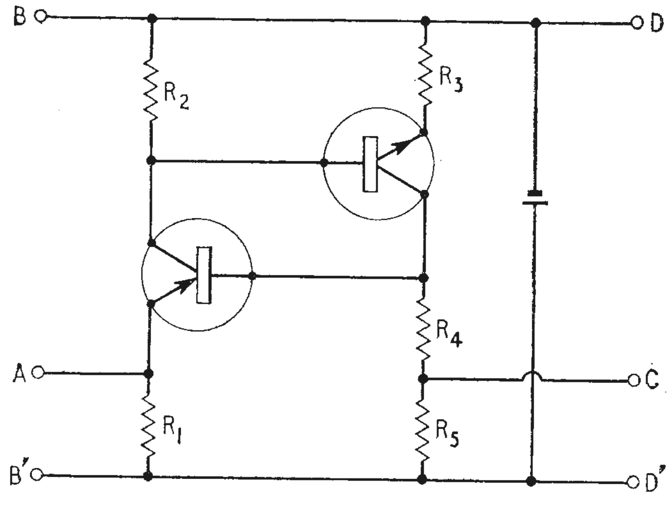


Fig. 4. Negative impedance converter due to Yanagisawa.

Even with no gate current the device can have a negative resistance characteristic, for the low values of α at low current will be incrcased by avalance multiplication. Normally the load-line will be somewhere in the region shown in Fig. 6. Initially the system is stable on the low-current branch which starts at the origin, but as the gate current is increased the S of the active device contracts until the circuit is unlatched, leaving only one intersection. The current just before unlatch is described as the pickup current. It seems probable that the trajectory of the transistion will depend entirely on the characteristics of the load, because the load line is a very long way from the negative resistance line.

To switch off we reduce the current through the circuit. In a power unit we shall probably do this by reducing the voltage, or rather by letting the local Electricity Board do this for us, as they do every 10 milliseconds. The load will remain constant and the load line will move parallel to itself until it unlatches the circuit at the top bend. The current just before unlatch is called the holding current. Once the circuit has unlatched it has no access to the upper branch.

Unlatching in systems with a reactive load introduces the possibility of using a rotating load line to swing the load line round to produce the unlatching effect. Usually, I think, this will be found in combination with a sideways shift of the load line, produced by the firing of a second s.c.r. which quenches the first by a push and a swing. This is the kind of action which must be considered when the s.c.r. is to be used to control d.c.

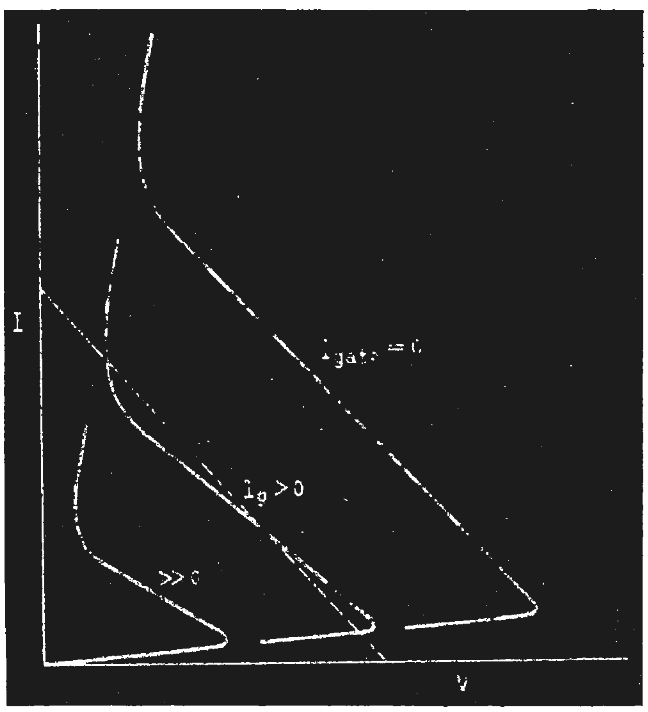


Fig. 5. Negative resistance characteristic system.

I shall come back to the actual switch-off process, but I think the last sentence must be expanded. The use of the s.c.r. in d.c. circuits provides an extremely efficient and, probably, safe solution to a number of problems. One class of circuit which has a d.c. input is, of course, the inverter. Just where the changeover will be is difficult to estimate, but there is little reason to doubt that the s.c.r. inverter will take over from the transistor inverter at high power levels. The level may well be much higher than will concern most of us, now that the power ratings of transistors are rising so high. The fact that a transistor is easily turned off is of great value. S.c.r. circuits in which the d.c. is interrupted offer the possibility of controlling high currents by a pulse modulation process. The current is allowed to pass for a variable pulse duration, and the control signal alters the actual modulation. This is very much like the Ettinger-Cooper d.c. amplifier except that the circuit arrangements can be simpler.

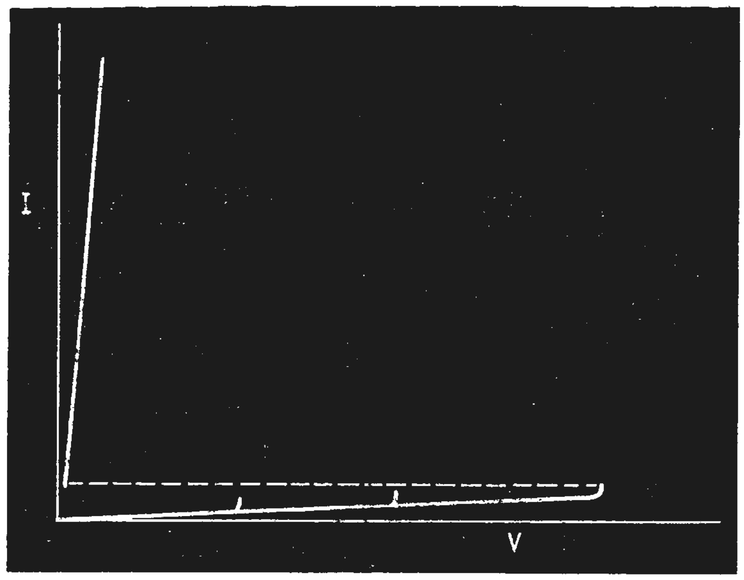


Fig. 6. Characteristics of an s.c.r. are usually shown like this. This region shown in Fig. 5. is the thin layer at the bottom of this diagram.

The distinction between the transistor and the s.c.r. in this kind of circuit is rather interesting. We have a fairly simple control for the transistor current, the current into the base. The very simplicity leads to a disadvantage when high powers are to be handled. The transistor can be left half-way on. In the simplest circuits, with the base drive taken from the output, we may find that under some load conditions the drive is not sufficient for proper switching. I know that this difficulty can be surmounted by proper design: I merely state that this is the design problem. When we consider the s.c.r. circuits we find that there is no possibility of an s.c.r. sticking half-way on, but there is a very real danger that the s.c.r. will not turn off at all. Turn-off is the great problem in s.c.r. circuits.

We must record the details of the turn-on process. Obviously we have to get the carriers into the base, get the lower transistor structure functioning, and then finish up with the rearranged potential level of the second base. Typically it will be about 1 microsecond before the anode voltage begins to move when the gate is triggered with a signal which is usually some 4-10 volts applied through a resistance of the order of 25 ohms. Once the s.c.r. is unlatched, the anode voltage falls in a decay waveform (it looks like an exponential, but we cannot commit ourselves to this formal statement). The rate of fall depends on the current limit, presumably because as the current rises the αs which drive the switching process becomes smaller, and times of several microseconds are typical. Details must be taken from the data sheets for particular types.

Turn-off is a little more complicated. The two central regions are saturated with charge carriers, and if the current is merely interrupted, time must be allowed for these to diffuse away before the voltage is reapplied. Otherwise the stored charge will be enough to initiate conduction. Rather roughly we may expect to require that we should allow 20 microseconds for this. The operation can be speeded up by applying a reversed voltage to the s.c.r. In a typical situation a reversed current of some 5-20A will flow for a few microseconds and will decay to zero as the carriers are swept away. Once the bulk of the carriers have been moved the voltage may be reapplied in the normal direction, but it may not be applied too soon, too quickly. Typically, if you reapply forward voltage 12 microseconds after initiating turn-off you should not allow the forward voltage to rise at faster than 20 volts/microsecond.

This detail may look rather pernickety but is very important in inverter and chopper circuits. Since we cannot turn off at the base we must provide a reversed pulse, the push and swing referred to above, at the anode. We can get this by means of a capacitor connected to the anode of another s.c.r., the one which is being turned on. This capacitor must be capable of delivering a sufficiently large, sufficiently long, pulse.

It is tempting to wonder whether we cannot cut the s.c.r. off by means of a reversed gate current. Experimental devices in which this can be done do not seem to have proved commercially possible. It is conceivable that if the characteristics for negative gate currents were shown we might be encouraged to try to do this, but the information available is pretty discouraging. The region shown in Fig. 5 is the ten-milliamp region. To shift the negative resistance line up into the 10 amp region we can expect to need some amps of turn-off gate drive. Turning back to Fig. 3 we see that we should need to extract almost all the collector current of the p-n-p section in competition with the emitter-base diode of the n-p-n section. With normal construction the ohmic resistance of the gate current path would probably make this either impossible, or so dissipative that the device would be burnt out. In fact we may almost say that the current needed for turn-off at the gate is equal to the anode-cathode current and that it can only be injected at one or other of these major electrodes.

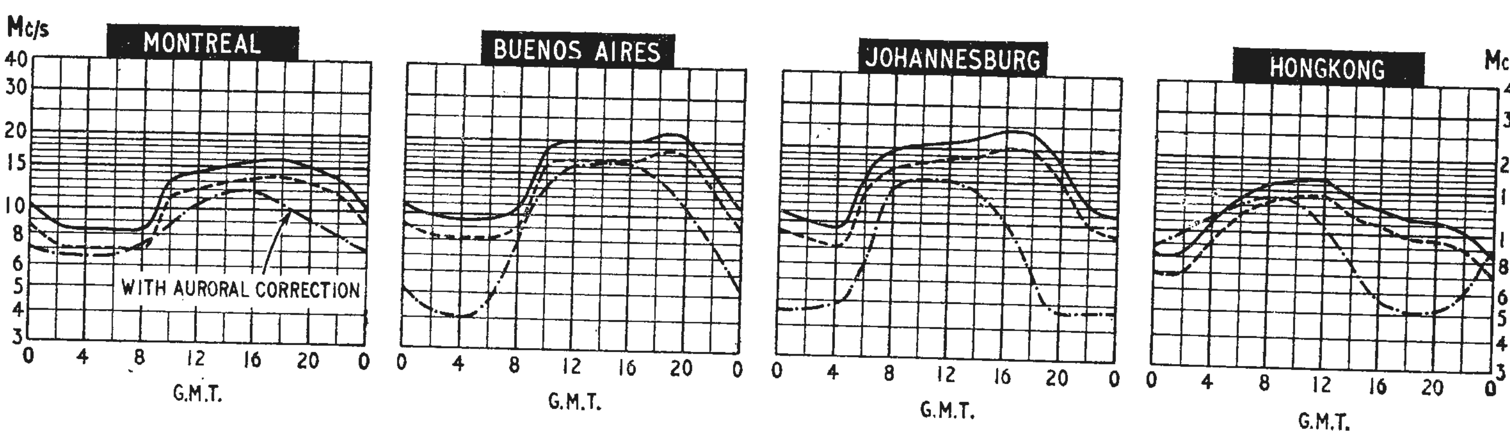
The expression which was derived near the beginning of this article $\alpha_o = \alpha_1/(1-\alpha_2)$, is not the only form which can be used. An alternative treatment takes $\alpha_o = 1$ as its beginning. We may then write the current through the central junction as $I\alpha_1 + I\alpha_2 + I_{co}$, where I is the external terminal current and I_{co} the leakage current. Since this must be I, we get

$$I = I_{co}/(1-\alpha_1-\alpha_2)$$

for the current with an open-circuited gate. When $(\alpha_1 + \alpha_2)$ becomes equal to unity the junction current will apparently go off to infinity, a condition we always associate with the infinite gain of a trigger system. It might seem that we have two answers which are in conflict, for earlier we were concerned with $\alpha_1/(1-\alpha_2)$ and now we are concerned with something we can write as $\alpha_1-(1-\alpha_2)$. There is not, in fact, any difference between these two forms, for if we set $\alpha_o = 1$ we have $\alpha_1/(1-\alpha_2) = 1$, or $(1-\alpha_1-\alpha_2) = 0$. The only reason why we arrive at different forms is that in our first treatment we looked for the actual value of α_o, and associated potential instability with $\alpha_o > 1$, a gross over-simplification, while in the second case we have made $\alpha_o = 1$ and then looked for the instability, though now we have simplified the gate current out of the analysis. This is just as dangerous as assuming that $\alpha_o > 1$ is all we need to know.

The main purpose of this article has been to describe the s.c.r. in transistor language so that when you get to work with s.c.rs. you will feel that you just have another transistor bi-stable switch. Although this way of looking at the device does not provide all the answers, it does at least give you the chance of starting from familiar foundations.

H. F. PREDICTIONS — SEPTEMBER



MEDIAN STANDARD MUF
OPTIMUM TRAFFIC FREQUENCY
LOWEST USABLE HF

After hovering around 20 for some months the sunspot number for May leapt to 52 and subsided to 37 in June. Although month-to-month variations of this magnetitude are not uncommon the figure for May emphasizes that solar activity has now declined very little over a period of 2 years. A slow decline may be expected in coming months but the effect of this will be masked by the more significant seasonal changes.

The prediction curves show the median standard MUF, optimum traffic frequency and the lowest usable high frequency (LUF) for reception in this country. Unlike the MUF, the LUF is closely dependent upon such factors as transmitter power, aerials, local noise level and the type of modulation: it should generally be regarded with more diffidence than the MUF. The LUF curves shown are those drawn by Cable and Wireless, Ltd., for commercial telegraphy and they serve to give some idea of the period of the day for which communication can be expected.

DIFFRACTION

By "CATHODE RAY"

WHEN 625-line television comes it will bring with it an accentuation of those interesting effects such as "ghosts" that haunt the screen in many areas. This will not, of course, be due directly to the increased number of lines, but to the higher frequencies (u.h.f.) on which the programmes are to be radiated, the v.h.f. channels being already occupied by 405-line transmissions. We are often reminded that the higher the frequency the closer the resemblance to light waves, so that we must expect the shadows cast by intervening hills and buildings to be more noticeable. If the receiver is in such a shadow, reflections from other hills or buildings or from aircraft may well be comparable in strength with the primary signal, weakened as it is by the obstruction. The reflected signals, having travelled farther, arrive a little later and produce images displaced to the right, as for example in Fig. 1.

I don't know whether most people are more surprised by the fact that light doesn't go round corners or that sound and the longer radio waves do. Those who haven't thought about it much may assume that their ability to hear what is going on around the corner and to receive fairly well on a portable set even when there is a substantial obstruction between it and the sending aerial may be due to the same reason that it is still fairly light for some time after sunset and that a whole room is more or less illuminated by even a small window. If so, they clearly need to think about it more carefully. The following is intended to assist that process.

There is nothing to be ashamed of in having to give thought to this matter; even the great Newton went wrong over it. In spite of some of his own experiments (e.g., "Newton's rings") which strongly suggested a wavelike nature, he concluded that light was corpuscular—that it consisted of tiny particles shot out from the source at enormous speed. In this he now appears to have been at least partly right—but for the wrong reasons.

The best starting point is to consider what waves are. We all realize, I suppose, that although they may necessitate movement of some kind of substance, that movement is quite local—not to be confused with the movement of the waves themselves. For instance, the water of which sea waves are made does not flow towards the shore at the speed of the waves; it performs a circular movement in one place, combined with a slow tidal flow that is just as likely to be in the opposite direction to the waves as in the same direction. No; what moves as waves is a *state* or condition, usually an alternating departure from the normal state of what is called the *medium*. The medium for sea waves is water, and the waves consist of local departures or displacements from the normal height of its surface. Because these take place at right angles to the direction in which the waves travel, sea waves are classified as transverse. And because the displacements of the surface are up and down and not from side to side the waves are said to be vertically polarized.

Sound waves are different. The medium can be almost any substance, but we are most concerned with air. Its movement is to and fro in the same direction as that in which the waves are moving, so the waves are called longitudinal. The air—let us assume that is the medium—moving to and fro must have a corresponding alternating velocity. And because its displacement increases the density of the air on one side and reduces it on the other, it causes alternating variations in pressure. The same sort of thing happens in water waves; obviously the water is deeper at the crest of the wave and a greater pressure results.

Now if you exert pressure on something it tends to give way, and in so doing it exerts pressure on whatever is beyond it, and so on. A wave of pressure is propagated in that direction. All this can be worked out mathematically for the particular medium and kind of wave. The wave's velocity (which is continuous, not alternating like the local to-and-fro velocity of the medium) depends on the density and elasticity of the medium.

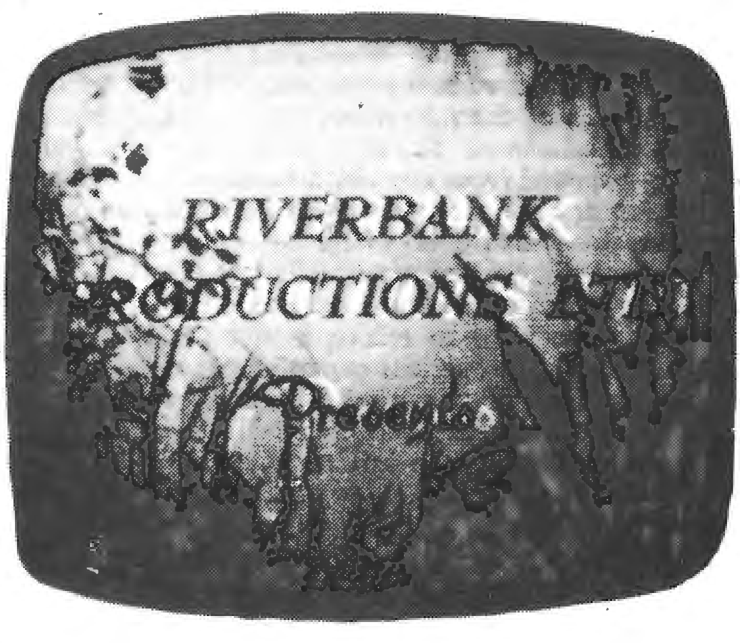


Fig. 1. "Ghosts" are usually due to differences between arrival times of diffracted and reflected waves.

If the medium extends in all directions, any disturbance or displacement caused anywhere is propagated as a wave in all directions. Water waves are confined to a single plane, of course; within that limitation the much-quoted experiment of dropping a stone in a quiet pond demonstrates the truth of what I have just said. Air is in three dimensions, so instead of spreading out merely in circles the waves caused by a shot—the atmospheric equivalent

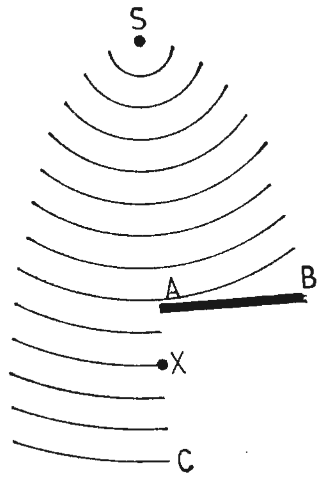


Fig. 2. Is this what happens when an opaque object stops waves and casts a shadow?

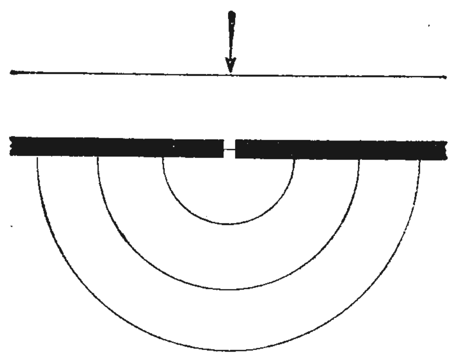


Fig. 3. Bath experiment to demonstrate nearly complete diffraction.

of the stone in the pond—take the form of expanding spheres.

The important point—associated historically with the Dutch scientist Huygens, who although he died 32 years earlier than Newton, was ahead of him on the wave nature of light—is that since the waves moving outward from any disturbance of the medium (stone, shot, etc.) are themselves disturbances of the medium they must everywhere be centres of secondary waves. These are often called wavelets.

In an unobstructed medium this principle, although it is hard to refute, is not at all obvious. One sees only the original expanding circular ripples on the surface of the pond (until they reach the shore, where they are reflected). It can be shown mathematically that the infinite number of wavelets cancel one another out everywhere except in directions away from the original source; in those directions they combine to form the expanding wave-front that one sees.

So far Huygens' principle seems to be no more than a complicated way of explaining something that previously looked quite simple. Its value appears when we consider what we set out to consider—the effect of an obstruction. Let us draw a diagram (Fig. 2) of what we suppose happens when waves encounter an impenetrable (and, to simplify the diagram, totally absorbing and therefore non-reflecting) screen AB, assuming that the original waves are all. Successive crests of them are shown as concentric circles around the source S. Since the screen absorbs those hitting it, everything behind it is in shadow, as shown. This necessitates wave crests coming to sudden ends along the edge of the shadow, AC. But that is impossible! Consider a fixed point on this edge, say X. At this moment a wave crest is sweeping past it. During the next few moments that crest will fall, reverse in sign to become a trough, build up to another crest, and so on.

Such periodic disturbance of the medium at that point is itself inevitably a source of waves radiating in all directions, as is any point in the track of the waves. This can be demonstrated with a tank or even in the bath by dividing it in two by a barrier having a narrow channel cut in it as shown in Fig. 3. You start a train of waves on one side of the barrier by dropping something into the water. When the waves emerge from the channel on the far side they don't continue like a ray of light, restricted to the width of the channel; they spread out through a full 180° as shown, just as if the mouth of the channel were an original source. Here is a Huygens wavelet for all to see.

Point X in Fig. 2 is also a disturbing source, as we have seen, and by itself would radiate waves throughout the region screened off from the original source S. But every point along AC is another such source, and to discover what is happening at any point in the shadow their separate effects at that point have to be added together in appropriate phase to give the resultant.

Instead of working like this from the edge AC it is simpler to reckon from the wavefront where it passes the screen, especially if that front is far enough from the source for it to be taken as a straight-line continuation of BA. We are then getting to something rather like our bath demonstration, Fig. 3, the only difference being that there is an indefinitely large gap instead of a narrow one. And here you may ask how narrow is "narrow"? There must be some standard of comparison. Narrow compared with the thickness of the barrier? Not necessarily. The standard is the wavelength, or rather half a wavelength, and the width of the channel should be small compared with that.

The reason is that if the gap width, DE in Fig. 4, is (say) half a wavelength, then there is half a wavelength difference in phase between the wavelets reaching a point such as P from D and E and so they will cancel out there. If DE is small compared with half a wavelength, then the wavelets reaching any point in the shadow will be approximately in phase and will add up to a wave there. One can easily see that if the hole is to let anything through at all it must have *some* width, and that the effect of the resulting phase differences tends to be greater (and the bent waves therefore weaker) the greater the angle compared with the direction of the original waves. This is evident in the bath experiment; the emerging waves are noticeably weaker at points such as P, close to the back of the barrier.

By widening the channel you can easily show that the wider it is the greater the tendency for the emerging waves to continue in their original direction, and the less the water in the "shadow" is disturbed. But this absence of disturbance is *not* due to the inability of the waves to turn corners. As we have seen, they tend to go equally in all directions and have no difficulty in turning through 90°, but unless the primary wave disturbance is confined to a front that is small compared with half a wavelength this tendency is largely nullified by mutual cancellations. The residual bending round corners is called *diffraction*, not to be confused

Fig. 4. Although opposite sides, D and E, of this wider opening are in phase as regards the original source of waves, their wavelets reach P out of phase, tending to cancel one another and reduce diffraction.

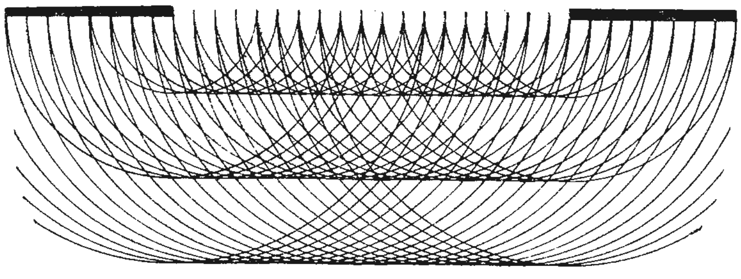


Fig. 5. By drawing Huygens wavelets at close intervals, the resultant wave pattern with shadow effect is revealed.

with refraction, which also makes waves go round corners but for a different reason—variations in characteristics of the medium.

I suggested varying the channel width in the bath experiment because it is probably easier to do that than vary the wavelength, which is what we are trying to study. But having widened the channel in a certain ratio we can reduce the scale of the resulting pattern (including the wavelength) in the same ratio and arrive at the conclusion that shortening the wavelength increases the shadow effect.

On paper a rough picture of how the Huygens wavelets combine can be made by drawing semicircles at close intervals along the width of the gap, as in Fig. 5. We see that they combine in phase to form waves that travel straight through, but fall increasingly out of step, with mutual cancellations, at the sides.

The only complete method is mathematical integration of the infinite number of wavelets, and I'm not going to do that because it is a standard routine to be found in textbooks on optics. But Fig. 6 is a graph of wave intensity some distance beyond a hole several wavelengths wide. The interesting features are the diffraction of waves into the shadow —fairly slight in this case—and the uneven transmission through the hole, remarkably like the result of transmitting a square-wave signal through a low-pass filter.

Now Newton was fully acquainted with diffraction of waves, but his experiments with light appeared to show that it travelled in straight lines and was not diffracted. Hence his rejection of the wave theory of light. It doesn't seem to have occurred to him that light waves could be thousands of times shorter than those he knew, so that their diffraction was just too slight to be clearly seen in his experiments. It is in fact quite difficult to demonstrate diffraction of light unmistakably, because unless the source of light is very concentrated the diffraction is confused by the penumbra, (Fig. 7) where there is a gradual transition from light to dark. However, as early as 1715 Delisle noticed that the shadow of a small circular object had a bright centre, but the report was received by scientists with incredulity and the phenomenon had to wait about 100 years to be accepted.

Newton's other reason for rejecting the wave theory of light, incidentally, was polarization, which of course cannot take place with the longitudinal waves of sound with which he was familiar. One would have thought that the transverse nature of water waves would have suggested the possibility of wave polarization (he had no children to play with waves along ropes and show it to him that way), but it is easy for us to be wise three centuries after the event.

Getting back to our subject, we should now see that the extent of diffraction depends on the wavelength compared with the size of the obstruction or the channel; if the wavelength is relatively large, then diffraction will be nearly complete; if small, there will be little diffraction and a pronounced shadow.

One way in which this is evident, as we said at the start, is the increasing shadow effects as radio wavelengths are reduced. Long waves penetrate fairly well into valleys but very short waves are severely cut off.

Another example is noticeable when somebody gets between you and a loudspeaker; he acts as a top-cut tone control, attenuating the highest frequencies (shortest waves) but hardly affecting the low.

We can use radio waves to explore a coastline, by aiming the waves at it and recording the reflections. That in fact is what is done by radar. We can also use it to detect aircraft. But with metre-wavelength radar the details of the aircraft escape us, because the waves are of the same order of magnitude as those details, so there is sufficient diffraction to obscure them. Centimetre waves give a clear picture, but still nothing like as detailed as we can get using our own sense of sight which makes use of the far shorter waves of light. When we seek still finer detail, we find that the magnification obtainable with miscroscopes is limited ultimately by the wavelength of light. Details of comparable or smaller size are obscured by diffraction.

The main difficulty in calculating diffraction effects precisely is the infinite number of wavelets to be summed to find the resultant, and the fact that this resultant varies with angle and distance. The problem is very much simpler when the wavelets are restricted to groups so small that they can be regarded as approximations to single wavelets. This is what we did in the first bath experiment, when we made a single channel, narrow compared with half a wavelength (Fig. 3).

It is quite easy to extend this experiment to two

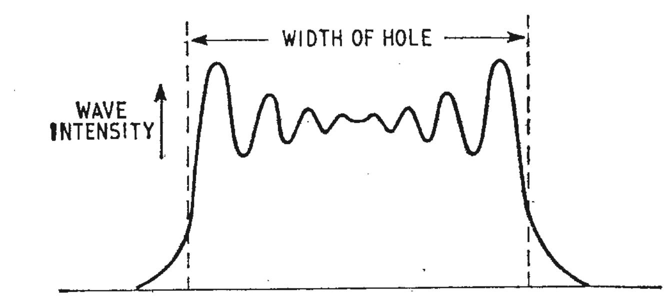


Fig. 6. Graph of wave intensity received at some distance from a hole several wavelengths wide.

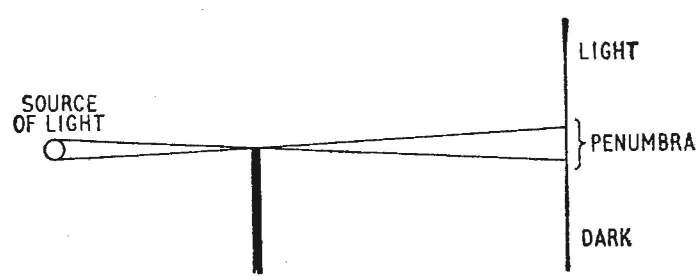


Fig. 7. The penumbra is the transition region between shadow and full light, where part of the source is hidden. It tends to obscure diffraction.

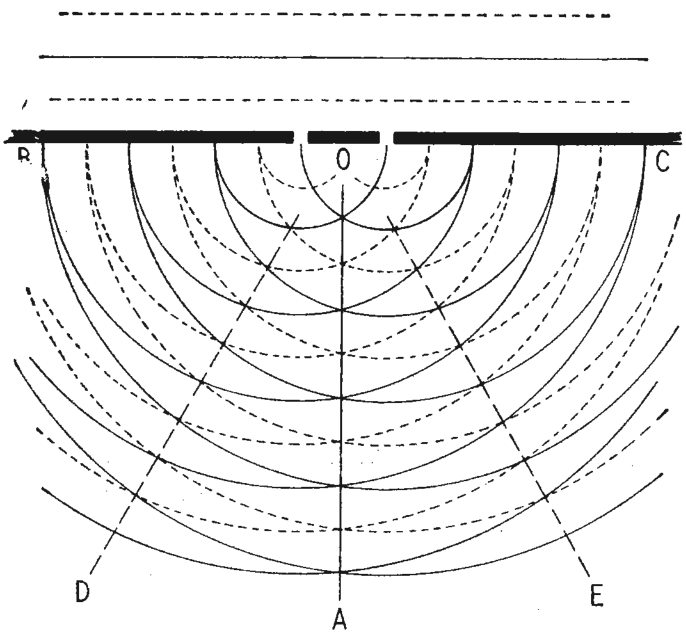


Fig. 8. The wave pattern produced by interference between two in-phase sources—in this example, one wavelength apart—is here plotted, and shows maximum build-up along OA, OB and OC and zeros along OD and OE.

or more such channels and thereby observe the interference effects (as they are called) between wavelets. It is perhaps even less trouble to plot them on paper, as for example in Fig. 8, where two holes are shown one wavelength apart, and besides the wave crests drawn as full semicircles the troughs are interpolated as dotted ones. Straight ahead (along OA) crests add to crests and troughs to troughs to yield a resultant wave, and the same happens along OB and OC. But intermediately, along OD and OE, there is complete mutual cancellation. The result—if we use the language of short-wave aerial technology—is one forward lobe and two side half-lobes. It is easy to see that as the wavelength is reduced the number of lobes is increased. The number is, in fact, twice the ratio of hole separation to wavelength, when two half-lobes are counted as one lobe.

When we want to concentrate radio waves in one particular direction, radiation to each side (whether in separate lobes or as a spreading of the main lobe) is undesirable. The solution to this problem is to add more aerial units (e.g., dipoles) at half-wavelength ($\lambda/2$) intervals. These all build up the main lobe in the forward direction—at right angles to the array of aerial units. Admittedly increasing the number of units (N) increases the number of lobes, which is 2(N-1), but the side lobes become comparatively weak, so the object of concentrating radiation into one direction is achieved. Fig. 9, for example, compares six dipoles with two. In practice the equal backward radiation, omitted here, is usually reversed and made to augment the forward radiation by means of a reflector behind the aerial array.

The radiation pattern of an aerial system holds good for reception too, and so far as broadcasting is concerned it is receivers rather than senders that are preferably directional. It happens that these broadside arrays are seldom used for domestic reception, because the Yagi type of "end-fire" array is more convenient mechanically, and these are rather off our present subject of diffraction.

The principle of the broadside aerial array is of immense importance at the very much shorter electromagnetic wavelengths of light—and infra-red, ultra-violet, X-rays, etc., too. It is obviously impracticable to mount lights at half-wavelength intervals—or even several-wavelength intervals—but the same effect can be obtained on the principle of the bath experiment illustrated in Fig. 8, by shining a light through extremely narrow closely-spaced slits cut in an opaque strip. At light wavelengths the spacing has to be of the order of 1/20,000th of an inch, so the production of diffraction gratings, as they are called, necessitates some pretty precise mechanical engineering. In an alternative form the light is reflected from lines ruled in a strip of suitable metal. The exceedingly small scale of such arrays enables vastly more elements to be used than in radio practice—many thousands, in fact. The object is not so much to concentrate light into one direction as to separate radiations of different wavelengths. Violet light, for example, has only half the wavelength of red, so the lobe patterns are very greatly different. Wavelengths that are nearly equal can be separated by a diffraction grating, which is why it is the essential component of most good spectrographs and a considerable improvement on the glass prisms with which Newton carried out his pioneer investigations. To use our own term, the selectivity of a diffraction grating can be made very high.

This separating effect must have been noticed by everyone when handling gramophone records. Although the spacing of the grooves is comparatively coarse, the effect of much closer spacing can be obtained by holding the disk so that light is reflected at a very small angle with its surface, when one can see colour spectrum effects quite plainly.

Average X-ray wavelengths are about 1,000 times smaller still, which puts the manufacture of diffraction gratings for them beyond even the most skilled instrument maker. But suitable gratings abound in nature in the form of crystals, the atoms of which

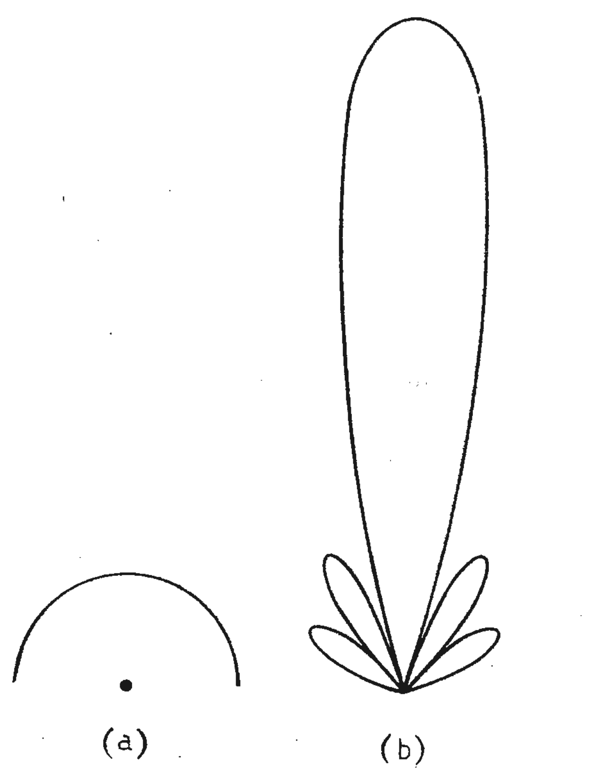


Fig. 9. Comparison of horizontal polar diagrams of (a) single vertical half-wave dipole with (b) array of six such dipoles spaced half a wavelength apart. Only half of each diagram is shown; the whole of (a) is a circle.

are arrayed in regular formation at about the right intervals. They can be used for analysing X-rays and (once the spacings have been determined) for measuring X-ray wavelengths; but the reverse processes have proved of even greater value to science, and very much of our present knowledge of crystal structure and much besides was obtained by the interactions between them and X-rays. This is another example of the general principle that if you want to look at anything clearly you have to use waves of smaller size than the details to be examined.

One of the most significant discoveries of modern science was that diffraction patterns formed by X-rays striking crystals can be duplicated by beams of electrons striking crystals. It implied that electrons are by nature similar to electromagnetic radiations. But that is another story.

BOOKS RECEIVED

The International "At a Glance" Radio Valve and Television Tube Equivalents Manual, by B. B. Babani, is intended to be a quick reference when an equivalent of a valve is required. Only valves having octal, loctal, B7G and B9A bases are included. Beginning with an index of valves, the book is divided into sections headed, R.A.F. valves with commercial equivalents, commercial valve equivalents, C.V. types with commercial equivalents, British Army valves with commercial equivalents, British Navy valves with commercial equivalents, wartime civilian valves with commercial equivalents, and U.S.A. service types with commercial equivalents. The index lists some 1,560 types. Pp. 24. Bernards (Publishers) Ltd., The Grampians, Western Gate, London, W.6. Price 3s 6d.

American Miniature and Microminiature Electronic Assemblies Data Annual 1963-64, edited by G. W. A. Dummer, M.B.E., M.I.E.E., M.Brit.I.R.E., and J. Mackenzie Robertson, consists of a data-sheet presentation of small size electronic assemblies at present available in the U.S.A. In selecting the material included in the book, the editors have taken as parameters—"campactness (as allied to unit types and function), quality, usefulness and anticipated design interest." Pp. 359. Pergamon Press Ltd., 455 Fitzroy Square, London, W.1. Price £5 5s.

Single Sideband for the Radio Amateur (3rd edition) is a digest of articles published in *QST*, the journal of the American Radio Relay League. The contents range from the history of s.s.b. through detailed descriptions of systems to accessories and test gear. Pp. 224. American Radio Relay League, West Hartford, 7, Connecticut, U.S.A. Price $2.00.

Penguin Science Survey 1963, Volume A, edited by Arthur Garratt, presents the general trend in selected fields of research in the physical sciences. The subjects of interest include a treatise by Sir Harrie Massey on the upper atmosphere and a progress review of computers by K. L. Smith. Pp. 224. Penguin Books Ltd., Harmondsworth, Middlesex. Price 7s 6d.

Trouble-Shooting High Fidelity Amplifiers, by M. Horowitz. This book deals quite thoroughly with fault finding and repair of audio amplifiers. Preceded by a section on workshop layout and test instruments, each stage of an amplifier is considered in separate sections. Chapters include the subjects of distortion measurement, hum loops and servicing problems specifically connected with stereo sound reproductions. Pp. 127. Elgin Press, Inc. New York. Price $2.95.

Pulse Circuits, by B. Chatterjee, Ph.D. Written primarily to cover the course on pulse circuits offered at the Indian Institute of Technology (Kharagpur), it includes chapters on pulse shaping circuits, delay lines, trigger and counter circuits and a final chapter devoted to pulse measurements and waveform synthesis. Pp. 159. Asia Publishing House, 447 Strand, London, W.C.2. Price 25s.

Methods of Testing Permittivity and Loss Tangent of Dielectric Materials. E.R.A. Report Ref. L/S9 is divided into three parts on a frequency basis. Techniques discussed include bridge methods (up to 1 Mc/s), Hartshorn and Ward method (10 kc/s to 100 Mc/s) and cavity resonator and standing wave methods (100 Mc/s to 36 Gc/s). Pp. 54. Electrical Research Association, Thorncroft Manor, Dorking Road, Leatherhead, Surrey. Price 24s.

World Radio TV Handbook.—The 17th edition of this guide for broadcast listeners has all the usual features, including the times of regular "language" transmissions. In addition to general information on the national and international broadcasting organizations, it gives operating details (frequency, power and call sign) of the long, medium and short-wave stations in each country. A separate section is devoted to the world's television stations. Pp. 246. Published in Denmark by O. Lund Johansen, the English version is available in this country from Surridge Dawson & Co., 136-142 New Kent Road, London, S.E.1, price 22s.

The Technique of the Sound Studio, by Alec Nisbett, should be of value both to the embryo professional sound engineer and to the amateur sound recordist. The author has had experience both as a studio manager and producer in the B.B.C.'s sound service, and in this volume he describes the main principles underlying the production of a good programme and the minor details which can make or mar it. Although the technical coverage is wide, and includes recording, sound effects, etc., this is only part of the story, and the author succeeds in imparting an appreciation of the art as well as the science of what the French call succinctly *prise de son*. Pp. 288. Focal Press Ltd., 31 Fitzroy Square, London, W.1. Price 42s.

UNBIASED

By "FREE GRID"

Hi-fi and Hi-π

WE often read that science is measurement, and I, for one, wouldn't think of disputing it. In fact, I always try to express things in the appropriate units of measurement if I possibly can. I was a little surprised, however, to read in *Wireless & Electrical Trader* a few weeks ago that Rex Hassan, the well known director of the London Audio Festival and Fair, had said that the quality of visitors to this year's show was far superior to that of other years.

This has set me wondering about the methods employed to gauge the quality of us visitors and the units of measurement used. One thing the statement might have meant was that we were all a bit better dressed than usual. This could easily have been measured—but not very scientifically—by having experts from Dior and Savile Row concealed near the entrance, the unit of measurement naturally being the micro-brummel for men. If so, I rather fear I let the side down, as I have never been one to pay much attention to sartorial matters.

I cannot think, however, that sartorial elegance was what Mr. Rex Hassan had in mind. It was much more likely to have been the quality of our musical or technical knowledge; maybe both, because hi-fi and hi-π is really what the Audio Festival is all about. Hi-π is intended to represent a high degree of technical knowledge, as I cannot think of any more succint expression; can you?

The measurement, or at any rate estimate, of these qualities must have been based on a comparison of the degree of fi and π knowledge exhibited by this year's visitors as compared with those of previous years, revealed presumably by the questions we asked the technical representatives on the stands.

However, I may be quite wrong in my deductions, and, if so, I shall be very interested to know how our "superior" quality was assessed this year.

Telepathic Skip-Distance?

A GREAT deal of correspondence has been going on recently in some newspapers about telepathy. If we allow that telepathy does in fact exist, the problem to be decided is whether it belongs to the world of physics or to that of what I will call psychics; in other words is it transmitted by what we call electromagnetic waves or by some means outside the world of physical science.

Professor Mundle, of the University of Bangor, writing in *The Sunday Times* thinks that there is no case for telepathy being a matter of physics as the received signal strength is the same at a distance of several hundred miles as it is at a few feet; it does not decrease with distance as wireless signals do. However, the learned professor does not say whether signal strength is the same at all points between the distances he mentions. If not, surely we may have the same skip-distance effect we get with radio transmissions?

Copenhagen Calling

MANY of us received our first impressions of Denmark at a very tender age from the tales of Hans Andersen; very pleasant and fairylike impressions they were too.

In my own case these fairylike impressions were amply confirmed when I first went there, and I was not surprised when an ancient building in Copenhagen with a quaintly twisted spire and an Andersen-like history was pointed out to me. I was told that the architect of the building had killed himself because the builder—obviously one of Andersen's wicked fairies in disguise—had given the spire a left-handed twist instead of the right-handed one on the architect's drawing board.

However, that is by the way. There is another building in Copenhagen in which a museum of sound radio, television, gramophones and tape recorders, etc., was opened not so long ago. I can only hope that the museum remains free from all Andersen-inspired torts (legal jargon for twists and faults) as at present because, judging by a handbook which the Editor has shown me, I have seldom seen a better arranged or more carefully catalogued exhibition. The things on show are from many countries but naturally the Danes have not neglected the works of their own Poulsen, of arc-generated-c.w. fame, nor the pioneering work of Oersted.

The museum authorities are anxious to increase the range and number of their exhibits, including those which are typical of British developments. Unfortunately I cannot help personally as I disposed of all my old gear to our own Science Museum last December as I recounted then in *W.W.* If any of you have any old apparatus of museum interest which you can let the Copenhagen museum have, please write in the first instance to Mr. Tage Schouboe, TS Museum, Struenseegade 15A, Copenhagen N.

The Danish authorities even offer to pay carriage, and, in certain cases, reasonable prices for apparatus which is accepted for inclusion. It would, however, be a far better thing to present it, and put away all unworthy thoughts of trying to get back a bit of Danegeld which your ancestors may have had to pay nearly a thousand years ago in the time of Ethelred the Unready.

Binarized Brides

THOSE readers who have passed, as I once did, through the part-physiological and part-psychological process known as "falling in love" will know how mentally disturbing it can be, distracting the mind from mathematics, electronics, acoustics and all the other serious things of life.

Personally speaking, I tried 40 years or so ago to knock the painful process into scientific shape by making "amatics" follow the same logical processes as mathematics and all the other "ics" which I have mentioned above. I can only say that my efforts resulted in what Shakespeare so aptly describes as "Love's Labours Lost," as I failed to take into consideration the illogicality of the female mind.

Nowadays similar efforts are being made by others with more advanced scientific methods than I had available. Several journals have reported that electronic computers are being used in the U.S.A. by marriage brokers to match up clients on their books. *The Times* mentions one instance of a retired Methodist minister, a widower, who answered no fewer than 700 questions about his likes and dislikes in order to provide data for feeding into a computer. Time alone will tell if the resultant electronically assisted marriage proves to have been made in heaven, as the old saying has it.

One objection which I see is the necessity of answering such an enormous number of questions; I can truthfully say I should not like to have to go through such an ordeal. Fortunately it is not necessary in this country as we are far more advanced than they are in the U.S.A. Nearly eight years ago (Nov. 1955) I mentioned in these columns, under the heading of "Walter, lead me to the altar," how Dr. Grey Walter had devised a system whereby the suitability of budding benedicks for each other was decided by comparing an encephalogram of each would-be partner.

These encephalograms were put in front of an expert, who picked out the vital data from each. Such data, when compared, enabled him to make a decision about the compatibility of the two persons concerned.

Despite these great scientific aids to choosing a marriage partner, I fear that the young people of today will still go in for the old, illogical and discredited method of "falling in love."

Exhibitiana

IT seems odd that at this time of the year we are not all preparing to pay a visit to the National Radio Show at Earls Court. I am only too glad that the idea of a biennial show has been abandoned, and that Earls Court has been booked for several years ahead, commencing with 1964.

There are, I think, one or two advantages in not having a show this year. One is that by August of next year the B.B.C.'s 625-line service should be in full swing, and, therefore, those of us who wish to buy a new set can do so without wondering whether we ought to buy a convertible one. Those with 405-line sets will, of course, be able if they wish to use them for some years to come in order to receive the same programmes which they do now.

They will, of course, miss the alternative B.B.C. service, but nobody can say at present whether that will be any disadvantage. It is, however, my opinion that people will think they are missing something. That will naturally result in a big demand for new sets.

Another great advantage in not having a show this year is that it will give the organizers more time to give the show a "new look."

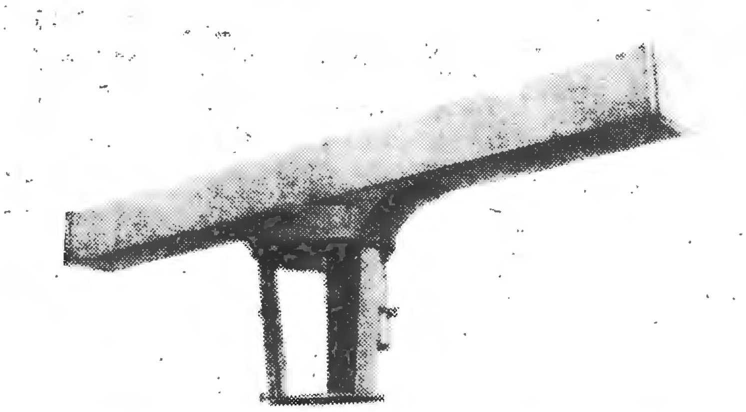
I once suggested that apart from each manufacturer having his own stand as at present, there should also be other stands in one section of the hall to which all manufacturers made a contribution so that those of us who wanted, for instance, a midget transistor receiver, would see all makes of them on one stand, with all makes of extension loudspeakers on another stand, and so on. This would save us being compelled to elbow our way from one end of the hall to another to compare the different makes on show but, it may be argued by some that "comparisons are odious."

As for the extra space required, there always seems to me to be plenty of wide open spaces on the gallery floor of Earls Court, crying out to be filled. However, I am quite sure the organizers will not agree with my idea but will have something far better up their sleeves to provide the "new look" for 1964.

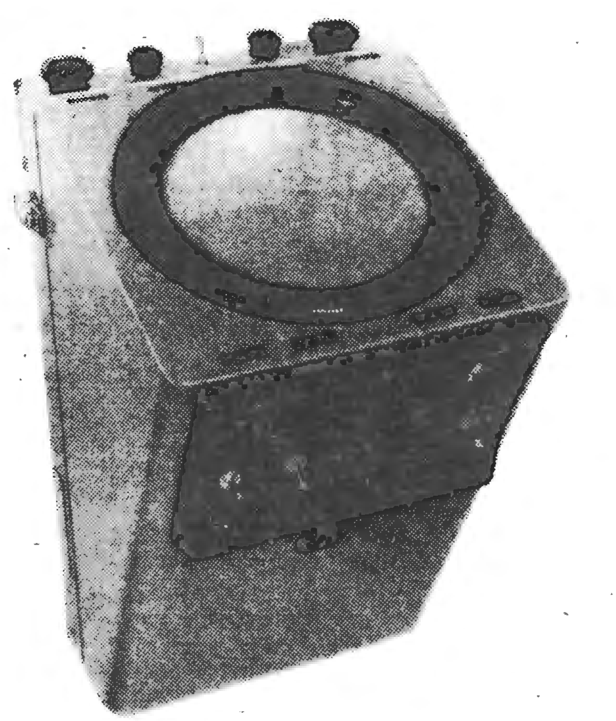
KELVIN HUGHES TYPE 17 RADAR

DESIGNED for small vessels the latest Kelvin Hughes marine radar is light and compact. The transmitter/receiver unit with a nominal peak power of 3kW measures only 21in × 12in × 6in and weighs 31 lb; the display unit is 20in × 14in × 12in and weighs 48 lb; the motor alternator which is 12in × 9in × 7in also weighs 48 lb; and the heaviest item, the aerial unit, weighs 103 lb for the standard 6ft end-fed slotted array or 95 lb for the alternative 4ft unit.

Wide use has been made of transistors in the display and receiver units and these are of the silicon type throughout to give an increased factor of safety under high ambient temperature operating conditions.



Scanner unit encased in fibre-glass and incorporating the turning mechanism has been proved in wind speeds up to 120 knots.



The display unit, which uses silicon transistors, is designed for bulkhead, deckhead or table mounting.

The Type 17 has been designed to meet the M.o.T. Type Approval Specification and with the 6ft aerial gives a 1.2° beam width. Three pulse lengths (0.06, 0.2 and 0.5μsec) are available and are automatically selected according to the range scale in use. Altogether there are eight ranges from ¼ to 24 miles.

The price of the Type 17, at the works of the Kelvin Hughes Division, S. Smith & Sons (England) Ltd., New North Road, Hainault, Ilford, Essex, is £895.

Commercial Literature

The Marconi **vidicon colour camera** channel Type V3310 is described in a leaflet available from the closed circuit television division of Marconi's W/T Company, Basildon, Essex. Technical details and performance data are included in the description of the camera, associated monitor and power supply unit. A block schematic, showing the integral parts of the camera, control unit and monitor, and how they are interconnected, is included. **(316)**

The Valve and Semiconductor Group of Associated Electrical Industries Ltd., of Carholme Road, Lincoln, have issued a 25-page booklet on their **semiconductor devices.** Brief technical details with dimensional data and, where applicable, service-type numbers have been included. Two pages of this publication list some 200 semiconductor devices with A.E.I. near equivalents. **(317)**

An abridged catalogue from **Muirhead and Co. Ltd.,** Beckenham, Kent, describes briefly their precision electrical instruments, resistance networks and inductors, facsimile equipment and servo components. **(318)**

S.T.C. Components.—A catalogue listing physical dimensions and operating characteristics of the products of the Components Group of Standard Telephones and Cables Ltd. is now available from Footscray, Sidcup, Kent. It is sub-divided to cover the quartz crystal, magnetic materials, capacitor, rectifier, transistor and valve divisions. **(319)**

Microwave Resistors.—A leaflet describing a new range of thin-film carbon resistors is available from the film components division of E.I. Doucette Assoc. Inc., 246 Main Street, Chatham, New Jersey, U.S.A. Technical and dimensional details are given of the various types they manufacture. The resistors described have a frequency range of d.c. to 10,000 M/cs; a resistance range of 0.001Ω to 1500Ω; and a temperature range of −55°C to +150°C. A tolerance of ±1% is quoted as standard, with ±0.5% and ±0.1% as specials. **(320)**

Plastic lacquer capacitors manufactured by Siemens and Halske of west Germany are described in a leaflet now available from their U.K. agents, R. H. Cole (Overseas) Ltd., 26-32 Caxton Street, Westminster, London, S.W.1. The leaflet contains technical and dimensional data of their MKL range of lacquered foil capacitors. **(321)**

Servo Consultants Ltd. have recently released a leaflet describing their new high-speed, linear, **electro-hydraulic actuator.** The leaflet includes a technical description and specification, and is available from 162-166 Kensal Road, London, W.10. **(322)**

Insulating Sleeves and Tapes Ltd. have recently issued some new data sheets on their **electrical insulating materials** which include resin-impregnated unidirectional banding tapes, epoxy resin-bonded glass fabric laminates, and silicone resin-bonded glass fabric laminates. These data sheets are available from their head office in Brook Street, Preston, Lancs. **(323)**

The Universal Instrument Corporation of New York have recently issued a leaflet on their "Uniac" universal insertion and clinching **machines for assembling printed circuit boards.** Leaflets are obtainable in this country from the U.K. representative, A. Dunkley, 14 Wellington Road, Ashford, Middx. **(324)**

A condensed catalogue covering SGS Fairchild's range of **semiconductors** is now available from 23 Stonefield Way, Ruislip, Middx. It includes tabulated technical information on their diodes and transistors. Other products dealt with in this catalogue include micrologic units and semiconductor test equipment. **(325)**

For the convenience of readers a number has been appended to each of the above items so that when applying for literature all that is necessary is to circle the appropriate number on the Information Service form at the back of this issue.