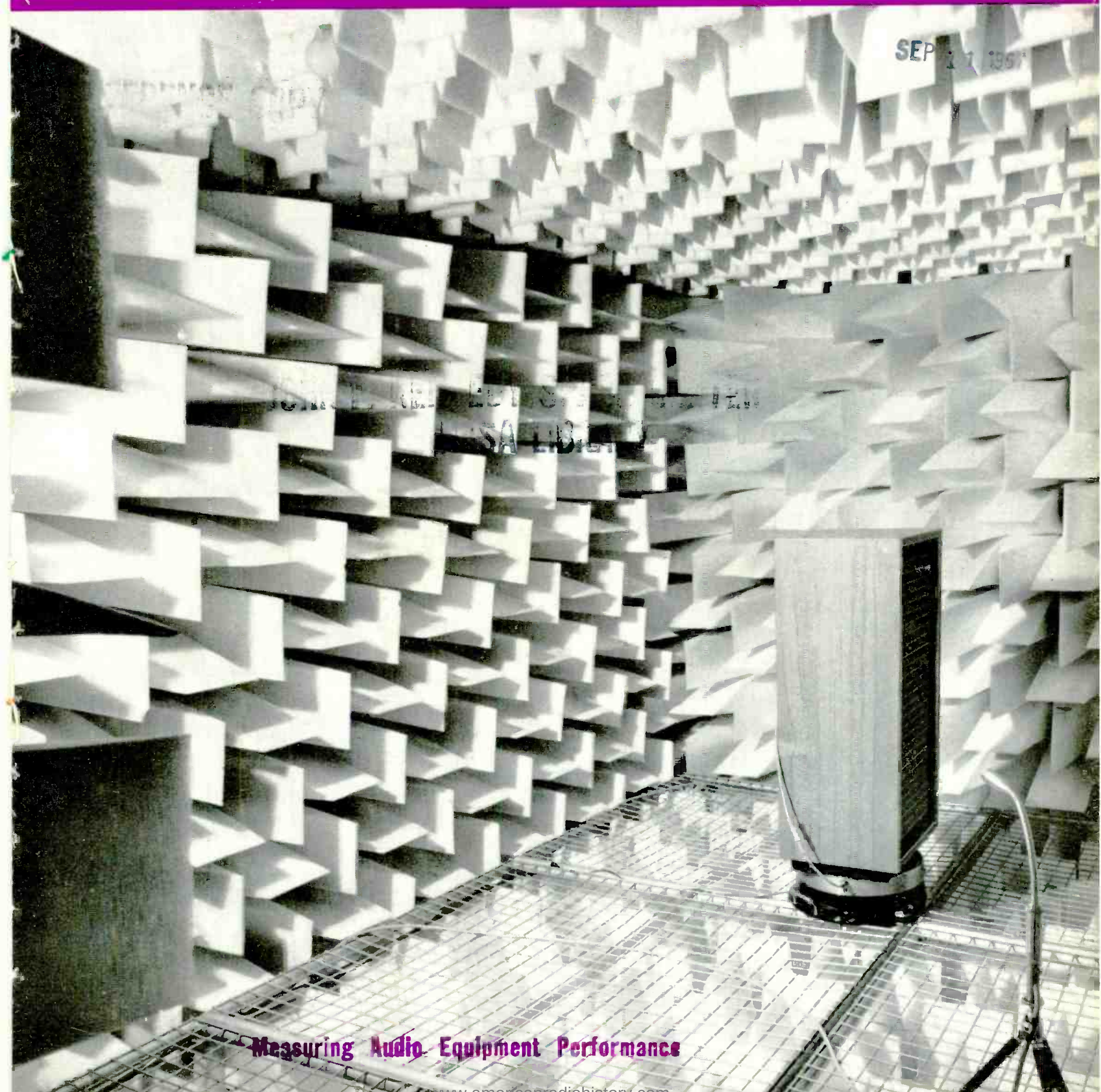
-WATT CLASS D AMPLIFIER

APRIL 1967
Three Shillings

Wireless World

ELECTRONICS • TELEVISION • RADIO • AUDIO



Wireless World

ELECTRONICS, TELEVISION, RADIO, AUDIO

APRIL 1967

SHORT ITEMS

REGULAR FEATURES

Editor-in-chief:
W. T. COCKING, F.I.E.E.

Editor:
H. W. BARNARD

Technical Editor:
T. E. IVALL

Editorial:
B. S. CRANK
F. MILLS
G. B. SHORTER, B.Sc.

Drawing Office:
H. J. COOKE

Production:
D. R. BRAY

Advertisements:
G. BENTON ROWELL (*Manager*)
J. R. EYTON-JONES

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

VOLUME 73 No. 4
PRICE: 3s.

FIFTY-SEVENTH YEAR OF PUBLICATION

PUBLISHED MONTHLY (3rd Monday of preceding month). *Telephone:* 01-928 3333 (70 lines). *Telegrams/Telex:* Wiworld Iliffepres 25137 London. *Cables:* "Ethaworld, London, S.E.1." *Annual Subscriptions: Home;* £2 6s 0d. *Overseas;* £2 15s 0d. *Canada and U.S.A.;* $8.00. Second-Class mail privileges authorised at New York N.Y. BRANCH OFFICES: *BIRMINGHAM:* 401, Lynton House, Walsall Road, 22b. *Telephone:* Birchfields 4838. *BRISTOL:* 11 Marsh Street, 1. *Telephone:* Bristol 21491/2. *COVENTRY:* 8-10, Corporation Street. *Telephone:* Coventry 25210. *GLASGOW:* 123, Hope Street, C.2. *Telephone:* Central 1265-6. *MANCHESTER:* 260, Deansgate, 3. *Telephone:* Blackfriars 4412. NEW YORK OFFICE U.S.A.: 300 East 42nd Street, New York 10017. *Telephone:* 867-3900.

Wireless World

ELECTRONICS, TELEVISION, RADIO, AUDIO

Fidelity in Sound and Vision

WHEN the Hotel Russell in London open its doors for the annual International Audio Festival and Fair on March 30th a flood of enthusiasts will be let in to see and to hear what is the latest in the field of sound reproduction. This mecca of the audiophile highlights the interest in quality reproduction shown by the ever increasing number of visitors. What is it that makes people spend large sums of money on audio equipment? It is certainly not a case of keeping up with the Joneses as it may well be with the acquisition of a colour television receiver. It would appear to be a sincere desire to get the best from discs, tape or radio. But, as with so many of our likes and dislikes, "best" is largely a matter of taste. Isn't this why owners of expensive amplifiers (with almost flat response curves) still like to play with the tone controls? The designers go to great lengths to obtain an even response but one wonders if much of it is wasted effort.

In this issue among several articles covering audio topics there is one dealing with the acoustics of the recently opened Queen Elizabeth Hall in London. Tremendous research and effort has gone into the design of this concert hall, but when a performance is broadcast from there it may be reproduced in a heavily furnished room which is acoustically almost as dead as an anechoic chamber or in a sparsely furnished room which introduces its own acoustic colouring. Neither is giving true fidelity of the original performance.

However, such facts must not be taken as giving license to manufacturers to produce second rate equipment. There is, as has been shown by recent correspondence, an appreciable market among discerning listeners, and viewers for that matter, for good sound reproduction from domestic equipment.

While the auditory perception of the average listener is very accommodating and will make allowances for imperfections in reproduction, the eye is not so helpful, especially where colour is concerned. As reported in this issue there was considerable discussion at the recent colour camera symposium at the I.E.E. on refinements in the design of cameras to get the best colour rendition. Much of this came from research and development engineers, but it needed an American with field experience of colour camera operation to point the moral that it is consistent performance and reliability that are essential. More to the point so far as fidelity of colour in the home is concerned will be the use or misuse of the colour saturation control on the domestic receiver. This, of course, is the only additional control to those on a monochrome receiver. With it the flesh tones of bathing beauties can be changed from pallid through pink to puce. Is this colour intensity control going to be the rock on which the matrimonial bliss of some homes will be wrecked?

Perhaps engineering people tend to forget that communications channels end not at the loudspeaker or cathode-ray tube but in the brain of the listener or viewer. The design of these channels—particularly where fidelity of reproduction is concerned—must therefore take into account the psychology of perception. We must not be so naïve as to think that accurate reproduction can be achieved by straightforward objective means, that reality can be conveyed with the precision of a mathematical formula. Ten years ago Professor Colin Cherry wrote in these pages that the purpose of a communication system is "to transmit those data or 'clues' sufficient to set up in the mind of the recipient those illusions which are desired by the sender, under given environmental conditions."

"Illusion" is the operative word. It is through illusion that we attempt to convey reality.

VOL 73 NO 4
APRIL 1967

Efficiency Considerations in a Class D Amplifier

5W DESIGN GIVING IMPROVED PERFORMANCE

BY G. F. TURNBULL, M.Sc., AND J. M. TOWNSEND, M.Sc.

Considerable interest and discussion was stimulated by the authors' article describing a class D, or modulated pulse, audio amplifier design in the April 1965 issue. Because the authors feel that such amplifiers are in danger of being treated as mere novelties they have developed a higher-power design with improved efficiency and distortion figures. This article deals mainly with distortion and efficiency of two 5 W designs and comparisons are made with a class B amplifier of comparable complexity.

DESPITE the not insignificant amount of material that has appeared in the past on modulated pulse audio amplifiers, there seems to be no degree of agreement as to whether or not this type of amplifier should be considered as a serious competitor to more conventional designs. Some sort of comparison would therefore seem desirable, which requires that the various aspects of importance should be treated in some detail. The major attribute of the modulated pulse amplifier has always been assumed to be that of efficiency and therefore it would seem desirable to examine this aspect first, recognising that it obviously cannot be treated in isolation. Possibly the first question which an attempt should be made to answer is whether significant improvement in efficiency over a class B amplifier be obtained in a class D amplifier of comparable complexity (the two amplifiers having comparable distortion figures and frequency response). In attempting to answer this question it is hoped to contribute toward deciding whether this type of amplifier has more than just novelty value.

SYMBOLS

ω_{IN}	Angular frequency of a.f.
ω_{osc}	Angular frequency of h.f.
h	height of output square wave
xh	Mean value of output square wave
$\hat{x}h$	Max. value of xh when x is sinusoidally varied at ω_{IN}
$\hat{x}_{max}$	Largest expected value of x
V_B	Bottoming voltage of diode or transistor
R_I	Incremental resistance of transistor or diode in bottomed state
$I+$	Current flowing in output stage of amplifier when output voltage is positive
δ	Peak value of fluctuations in output current at ω_{osc} caused by inductive component of the load
$\overline{P}$	Average power dissipated in a component over one cycle of ω_{IN}
β/π	Fraction of cycle of ω_{osc} for which output square wave is positive.

DEFINITIONS

Correspondence in the past has stressed the desirability of avoiding any sort of confusion over definitions and therefore a first step is to define the various quantities and types of operation of concern.

Efficiency. Two efficiencies are of interest and will be considered in detail, namely overall efficiency (η) and output stage efficiency (η_{op}) according to the following definitions:—

$$\eta = \frac{\text{power output}}{\text{power input}} = \frac{\text{power output}}{\text{output} + \text{losses}}$$

$$\eta_{op} = \frac{\text{power output}}{\text{output} + \text{output stage losses}\dagger}$$

† Transistors and diodes only.

Initially a resistive load R_L will be considered and, in line with common practice, application of a sinusoidal input of frequency ω_{in} (the range of ω_{in} being approximately 10 c/s-20 kc/s) will be considered and the average power dissipation over a full cycle evaluated. The method of analysis is shown in Appendix 1. Briefly, the method of approach for class D is to obtain an expression showing how the power dissipated in any component during one cycle of the high frequency oscillation varies with the mean level of the output square wave hx. This level is then allowed to vary sinusoidally, $x = \hat{x} \sin \omega_{in}t$, and the average power dissipated in the component over one cycle of ω_{in} evaluated. For the class B output stage the instantaneous power is evaluated as a function of x and this is then averaged over one cycle of ω_{in}. Expressions for two efficiencies can then be obtained using the definitions already given. These will be functions of powers of x and for the configurations considered in this article the two efficiencies may be expressed in the form of equations 1 and 2.

$$\eta = \frac{\hat{x}^2}{a_3\hat{x}^3 + a_2\hat{x}^2 + a_1\hat{x} + a_0} \quad .. \quad 1$$

$$\eta_{op} = \frac{\hat{x}^2}{b_3\hat{x}^3 + b_2\hat{x}^2 + b_1\hat{x} + b_0} \quad .. \quad 2$$

where $\hat{x}^2h^2/2R_L$ (see Fig. 1) is the power output and the range of $\hat{x}$ is thus from 0 to + 1. Coefficients for the configurations are listed in Table 1.

Class B operation. Comparisons will be made with true class B operation where the standing current at $\hat{x} = 0$ is zero and for which the efficiency coefficients are as listed. In practice a small standing current is necessary to reduce "cross-over" distortion to an acceptable level and the efficiency η_{op} will then be slightly

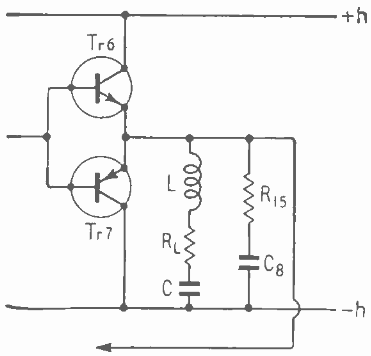


Fig. 1. Output stage configuration 1.

reduced. The value of η will be further reduced by losses in the rest of the circuit.

Class D operation. A reasonable definition of class D working might be as follows. A class D output stage is one in which the output voltage has essentially only two levels and changes between these levels take place in a very short time (the changeover period is normally less than 1 μs). Control of the output power is achieved by varying the proportion of time spent at the two levels and switching normally occurs at frequencies well above ω_{in} (e.g. > 50 kc/s). In true class D operation transistors only conduct when they are bottomed and diodes only in the forward direction except during the change-over periods. In practice deviation from true class D operation may be tolerated on extreme swings.

In deriving simplified expressions for efficiency in various class D configurations it will be assumed that the voltage across a transistor which is bottomed can be represented approximately as $V = V_B + R_I I$ and that all transistors and diodes are identical. The curves of Fig. 5 are obtained by substituting typical values (V_B = 1 V, R_I = 1 Ω) into these expressions. In practice, values could be rather different from these, which will significantly affect η_{op} but only slightly affect η. The curves are however useful in comparing various configurations and in roughly assessing what sort of efficiencies are possible.

CONFIGURATION 1

A simple output stage is shown in Fig. 1, being the one employed in a previous design[1] (and also in Fig. 6). R_{15} is to ensure true class D operation and its value is largely determined by the size of L. (In considering the effect the impedance of the speaker at ω_{osc}, this must be included in the series LCR combination.) In the discussion below it is intended to show how, from efficiency considerations, L should be made as large as frequency response will allow and to consider the optimum values for R_{15} and C_8.

Consider first the case where R_{15} is very large, and $\omega_{osc}L \ll R_L$. Current and voltage waveforms will be identical (Fig. 2) and the coefficients a_n and b_n (equations 1 and 2) as listed in Table 1. Fig. 5 (b) shows that this amplifier has poor efficiency (maximum value η_{max} <50%) and only slight improvement in η_{op} over class B operation providing very good transistors are used. If, however, $\omega_{osc}L \gg R_L$ then the current waveform corresponding to the conditions of Fig. 2 is as shown in Fig. 3. It is now possible to pro-

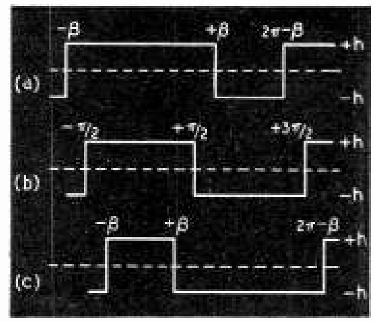


Fig. 2. Voltage and current waveform at output when R_{15} is large and $\omega_{osc}L \ll R_L$.

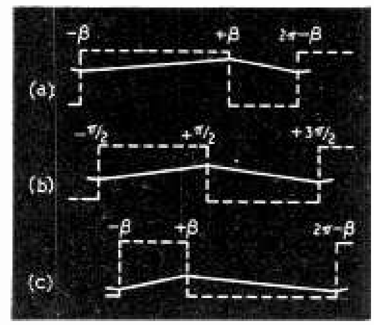


Fig. 3. Voltage and current waveforms at load when $\omega_{osc}L \gg R_L$. Note that in cases (a) and (c) the current is unidirectional and only one transistor conducts.

TABLE 1 THEORETICAL EFFICIENCY COEFFICIENTS

Operation and Configuration	a_3	a_2	a_1	a_0	b_3	b_2	b_1	b_0
(a) Class B	0	0	$\frac{4}{\pi}$	0	0	0	$\frac{4}{\pi}$	0
(b) Class D, configuration 1 $\omega_{osc}L \ll R$, $R_{15}=\infty$	0	0	0	$2\left[1+\frac{V_B}{h}+\frac{R_I}{R_L}\right]$	0	1	0	$2\left[\frac{V_B}{h}+\frac{R_I}{R_L}\right]$
(c) Incorrect operation, configuration 1 $\omega_{osc}L \gg R$, $R_{15}=\infty$	$\frac{R_I}{R_L}\cdot\frac{4}{3\pi}$	$\frac{V_B}{2h}+\frac{R_I}{2R_L}$	$\frac{V_B}{h}\cdot\frac{2}{\pi}+\frac{4}{\pi}$	0	$\frac{R_I}{R_L}\cdot\frac{4}{3\pi}$	$\frac{V_B}{2h}+\frac{R_I}{2R_L}$	$\frac{V_B}{h}\cdot\frac{2}{\pi}+\frac{4}{\pi}$	0
(d) Class D, configuration 1 $\omega_{osc}L \gg R$, $1/\omega_{in}C_8 \ll R_{15}$, $R_{15}=R_L$	0	$1+\frac{V_B}{h}+\frac{3R_I}{R_L}$	0	$2+\frac{2V_B}{h}+\frac{2R_I}{R_L}$	0	$1+\frac{V_B}{h}+\frac{3R_I}{R_L}$	0	$\frac{2V_B}{h}+\frac{2R_I}{R_L}$
(e) Class D, configuration 1 $\omega_{osc}L \gg R$, $1/\omega_{in}C_8$ R_{15}, $R_{15}=2R_L$	0	$\frac{1}{2}+\frac{V_B}{2h}+\frac{3R_I}{4R_L}$	0	$1+\frac{V_B}{h}+\frac{R_I}{2R_L}$	0	$1+\frac{V_B}{2h}+\frac{3R_I}{4R_L}$	0	$\frac{V_B}{h}+\frac{R_I}{2R_L}$
(f) Class D, configuration 1 $\omega_{osc}L$ R $1/\omega_{in}C_8 \ll R_{15}$ $R_{15}=3R$ (valid to $x=0.5$)	0	$\frac{2}{3}+\frac{2V_B}{3h}+\frac{8R_I}{9R_L}$	0	$\frac{2}{3}+\frac{2V_B}{3h}+\frac{2R_I}{9R_L}$	0	$1+\frac{2V_B}{3h}+\frac{8R_I}{9R_L}$	0	$\frac{2V_B}{3h}+\frac{2R_I}{9R_L}$
(g) Class D, configuration 2 $\omega_{osc}L \gg R$	0	$1+\frac{R_I}{R_L}$	$\frac{4V_B}{\pi h}$	0	0	$1+\frac{R_I}{R_L}$	$\frac{4V_B}{\pi h}$	0

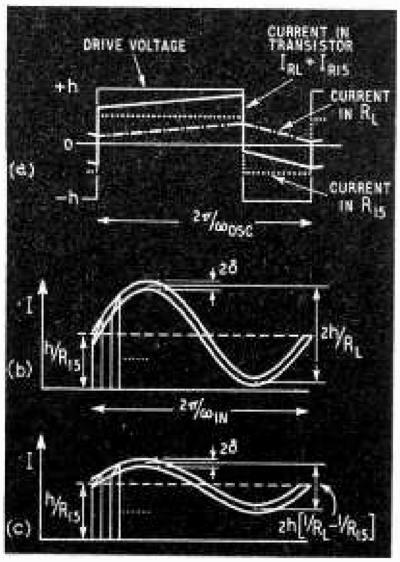


Fig. 4. Transistor current I^+ when $\omega_{osc}L \gg R_L$. (a) currents making up I^-. It can be seen that the current through R_{15} causes the total transistor current to go negative restoring class D operation. (b) I^+ when $1/\omega_{in} C_8 \ll R_{15}$ (c) I^+ when $1/\omega_{IN} C_8 \gg R_{15}$.

duce a situation where the load current in R_L is always in the same direction as shown in *a* and *c* in Fig. 3. One transistor must thus carry current in a direction opposite to the normal conduction direction. As M.D. Samain pointed out[2] if it is not possible for a transistor to conduct in the reverse direction then the opposite transistor of the output pair will be forced to continue conduction during the time when it has the full voltage across it, e.g. in condition (a) in Fig 3 Tr1 will conduct all the time. If this condition exists efficiency coefficients are as listed and the curves of Fig. 5 (c) obtained. As $V_B \to 0$ and $R_l \to 0$, then:—

$$\eta = \eta_{op} = \hat{x}\pi/4 \quad .. \quad .. \quad (3)$$

which is identical with class B.

The presence of R_{15} can ensure correct operation since by choice of a suitable value the combined load to the output stage can be made such that the total current into this load never flows in the "wrong" direction as discussed previously the current in the resistor R_{15} then always exceeds the magnitude of the current in R_L. Assuming initially that $1/\omega_{in}C_1 \ll R_{15}$ then a value of $R_{15} < R_L$ ensures class D operation at all times, i.e. during the time when the output voltage level is positive (or negative) the combined current I^+ (or I^-) into R_{15} and R_L is positive (or negative) and flows entirely in Tr1 (or Tr2). The current I^+ during a full cycle of the input waveform is shown in Fig. 4. Again efficiency coefficients are listed and curves of η and η_{op} plotted in Fig. 5 (d). These show very poor overall efficiency (η_{max} <33%) and that significant improvement over equation 3 for η_{op} will be very difficult to achieve (remembering that the effect of finite rise times has so far been ignored). However better results can be obtained if $1/\omega_{in}C_8 \gg R_{15}$ (providing $1/\omega_{osc}C_8 \ll R_{15}$) since it is then possible to ensure correct operation without wasting so much power. This can be seen if an expression for I^+ is obtained:—

$$I^+ = \frac{hx}{R_L} + \frac{h(1-x)}{R_{15}} + \delta\left(\frac{2\,\omega_{osc}t}{\pi(1+x)} - 1\right) \quad 4$$

$$\text{where } x = \frac{2\beta}{\pi} - 1 \quad .. \quad .. \quad 5$$

$$\text{and } \delta = \frac{h}{R_L}\frac{\pi(1-x^2)}{2\,\omega_{osc}T} \quad .. \quad .. \quad 6$$

$$(T = L/R_L)$$

Now this current (I^+) must never have a negative value if correct class D operation is to be maintained. The first two terms of equation 4 have their minimum value when $x = -\hat{x}$, i.e. on the maximum negative excursion of ω_{in}.

The minimum value of the third term of equation 4 (the inductance current component) is $-\delta$, being the value just after the output has changed from $-h$ to $+h$. The condition that I^+ is never negative may be expressed as:—

$$-\delta - \frac{h\hat{x}}{R_L} + \frac{h(1+\hat{x})}{R_{15}} \geqslant 0$$

The choice of R_1 will thus be governed by the largest value $\hat{x}_{max}$ expected for $\hat{x}$;

$$\text{i.e. } R_{15} \leqslant \frac{R_L(1+\hat{x}_{max})}{\hat{x}_{max} + \frac{\delta R_L}{h}}$$

Thus if $\omega_{osc}L \gg R_L$ δ will be negligible and the condition becomes:—

$$R_{15} \leqslant \frac{R_L(1+\hat{x}_{max})}{\hat{x}_{max}} \quad .. \quad .. \quad A$$

If $1/\omega C_8 \leqslant R_{15}$ then the expression for the current in R_{15} is independent of x and the condition that I^+ is never negative becomes:—

$$R_{15} \leqslant \frac{R_L}{\hat{x}_{max}} \quad .. \quad .. \quad .. \quad B$$

The difference between the two conditions is clearly shown in Fig. 4. A light coupling for R_{15} enables a larger value resistor to be employed for R_{15} whilst still maintaining correct operation. Assuming modulation to full depth ($x = 1$) then $R_{15} \leqslant 2R_L$ (condition A) and efficiency coefficients are as listed. Examination of Fig. 5e indicates significant improvement over previous configurations (b) and (d) in both η and η_{op}. In the original design $R_{15} = 3R_L$ was employed ensuring correct operation at low frequencies to $x = \frac{1}{2}$. The value of x_{max} was approximately $\frac{2}{3}$ so that reverse current was in fact demanded on peak swings as explained and illustrated[3]. Curves for this condition (Fig. 5f) lead to the general conclusion that a lightly coupled R_{15} whose value is around $R_{15} = 3R_L$ should give high values of η_{op} (especially at low levels) and a curve of η *vs* x which is not much worse than that for class B operation, at least at high levels.

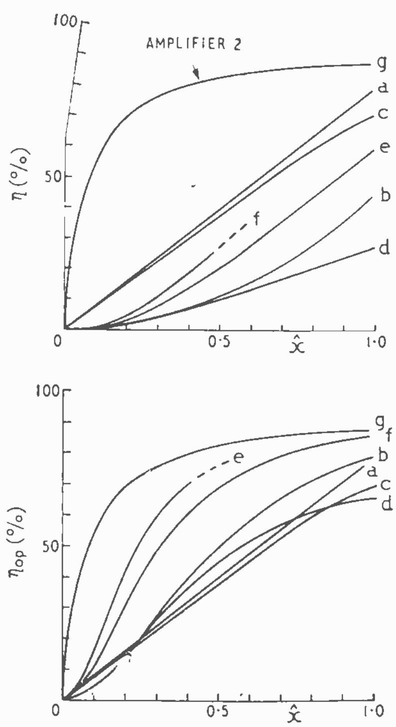


Fig. 5. Theoretical curves for overall and output stage efficiency. The curves correspond to the entries in Table 1.

TESTS ON AMPLIFIER 1

Fig. 6 shows an amplifier designed to deliver 5 W comfortably into a 15 Ω load (here h = 17 V so that 5 W corresponds to $x_{max} = \sqrt{150}/17$ = 0.72). The principles of design are almost exactly as before[1] (except for the double driver stage Tr3, Tr4) only in most cases transistors of increased speed and ratings have been used. The ZS72 diode in series with the C426 gives an output stage which is

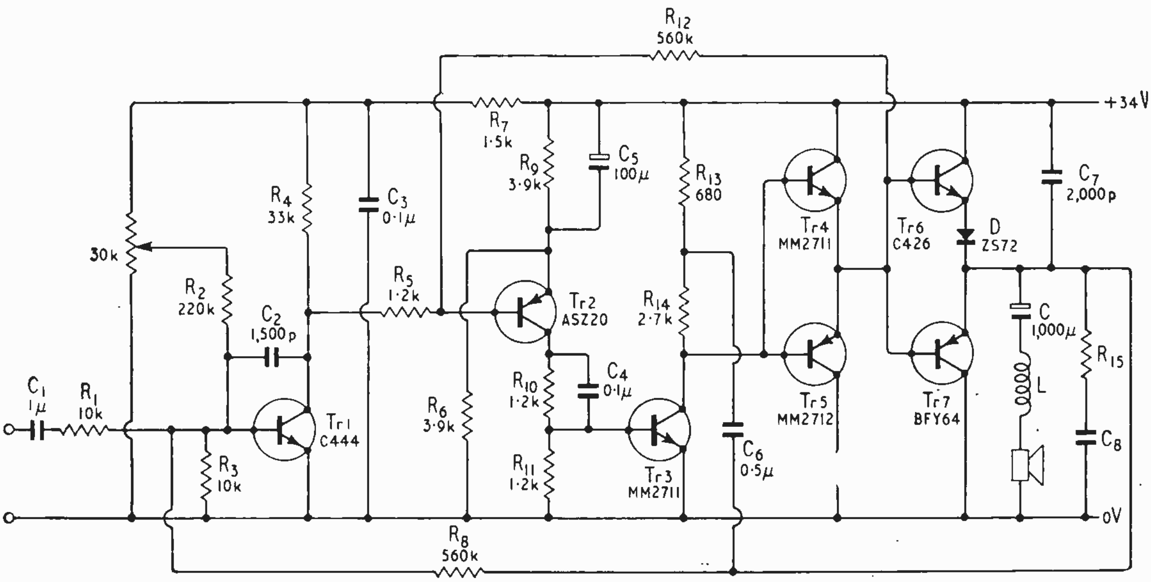


Fig. 6 Circuit of 5 W class D amplifier using configuration I.

almost symmetrical (i.e. this combination and the BFY64 both have approximate values of $V_B = 1$ V, $R_1 = 1\ \Omega$). This simplifies calculation and also gives slight improvement in distortion figures.

The choice of inductance L is extremely important and previously a value of 0.5 mH was used for high output stage efficiency and for other reasons outlined by Johnson[4]. However, it may be argued that, in attempting comparisons a value of L giving a 3 dB point at 20 kc/s would be more appropriate, i.e. $L = 100\ \mu$H. This low value necessitates an oscillation frequency at $x = 0$ in excess of 100 kc/s and in fact a value of approximately 125 kc/s was employed. Substitution into equation 6 gives

$$\frac{\delta R_L}{h} \approx \frac{3}{10}\,(1 - x^2)$$

for an open loop amplifier in which the frequency ω_{osc} is constant and

$$\frac{\delta R_L}{h} \approx \frac{3}{10} \quad \ldots \quad \ldots \quad \ldots \quad 7$$

for this closed loop amplifier for which

$$\omega_{osc} \approx \omega_{osc\,(max)}\,(1 - x^2) \quad \ldots \quad 8$$

The effects of finite edge times at this frequency are certainly significant (see below), these being approximately 0.48 and 0.08 μs on positive and negative going edges respectively. A more accurate expression than was used to compute Table 1 for average power loss ($\bar{P}_T$) in each transistor is

$$\bar{P}_T = \frac{h^2}{2R_L}\left[\frac{V_B}{h}\left(\frac{R_L}{R_{15}} + \frac{\hat{x}^2}{2}\left(1 - \frac{R_L}{R_{15}}\right)\right) + \frac{R_I}{R_L}\left[\left(\frac{R_L}{R_{15}}\right)^2 + \frac{\hat{x}^2}{2}\left(1 - \left(\frac{R_L}{R_{15}}\right)^2\right)\right] + \frac{R_I}{3R}\left(\frac{\delta R_L}{h}\right)^2\right] + P_E \quad \ldots \quad (9)$$

providing correct operation of the output stage is ensured by correct choice of R_{15} according to condition A. The value of δ is given in equation 7 and P_E denotes the extra power dissipated due to the finite edges (approximate expressions are readily obtainable in the manner of the original paper[1] but exact calculation is made difficult by ringing effects, mainly in the current waveform). Other losses in the circuit at low frequencies are:—

(1) in the resistor R_{15}',

$$\bar{P}_{R15} = \frac{h^2}{R_{15}'}\left(1 - \frac{\hat{x}^2}{2}\right)$$

where R_{15}' is R_{15} in parallel with R_{13}.

(2) in the resistor R_{14},

$$\bar{P}_{R14} = \frac{h^2}{R_{14}}\left(1 + \frac{\hat{x}^2}{2}\right)$$

(3) h.f. heating in the load, $\bar{P}_{RL} = \delta^2 R_L/3$.

(4) power losses in the rest of the circuit which are substantially independent of $\hat{x}$.

It was decided first to choose a value of R_{15} to ensure correct operation at all times in order to compare practical and theoretical efficiencies. A value of $R_{15} = 1.64R_L$ gives correct operation to $x_{max} = 0.8$ so that $R_{15} = 24.6\ \Omega$ was the value used. The value of C_8 was chosen such that $\omega C_8 R_{15} \approx 1$ at a frequency of 5 kc/s

TABLE 2. DISTRIBUTION OF POWER IN AMPLIFIER I

Component	Power
Output stage	$1.012 + 0.510\,\hat{x}^2 + P_E$
$R_{16}\ R_{13}$	$9.5\,(1 - \hat{x}^2/2)$
R_{14}	$0.083\,(1 + \hat{x}^2/2)$
$R_{12}\ R_9$	0.148
R_L (h.f. heating)	0.356
Remainder	0.060

in order to compromise between the conditions $1/\omega_{in}C_8 \gg R_{15}$, $1/\omega_{osc}C_8 \gg R_{15}$ (similarly for C_7).

In attempting to tie up theory and practice it is first necessary to make allowance for the fact that the output square wave has levels more nearly ±15 V due to the heavy currents flowing in R_{15} at $x = 0$ and R_L at high values of x. Hence the value of h used in computing theoretical values of $\bar{P}_T$, $\bar{P}_{R15}$ and $\bar{P}_{R14}$ was in fact 15 V. This gives a value $\delta \approx 4.5$V compared with a measured value of 4 V (accountable by the degree of approximation). The practical values of input power were computed from the input voltage (all tests were performed with a stabilized power supply) and the average value of input current. A wave analyser was used to measure the power into a 15 Ω resistor. The power in the

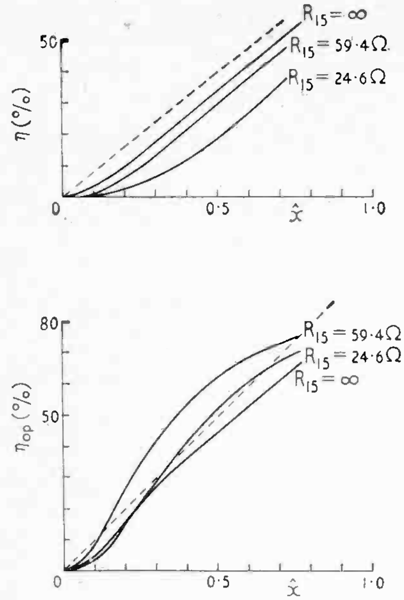


Fig. 7. Curves of overall and output stage efficiency for amplifier 1 (Fig. 6) with R_{15} as parameter.

TABLE 3. COMPARISON OF THEORETICAL AND PRACTICAL VALUES OF POWER DISSIPATION FOR AMPLIFIER 1

Power	Theoretical	Practical
Input (P_1) $\hat{x} = 0$	$P_E + 11{\cdot}2$	11·4
Output stage (P_2) $\hat{x} = 0$	$P_E + 1{\cdot}01$	2·23
Input $\hat{x} = 0{\cdot}565$	$P_1 = 1{\cdot}05 + P'_E$	$P_1 = 0{\cdot}93$
Output stage $\hat{x} = 0{\cdot}565$	$P_2 = P'_E + 0{\cdot}169$	$P_2 = 0{\cdot}04$

output stage was computed from can temperatures, having first of all taken a calibration curve of temperature rise *vs* power dissipation for each transistor.

Table 2 shows the distribution of power in the amplifier and Table 3 compares theoretical and practical values of input power and power loss in the output stage at values of $\hat{x} = 0$ and $\hat{x} = 0.5 \times 17/15 = 0.565$. Examination of Table 3 for $x = 0$ indicates first of all that P_E must be of the order of 1 W. Approximate calculations indicate this to be easily possible and proof was obtained by simply reducing f_{osc} to 14 kc/s (while increasing L in proportion to keep δ R_L constant) when the power dissipated in the output stage fell to 1.27 W. Allowing for the fact that the 24·6 Ω resistor had an inductance of 2 μH so that the power dissipated in it will be slightly less than calculated, theoretical and practical results are within the accuracies imposed by measurement and approximation errors at $\hat{x} = 0$. Comparison at $\hat{x} = 0.565$ indicates that P_E must fall as depth of modulation increases and a significant factor here is the rather drastic fall in the average value of ω_{osc} (Fig. 8).

Practical curves of η and η_{op} *vs* fractions of the theoretical maximum power $P_{max} = 17 \times 17/30 = 9.63$ W are shown in Fig. 7 (also in brackets are values of x based on a value of $h = 15$ V, to allow comparison with Fig. 5). They confirm earlier predictions of poor overall efficiency but an output stage efficiency at high levels which is better than that obtainable by a class B amplifier operating from the same supply lines. Fig. 8 shows that the distortion figures are quite acceptable.

Also shown in Fig. 7 and 8 are results of tests with $R_{15} = \infty$ ($R'_{15} = 45R_L$), when the output stage is working incorrectly all the time. The curves of Fig. 7 confirm the improvement in η at the expense of η_{op}. The shift in levels of the output square wave associated with transistors conducting at the wrong times can be seen to have considerably worsened the distortion figures (Fig. 8) although the average value of

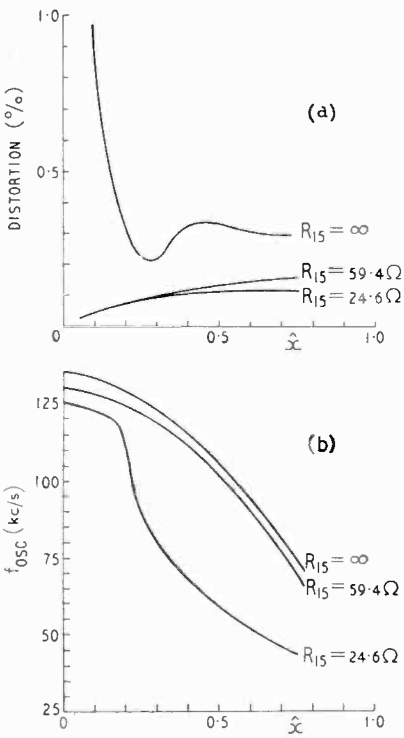


Fig. 8. Distortion and oscillation frequency for amplifier 1 with R_{15} as parameter.

oscillation frequency now falls less drastically—approximately according to the law

$$\omega_{osc} = \omega_{osc\,(max)} \left(\frac{1 - 2\hat{x}^2}{3}\right)$$

(This indicates that the instantaneous value does not exactly obey equation 8 for an ideal single time-constant system.)

The best compromise design seems to be with a value of $R_{15} = 4R_L$ (slightly larger than before). This gives an overall efficiency curve only slightly worse than for $R_{15} = \infty$ and better output stage efficiency than either $R_{15} = \infty$ or $R_{15} = 1.64\ R_L$ at all levels. Distortion figures and frequency response are acceptable (Fig. 8 and 14) and the fall in frequency is almost identical to $R_{15} = \infty$.

Methods of improving overall efficiency. At least two methods are available in order to improve overall efficiency. One is to modify the output stage so that significant reverse current can flow. This, however, is difficult with asymmetrical transistors, such as planar epitaxial types, whose current gain is much smaller in the reverse direction.

The other method, suggested by Johnson[4], is to use parallel diodes to carry the reverse current. This arrangement, to be known as configuration 2, will be discussed in detail in part 2 of the article, to be published next month.

REFERENCES

1. A Feedback Pulse-width Modulated Audio Amplifier, G. F. Turnbull and J. M. Townsend, *Wireless World*, April 1965.
2. M. D. Samain, *Letter to the Editor*, *Wireless World*, June 1965.
3. G. F. Turnbull and J. M. Townsend, *Letters to the Editor*, *Wireless World*, June 1965.
4. K. C. Johnson, *Letter to the Editor*, *Wireless World*, March 1963.

Quick-Acting Audio A.G.C.

USE OF FIELD EFFECT TRANSISTOR REDUCES ATTACK TIME

By ROBERT HIRST

AUTOMATIC gain control is not usually found in domestic audio equipment, but in dictating machines, where non-technical operators are required to make consistent recordings, some form of a.g.c. is essential. In this type of application a relatively wide-range control system is highly desirable, and such extensive control action can constitute the greatest problem in the design of a system.

Ideally the recorded material when played back should sound as if there had been no interference to the original signal. This, unfortunately, is an impossible requirement, as the presence of a.g.c. means that the system has been removed from its natural state and the signals are being integrated as a relatively constant level. With music, extensive compression of the signal is noticeable, but when a similar range of compression is applied to speech signals the ear is unable to make such a wide distinction and apparently hears sounds not far removed from the original, especially if the upper frequency response of the system is curtailed to some degree.

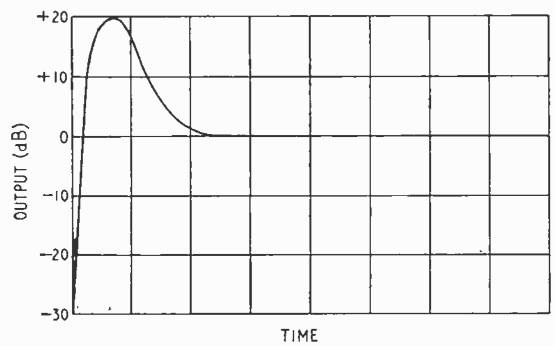


Fig. 1. Showing how the output of a system with a.g.c. is initially dependent on the control voltage rise time.

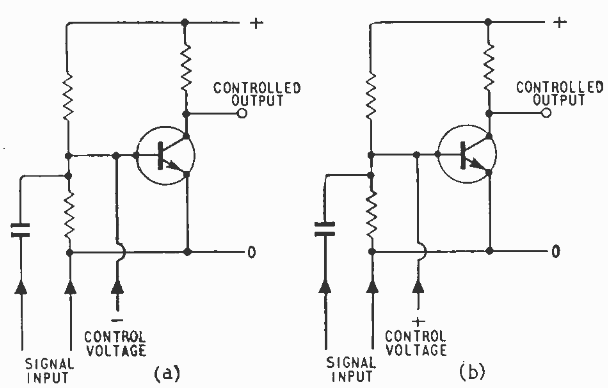


Fig. 2. Simple a.g.c. circuits: (a) based on reduction of collector current; (b) based on reduction of collector-emitter voltage.

The side effects of automatic gain control that appear to be more objectionable tend to be a function of noise level changes. During various listening tests it was established that if the signal-to-noise ratio remains relatively constant then it becomes progressively more difficult to identify a system that incorporates automatic gain control. It is obviously impossible to maintain a constant source signal to noise ratio when the variable input signal is made to give a constant output signal by the action of a.g.c. It is possible, however, to maintain a constant system signal to noise ratio, and should this s/n ratio be compatible with the source conditions then the detection of an a.g.c. system by an unskilled ear becomes less likely. In fact, the majority of listeners taking part in this test found that a system incorporating automatic gain control became markedly more intelligible and less fatiguing to listen to over a period of time.

A further undesirable feature of a.g.c. is the time it takes for the controlling action to have effect, and in the tests any period in excess of 50 milliseconds was noticeable. It is to the shortening of this attack time that the majority of investigations have been directed in the past.

Rise of control voltage

If we plot the rise of control voltage against time in a system then compute the signal output from the system we obtain a graph of the kind shown in Fig. 1. In this the output level of the amplifier, for a period of time, is dictated by the rise time of the control voltage, and in the simpler types of system as shown in Figs. 2(a) and (b) this rise time may well be of the order of 500 milliseconds. In Fig 2(a) the base voltage of the transistor becomes more negative as the input signal increases, thus reducing the collector current, and automatic gain control is obtained by the resulting reduction in h_{fe}. However,

Robert Hirst, who is 33, has for the past 18 months or so been with Dictaphone Ltd. in North London, working with the research and development team engaged on closed-circuit communication systems and educational recording equipment. Prior to joining Dictaphone he was a senior engineer with Newmarket Transistors where he was concerned with special packaged circuit applications.

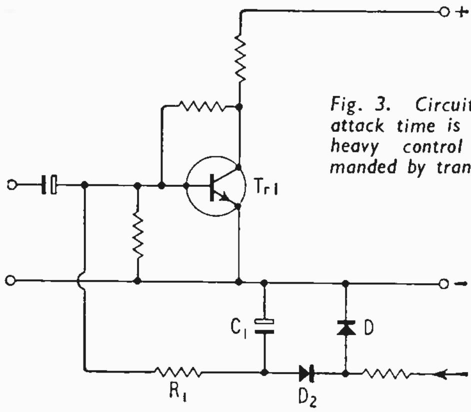


Fig. 3. Circuit to show how attack time is determined by heavy control current demanded by transistor.

in Fig. 2(b) the control voltage is reversed in polarity, and as the collector current increases, the resultant decrease in collector-to-emitter voltage produces a fall in the beta characteristic of the transistor. Both these systems have the common disadvantage of a lengthy delay time, plus the fact that the ever decreasing collector swing is unable to cope with the input signal.

The problem of attack time may be best illustrated by the circuitry of Fig. 3, where D_1 and D_2 are the rectifying diodes, C_1 is the reservoir capacitor and R_1, etc. is the discharge path. The value of C_1 relates directly to the frequency range that the system is required to handle and the current required to give the necessary control action. As a bi-polar transistor under the Fig. 3 conditions requires a relatively heavy control current, being a low resistance device, the value of R_1 is low and the value of C_1 reasonably large. In a case where the control signal is about 10 V peak-to-peak then R_1 and C_1 may quite well be of the order of 10 Ω and 100 μF respectively to produce the desired control action down to 50 c/s. The attack time of the circuit has been virtually predetermined as this time is a function of R_1 and C_1. In the case of the bi-polar transistor a combination of these conditions tends to give rise to a vicious-circle situation and the attack time of such a system can be, as previously indicated, as much as half a second. If the frequency requirements of the circuit were to remain constant and the source resistance be an unalterable factor, then in order to shorten the attack time it becomes necessary to reduce the current demand on the d.c. control supply so that R_1 will be increased in value and the subsequent reduction in the value of C_1 will shorten the attack time.

By using a field effect transistor for control in the form of a variable resistor, the simple circuit of Fig.4 provides a configuration that, because of its high impedance parameters, realises the low operating current requirements. The attack time of the system may now be of the order of 10 ms, or in fact may be adjusted over a wide range by varying the combination R_1, C_1, VR_2. The controlling element is placed in the front end of the amplifier, thus maintaining a constant system signal-to-noise ratio in the first instance. The control VR_1 is inserted to obtain the overall gain required just prior to the start of a.g.c. action, and VR_2 is included to set the required level of output. The f.e.t. is used as a series element of a variable attenuator because in the "off" condition this device is at its minimum resistance; therefore the attenuator is at its most inoperative point.

Non-linearity in characteristic

In order to preserve economy and at the same time reduce phase shift, the Fig. 4 amplifier is entirely directly coupled, the d.c. biasing point being established by R_2, R_3 and R_5. The d.c. and a.c. design is standard, and while gain figures are shown in Fig. 5, it is the response time, controlling action and distortion content that are the most important features. Owing to the symmetrical quality of a field effect transistor it is possible to use the reversed drain voltage characteristic, whereby an a.c. signal is applied across the device without the normal biasing voltage. The graph in Fig. 6 shows the variation in linearity in the reverse condition, but as we are not considering large signal voltages across the device any correcting action has been omitted. Application of feedback does tend to "iron out" the non-linearity of the reverse condition but this can never be a complete solution as there is always an optimum point at which this feedback performs correctly. Thus in a variable system there will always be discrepancies with respect to the linearity. There is also the problem of attenuation of the control signal due to the application of feedback making the controlling action even more difficult, so being able to dispense with the correcting action is, on the whole, desirable.

From the curve in Fig. 7 we can see the change in drain-to-source resistance against gate voltage, and it is on this para-

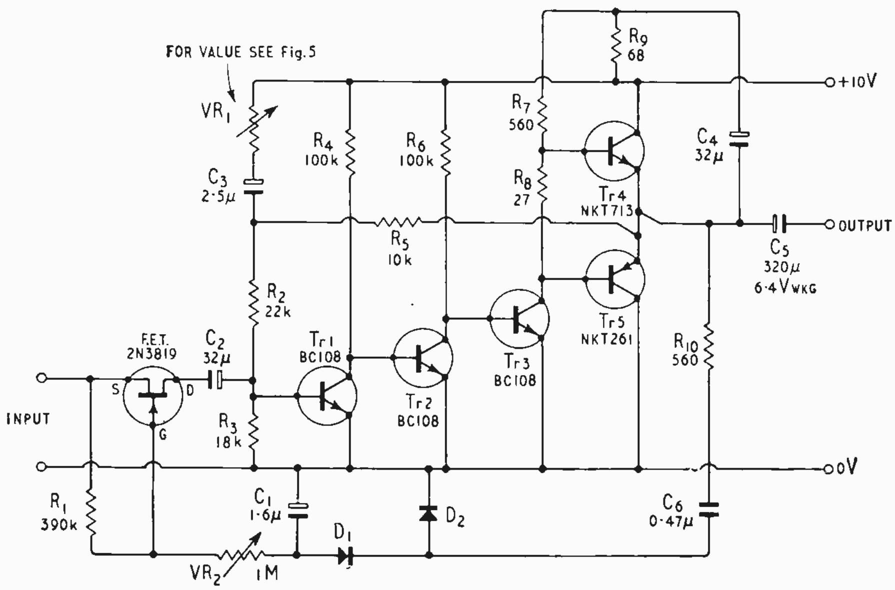


Fig. 4. Amplifier using an f.e.t. (Texas Instruments 2N3819, n-channel type) as the controlling element in the a.g.c. system.

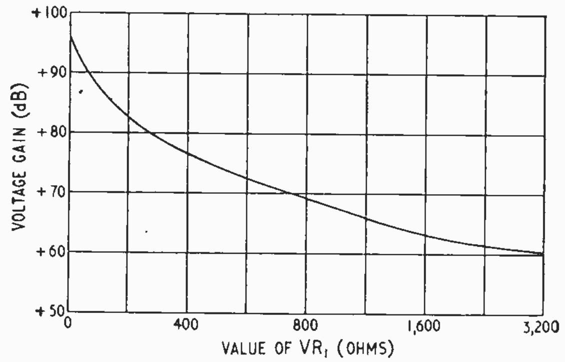


Fig. 5. Gain of Fig. 4 amplifier with variation of VR_1.

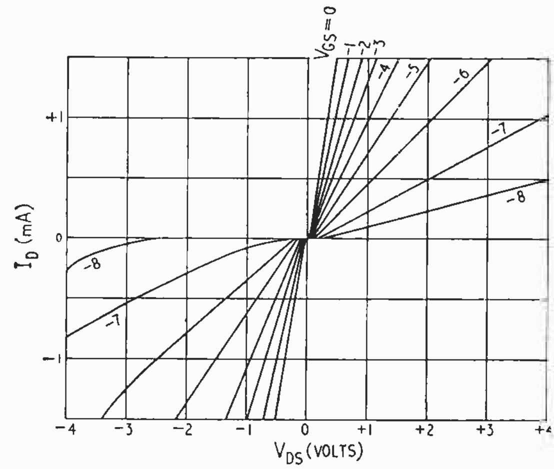


Fig. 6. Drain current vs. drain-source voltage characteristic of the f.e.t. showing non-linearity in reverse condition.

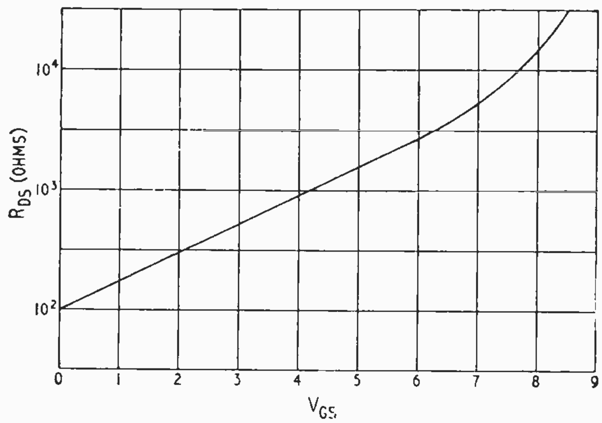


Fig. 7. Drain-to-source resistance of f.e.t. with variation of gate voltage.

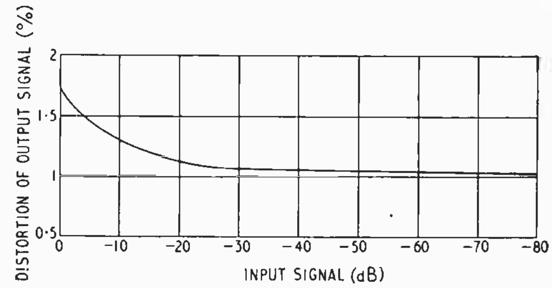


Fig. 8. Distortion in output signal of Fig. 4 amplifier with different input signal levels.

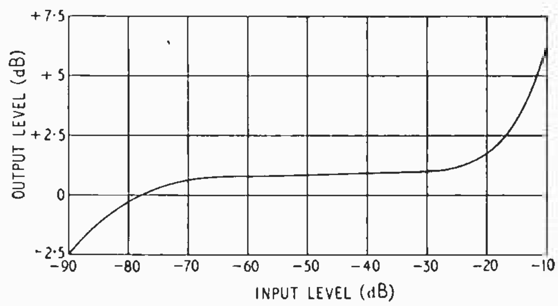


Fig. 9. Output level of Fig. 4 amplifier with different levels of input.

meter that the controlling action relies. As the gate voltage becomes more negative the internal resistance of the f.e.t. increases and, in conjunction with the low input impedance of the amplifier, forms a variable attenuator. The advantage of using an f.e.t. in this method of control lies in the fact that the f.e.t. does not form part of the dynamic circuitry but acts as a passive element. The first stage of the amplifier proper maintains a set d.c. condition, and as the input signal seen by the amplifier does not vary very much, owing to the increasing resistance of the f.e.t., the distortion content of the output signal remains relatively constant over a considerable change in input signal. The increase in distortion for set values of input signal may be seen in Fig. 8.

Guarding against instability

The attack time of the control system can now be substantially reduced because of the high input resistance of the f.e.t., and the values of R_1 and C_1 can be altered as indicated earlier. The attack time was found upon measurement to be as little as 15 ms, well within the limits imposed by the ear, and the resulting sound was free from the characteristic thumping that can be noticed in the majority of simple systems. It is highly desirable that the fed back controlling signal, although d.c., should be out of phase with the input signal, so that the possibility of instability resulting from positive feedback in the system is minimised. An in-phase control signal may be used if considered vitally necessary to obtain high input sensitivity, but it will be necessary to ensure that the control voltage is adequately decoupled. In this latter instance it may be advantageous to reduce the loop gain of the amplifier at the lower end of the frequency scale by reducing the value of input and output capacitors to give a compound low frequency attenuation.

Setting up.—After disconnecting R_{10} from the emitter of Tr5, VR_1 is adjusted so that for an output of 10 V peak-to-peak the input required is 1 mV peak-to-peak. Having established this setting, which under nor-

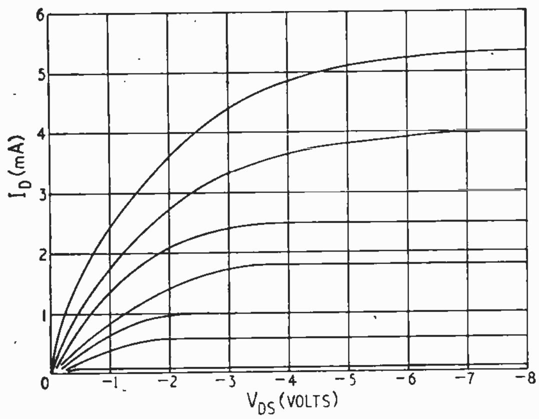


Fig. 10. Output characteristic of the field effect transistor.

mal production techniques would have been pre-determined and set with a fixed resistor, the emitter of Tr5 is re-connected and the value of VR_2 is reduced until the output falls to 9 V peak-to-peak. The graph in Fig. 9 shows the output level of the circuit as a whole with different levels of input. This output characteristic is very linear for an increase in input signal of as much as 50 dB, and it isn't until the input signal is advanced by a further 6 dB that any overloading of the circuit becomes apparent. This overloading takes the shape of the output characteristic of the field effect transistor where the f.e.t. runs into its normal operating point. At this stage very little change in resistance takes place for considerable changes in gate voltage; this can be seen from Fig. 10 which is the output characteristic of the field effect transistor. It is therefore apparent that the range of control that may be effected by any individual device is directly related to the pinch-off voltage of the f.e.t. in question.

In operation the circuit is very effective, and leaves little to be desired even when compared with the more complicated circuitry used professionally. The most promising advantages are the comparative simplicity of the setting up procedure and the economy effected over more complex configurations. Because of this simplicity the technique may well prove useful in the domestic equipment field for reducing the hazards that beset the non-technical operator.

OUR COVER

Anechoic Chamber at Northern Polytechnic

THE measurement of the performance of microphones, loudspeakers, and of sound insulation materials forms part of the training of every engineer, and to those specializing in audio and acoustical subjects the access to an anechoic chamber is of paramount importance. When the London County Council agreed to extend the laboratory facilities by building a thirteen-floor tower block at the Northern Polytechnic, Holloway, London, the Department of Electronics and Communication Engineering, of which John C. Gilbert is the head, requested that a large anechoic chamber should be included in the design. For many years several of the lecturing staff had specialized in high quality sound reproduction apparatus but the lack of an anechoic chamber limited the scope of the work. The design of the building did not permit the chamber being made as large as necessary to cover the whole of the audio spectrum under "free-field" conditions. However, the architects consulted the Research Department of the B.B.C., the Building Research Board, and several other authorities and decided that measurements below 85 c/s should be made in a separate acoustical tunnel.

The bare chamber measures 27 by 16 by 16ft with solid concrete walls 12in thick, partially floating from the main structure. The acoustic wedges are constructed from polyurethane ether as this material offered considerable advantages over glass-fibre or mineral wool. Each wedge has a square section base of 8in × 8in which fits into a honeycomb wooden lattice and is spaced 2in away from the wall. The length of each wedge is three feet. Access to the chamber is through a heavy solid wood door behind which is a movable wedge section suspended on an overhead runway. The floor consists of removable heavy steel wire panels.

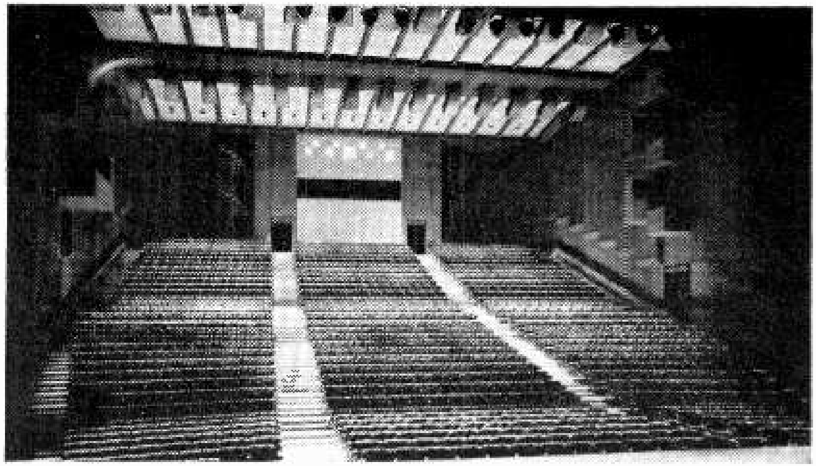
All of the measuring apparatus is housed outside the anechoic chamber, the necessary leads being fed to the equipment under measurement through a sealed tube through one of the walls. The apparatus is manufactured by Brüel and Kjaer and consists of an automatic frequency response recorder, spectrum recorder with one-third octave filters, polar diagram synchronized turntable, sine-random generators, microphone amplifiers and a range of one, half and quarter-inch capacitor microphones. To supplement microphone measurements a precision sound source in the form of a Pistonphone is available.

To measure the performance of the anechoic chamber the method recommended by the B.S.I. specification 2498 : 1954 was used. A Goodmans Maxim loudspeaker was mounted in a skeleton framework with a B. & K. condenser microphone exactly one metre from the face of the loudspeaker diaphragm. Response curves were recorded in various positions in the chamber and above 100 c/s the plotted curves were within ±1.5 dB. At low frequencies errors can occur when the wavelength of sound is approximately equal to or greater than the distance between the parallel surfaces of the wedges.

The acoustic tunnel is 26 feet long with a cross-section of 2ft × 2ft and at one end is a polyurethane ether wedge 7ft 6in long. The walls of the tunnel are highly damped and are 6in thick, finished externally as a wooden laboratory bench. A microphone can be mounted on a travelling platform, remotely positioned, and the loudspeaker under test is mounted on a one inch thick baffle board.

Whereas in the past the plotting of response curves of electro-acoustic transducers has been a long, laborious procedure, curves can now be run in a few minutes with repeatable accuracy, and the Department has been pleased to make these facilities available to Government and industrial organizations.

Acoustics of the Queen Elizabeth Hall



THE recently opened Queen Elizabeth Hall (situated next to the Royal Festival Hall), London, is by no means a new concept. A need has existed for some time now for a medium-size concert hall and in fact the hall was planned at the same time as the R.F.H. was conceived in 1948, but for various reasons work on it had been delayed.

The acoustical design of the concert hall, which is medium-sized with about 1,100 seats, and of its smaller neighbour (Purcell Room) with about 370 seats, was thus settled some considerable time ago. The acoustical consultants for the hall were P. H. Parkin, of the Building Research Station, and Hugh Creighton. (Mr. Parkin is well known for his work in connection with the Royal Festival Hall acoustics and assisted resonance.)

One of the main problems in the design of concert halls is the exclusion of external noise carried by both air and structure. The present hall is on a site with a relatively high ambient noise level—due to the proximity of road, rail, river and air traffic (a helicopter route is close by) and the air conditioning plant.

The required noise level reduction (to conform to criterion A*) was met in the case of the Q.E.H. by 15 in of surrounding concrete, care in the air-conditioner installations and by acoustically treating the airways or ducts for lengths of 70-80 ft. Noise absorbed into the air stream was reduced with honeycomb absorbers installed in the main supply. (Incidentally, air is extracted from under the seats and discharged at roof level by air outlets, which also serve to break up ceiling reflections.)

The elimination of noise from the smaller Purcell Room was a special problem since the air-conditioning plant was immediately above the auditorium ceiling. To give the required sound attenuation the supporting structure for the plant room straddles and is separate from the Purcell Room and a sealed air gap of 3 in is allowed between the two rooms.

As is well known the reverberation time (r.t.) of a hall depends on its volume and on the absorption by the surfaces and audience. The audience size for the Q.E.H. was, relatively, a fixed quantity and the reverberation time was required to be 2 sec at 500 c/s. These two factors meant a large volume and in fact although the hall seating capacity is only one-third that of the R.F.H., its volume (about 350,000 ft^3) is approximately a half. Absorption at the high frequencies is minimized by lack of soft furnishings. In order to control the low frequency r.t. large wood panels with air spaces behind are an obvious choice but in the Q.E.H. (and the Purcell Room) use is made of Helmholtz resonators as absorbers. The resonators can be seen in Fig. 2 and consist of an enclosed box of 2 in-thick block-board coupled to the auditorium by a vertical slot. There are four slot sizes corresponding to fundamental absorbing frequencies of 50, 70, 90, and 140 c/s, these being chosen after studies made at the N.P.L. The undamped Q of the resonators was around 30-40 giving too sharp a response and necessitating damping. Q was reduced to 10 by placing polyurethane at the rear of the cavity throat. The number of resonators required has been deliberately over-estimated by 25%, making the low-frequency absorption greater, but this can be decreased in order to increase the reverberation time, should this be found necessary. In the case of the Purcell Room, half of the 70 and 90 c/s resonators on two sides have been found to require sealing because of an unexpected dip in r.t. The great advantage of using Helmholtz resonators as absorbers is the ease with which modifications can be made—the larger slots can be readily partly or wholly blocked if less absorption is required. (Less conveniently, perhaps, the slot sizes could also be increased.) Thus the

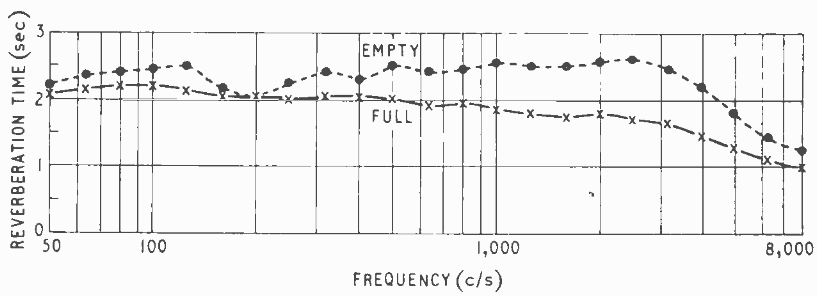


Fig. 1. Reverberation time of Q.E.H. measured by the Building Research Station at 1/3 octave intervals using recorded pistol shots. Design reverberation time was 2 sec. If necessary, the l.f. reverberation time can be increased by blocking up a number of Helmholtz resonators.

* "Acousics, Noise and Buildings," P. H. Parkin and H. R. Humphreys, p. 296 (Faber).

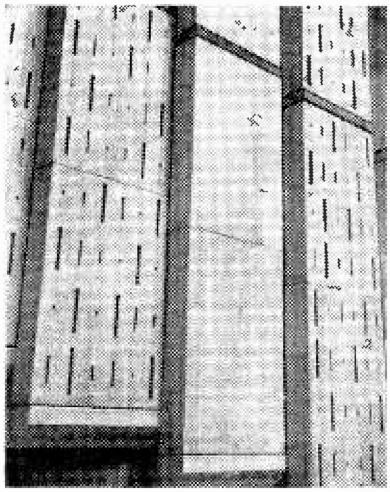


Fig. 2. Wall of Q.E.H. showing the four slot sizes of Helmholtz resonators. Absorption can be varied by partly or whooly blocking a number of cavities. Polyurethane damping material at back of slots reduces Q to 10.

curve of Fig. 1 can to some extent be tailored at the lower end of the spectrum.

Apart from giving some absorption at low frequencies the surfaces (the ceiling also gives some l.f. absorption by virtue of the fibrous plaster panels between the concrete beams) should also give some degree of diffusion toward the rear and this is achieved by the cast-aluminium air-conditioning outlets on the ceiling and also by the stepped surface (Fig. 2) along both sides. In the Purcell Room some diffusion is given by large corrugations on the rear wall.

Consideration of the task of ensuring good sound at the rear of the hall led to the use of a three-tier reflector above the stage area. The reflectors may be moved (electrically) into an inoperative position. An advantage of this arrangement is that the reflected sound can be optimized by altering the reflector angle for performing groups of differing size and arrangement. Additionally, the reflectors can also be moved vertically, within certain limits. The stage, incidentally, comprises 13 sections each of which can be adjusted up to a height of 6 ft above floor level. (Two of these can be lowered to provide an orchestra pit and one can be lowered below the stage to carry heavy instruments on and off the stage.) The surfaces around the stage are concrete and this allows some acoustical re-inforcement for the players.

Seating is, of course, raked in order that direct sound can reach the hall rear without passing directly over the audience. This is arranged because of the phenomenon in which sound travelling directly over a horizontally seated audience suffers a frequency selective absorption, particularly around 200 c/s or so.

The results of a test concert held in January showed that no obvious faults existed, such as echoes. The reverberation time was measured (Fig. 1) and the effect of varying the reflectors positions investigated. With the reflector up, results were said to be good by 80% of those questioned—however, one test concert is felt to provide insufficient evidence. Experience gained at future concerts will reveal whether some blocking of the Helmholtz absorbers is necessary—it has been stated that l.f. reverberation time should be about 1.2 times the mid-frequency value.

APRIL CONFERENCES & EXHIBITIONS

Further details can be obtained from the addresses in parentheses

LONDON

Apr. 17-19 — University College
Elementary Particles
(Inst. P. & Phys. Soc., 47 Belgrave Sq., S.W.1)

Apr. 17-20 — Alexandra Palace
Physics Exhibition
(Inst. P. & Phys. Soc., 47 Belgrave Sq., S.W.1)

Apr. 17-20 — Alexandra Palace
Instruments Exhibition
(Scientific Instrument Manufacturers' Assoc., 20 Peel St., W.8.)

Apr. 25-May 4 — Olympia
Engineering, Marine & Welding Exhibition
(F. W. Bridges & Sons, 1-19 New Oxford St., W.C.1)

BRISTOL

Apr. 11-14 — The University
Advances in Computer Control
(I.E.E., Savoy Pl., London, W.C.2)

EASTBOURNE

Apr. 11-12 — Grand Hotel
New Developments in Optics and their Applications in Industry
(British Scientific Instrument Research Assoc., South Hill, Chislehurst, Kent)

EXETER

Apr. 12-14 — The University
The Teaching of Mathematics to Physicists
(Inst. P. & Phys. Soc., 47 Belgrave Sq., London, S.W.1)

GREAT MALVERN

Apr. 24-26 — Royal Radar Establishment
Image Detection and Processing
(Inst. P. & Phys. Soc., 47 Belgrave Sq., London, S.W.1)

NOTTINGHAM

Apr. 3-5 — The University
Resistive and Dielectric Properties of Thin Films
(Inst. P. & Phys. Soc., 47 Belgrave Sq., London, S.W.1)

READING

Apr. 12 & 13 — The University
Point Defects in Metals
(Inst. P. & Phys. Soc., 47 Belgrave Sq., London, S.W.1)

ABROAD

Apr. 2-5 — Chicago
N.A.B. Conference & Exhibition
(National Assoc. of Broadcasters, 171 N. St.. N.W., Washington, D.C.)

Apr. 5-7 — Washington
International Magnetics Conference
(I.E.E.E., 345 E. 47th St., New York, N.Y. 10017)

Apr. 5-10 — Paris
Electronic Components & Audio Euipment Shows
(F.N.I.E., 16 rue de Presles, Paris 15e)

Apr. 10-15 — Paris
Electronics and Space Conference
(F.N.I.E., 16 rue de Presles, Paris 15e)

Apr. 14-21 — Paris
Mesucora—Measurement & Automation Exhibition
(Mesucora, 40 rue du Colisée, Paris 8)

Apr. 17-19 — Bad Nauheim
Semiconductors, Metals & Magnetics
(Deutsche Physikalische Gesell., Abbestrasse 2-12, 1 Berlin)

Apr. 19-22 — Bad Nauheim
Semiconductor Device Research Conference
Dr.-Ing H. H. Burghoff, Stresemann Allee 21, 6 Frankfurt)

Using a Three-Coloured Pencil of Light

SOME OF THE PROBLEMS OF DEFLECTION AND CONVERGENCE OF THE ELECTRON BEAMS IN THE PICTURE TUBE OF A COLOUR RECEIVER

By T. D. TOWERS,* M.B.E.

THE modern 25kV, 90°, rectangular, flat, large-screen, shadow-mask, three-gun, colour picture tube has all the beam deflection problems of its single-gun black-and-white counterpart, only in a more magnified form. Besides this, the colour version calls for special "convergence" circuits to keep the three electron beams in step over the screen face.

Looked at from the circuit end, colour deflection and convergence problems fall naturally into five main areas, each of which can conveniently be dealt with on its own: (1) line (horizontal) deflection; (2) field (vertical) deflection; (3) pincushion (raster) correction; (4) line convergence; and (5) field convergence.

How these five circuit sections broadly control the picture tube is illustrated in Fig. 1.

The line deflection section first drives the line coils in the deflection yoke, A. Besides this it also controls the line convergence section, which provides correcting currents to line coils in both the radial convergence assembly, B, and the blue-lateral assembly, D.

The field deflection section's main purpose is to drive the field coils in the deflection yoke. It also drives the radial convergence assembly, B.

(In passing it should be noted that the convergence signals to assemblies B and D are supplemented by six variable-position magnets; two in the "purity" magnet assembly, C; three in radial convergence, B; and one in lateral convergence, D. These magnets are designed to ensure that the three electron beams pass through the correct holes in the shadow mask at the centre of the screen and can be regarded in a way as d.c. preset bias to the dynamic convergence—to be described later.)

The remaining section outlined in Fig. 1 is for pincushion correction of the raster, and is shown connected between the output of the line deflection and field deflection sections.

Fig. 2 shows the appearance of typical colour-tube commercial deflection, radial convergence, and lateral convergence coil assemblies, denoted A, B and D respectively in Fig. 1.

Each of the five deflection and convergence circuit sections above is dealt with separately below. Discussion will be restricted to 625-line operation, so as to be able to omit the complex switching in of different component values for 405-line operation.

GENERAL CONSIDERATIONS OF DEFLECTION

Deflection circuit sweep currents in the deflection yoke act on the three electron beams as a whole after they leave the guns. (Convergence circuits on the other hand are pre-deflection; i.e. they work on each of the three beams separately within its own gun.) The deflection sections are designed to provide synchronized horizontal and vertical sweeps of satisfactory amplitude, linearity and centring without raster (pincushion) distortion.

For a discussion of the general problems of complete timebase sweep circuits leading up to deflection the reader is referred to the author's "Transistor Television Receivers", Iliffe Books, 1963. In the separate discussions of line deflection, field deflection and pincushion correction below, attention is directed mainly to the output stages of the timebases, because this is where colour brings in special problems.

LINE DEFLECTION

In a colour receiver the line deflection section is basically the same as in a black-and-white set, as illus-

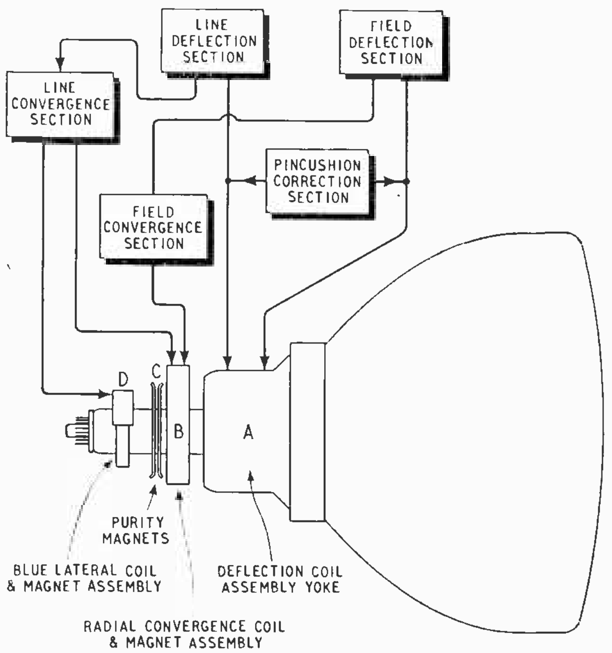


Fig. 1. Block diagram of deflection and convergence arrangements in colour television receiver.

*Newmarket Transistors Ltd.

trated in simplified form in Fig. 3(a). The valve V1 receives drive pulses at its grid from the line oscillator and drives the line output transformer. Conventionally, a voltage-dependent resistor VDR in the anode-grid feedback stabilizes the valve gain, and an efficiency diode V2 provides a boost h.t. voltage. The output transformer primarily provides sweep current to the line deflection coils, L_3 and L_4. However, it also has windings to provide sources for 25kV e.h.t., 5kV tube focus, e.h.t. rectifier heater, focus rectifier heater, flywheel sync, and chrominance burst blanking, none of which are really relevant to operation as a deflection circuit.

In Fig. 3(a) the linearity and width control by variable inductors L_1 and L_2 in series with the line coils follows black-and-white practice, but a new feature is the arrangement of splitting the transformer drive winding, g-h, to return one side direct to earth and the other through low impedance radial and lateral convergence networks to earth. Also new is the provision of a d.c. shift current in the line coils from the cathode of V1 via an isolating choke, L_5. The line coils themselves have typically an inductance of 3mH and a resistance of 3Ω and require a peak-to-peak scan current of 2.75A.

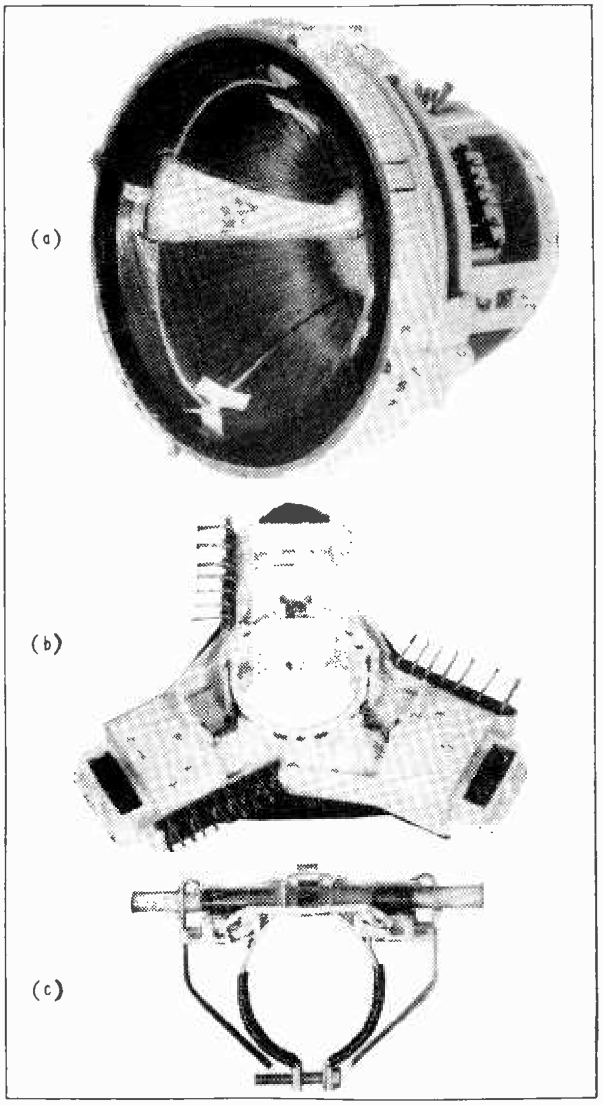


Fig. 2. Examples of modern colour tube deflection and convergence drive coils: (a) deflection yoke (Mullard AT/1022); (b) radial convergence assembly (AT/1023); and (c) lateral (blue) convergence assembly (AT/4040/04).

Fig. 3(b) shows the full circuit of a Mullard-designed line deflection stage, of which Fig. 3(a) was the skeleton diagram. The output transformer, T_1, is largely an auto-transformer. A number of refinements appear in the fuller diagram. The a.c. drive to the efficiency diode comes via a 2 μF capacitor from transformer tap 8, the choke L_1 providing a d.c. return path. The preset variable inductance L_3 provides for setting of the third-harmonic tuning for most efficient drive conditions of the PL505 output valve. The inductance L_6-L_7 is used to preset the symmetry of the line coil pair, mainly to simplify line convergence adjustments as described later. The preset RV_1 is used to adjust the anode-grid feedback stabilization network, and RV_2 sets the direct current through the line coils for picture horizontal shift setting. Connections are taken from across the line deflection coils at points (A) and (B) to the pincushion correction network to be described later.

The PL505 line output pentode in Fig 3(b) is an impressive "bottle" capable of dissipating 32 W (25 W anode, 7 W screen), of giving peak currents up to 1.4 A, and of withstanding anode flyback voltages of 7 kV. Some designs use two more normal pentodes in parallel instead. The operational conditions are so severe that it has not been possible so far to produce a semiconductor device to replace the line output thermionic valve.

FIELD DEFLECTION

Field deflection circuits in a colour television receiver bear superficially a marked resemblance to standard black-and-white practice, but significant differences do exist. Fig. 4 shows a recent circuit by Mullard for a 25 in, 90°, rectangular tube which can be used to illustrate some of the design features. In the figure, the drive valve (½ECC82) is included because the picture height adjustment, RV_2, is in its anode circuit. The two valves form a multivibrator with the line output valve PL508 anode feeding back through 0.1 μF and 56 kΩ to the grid of the ½ECC82. The field hold frequency is preset by RV_1, in the grid circuit of the ½ECC82, and synchronized by drive from the sync separator to the control grid of the PL508.

The PL508 pentode drives the 25 mH, 14 Ω field deflection coils (combined with the line deflection coils in a single deflection yoke) through the field output transformer, T_1. The deflection coils require about 0.9 A peak-to-peak current and are connected in parallel. They are combined with a thermistor, VA1033, which counteracts the increase of coil resistance with temperature, and stabilizes the vertical sweep amplitude or picture height.

Vertical linearity is controlled by two preset pots, RV_4 (top) and RV_5 (overall) in a feedback loop from anode to grid of the PL508 and from the anode to earth.

The field deflection coils in Fig. 4 have two special features. A preset 5 Ω potentiometer across the ends of the coils is used to adjust the symmetry of the assembly as an aid to easy field convergence adjustment. Also, adjustable d.c. shift current though the field coils for vertical positioning of the picture is obtained from the decoupled RV_3 in the h.t. anode lead of the PL508.

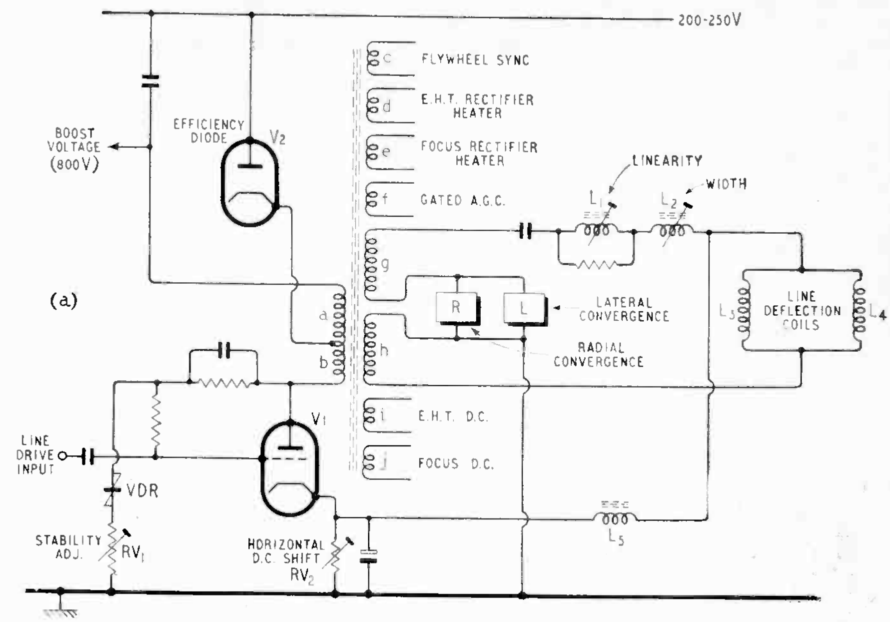
Field convergence correction currents are fed off both from the PL508 cathode (via a 400 μF capacitor and point (X) to a separate low-impedance circuit discussed later) and from a separate secondary winding on the transformer.

Finally signals are taken off at (C) and (D) to a separate pincushion correction network also described later.

PINCUSHION CORRECTION

Raster pincushion distortion results from large deflection angles in flat-faced picture tubes, where the corners of the tube face are substantially farther from the deflection yoke than the centre. This results in a "bowing" of straight lines in the raster, as is well known. In black-and-white receivers this could be corrected by a pair of small permanent magnets mounted near the deflection yoke. The fields of these magnets slightly deflect the beams outwards at the side centres and inwards radially at the corners to produce an undistorted raster.

Neither d.c. magnets nor deflection coil modifications can be used for pincushion correction with three-beam shadow-mask tubes, however, as the different beams would be affected differently and this would lead to severe impurity in the three colour fields. With colour tubes, the approach is to combine the vertical (field) scan current with a parabolic compensating current at horizontal (line) rate and vice versa. Many circuits using valves have been employed in the past to produce the required pincushion correction signals, but recent practice seems to be tending towards the use of saturable reactor coupling between the time bases. Fig. 5 illustrates one elegant example of this, derived from a Mullard design. The heart of the circuit is the special



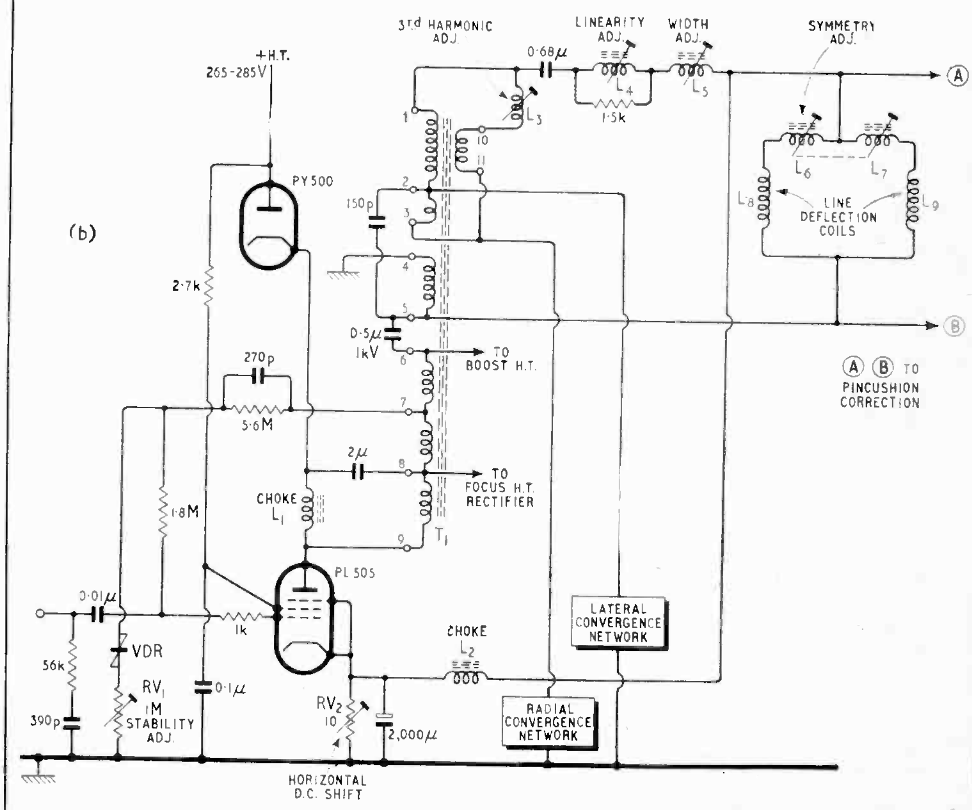


Fig. 3. Line deflection in colour receiver: (a) skeleton circuit showing all functions of line timebase output stage; (b) line deflection portion of practical (Mullard) circuit.

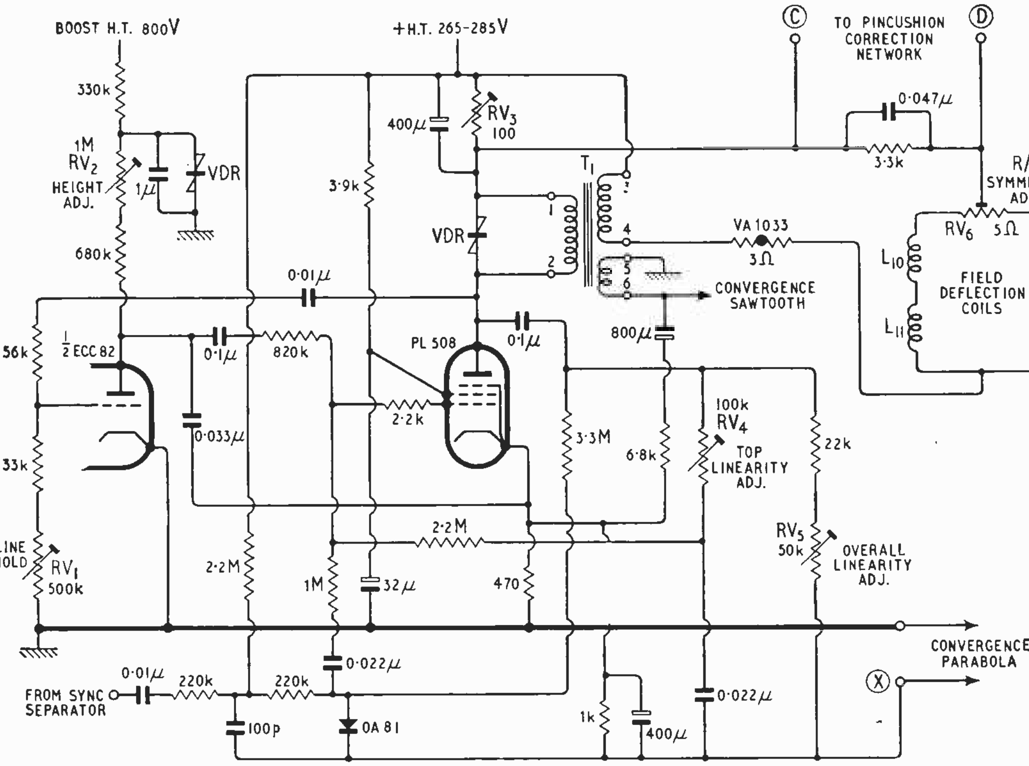


Fig. 4. Colour receiver field deflection illustrated in practical circuit of field timebase final stages (Mullard).

saturable-core transformer, L_{15}-L_{18} (christened "transductor" by Mullard) which is connected between the field and line windings of the deflection yoke. This three-leg, saturable-core transformer has two control windings L_{17}, L_{18} in parallel on the centre leg and control windings (L_{15} and L_{16}) on each of the outside legs, connected in phase opposition to reduce interaction between windings. Varying the current in the control windings varies the impedance of the load coils on the outside legs. As the control windings are connected in series with the field deflection coils, the impedance of the load windings, L_{15} and L_{16}, is varied proportionally to the field scan current. Now L_{15} and L_{16} are connected across the line deflection coils, so that the line scan is modulated at field scan rate to correct the horizontal components of pincushion distortion.

Vertical components of this distortion are corrected by a parabolic current at line frequency applied to the field-deflection coils. This is obtained from the integration by C_1 of out-of-balance line pulses induced in the control windings as a result of differential saturation of the saturable core by the two load windings. Preset inductor L_{14} controls the amplitude of this current and permits adjustment of the vertical components of pincushion distortion.

PURITY, STATIC CONVERGENCE AND DYNAMIC CONVERGENCE

In the colour receiver there is a considerable problem of ensuring that the beams from the separate red, blue and green guns pass through the correct holes in the shadow mask and fall on the correct phosphor spots on the screen. There are two main aspects to this problem: "purity" and "convergence."

Good purity means that electrons from the red gun strike only "red" phosphor spots on the screen and similarly for the other two colours. In modern sets

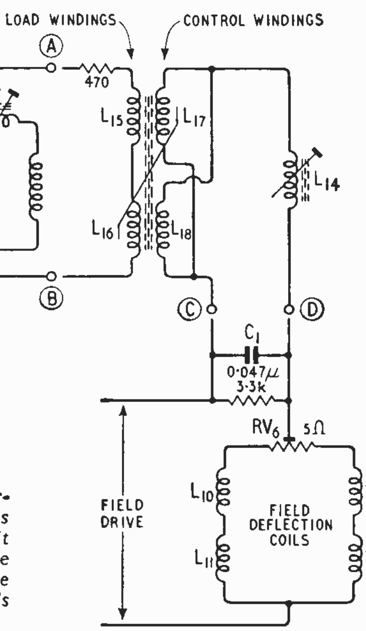


Fig. 5. Pincushion correction of raster is achieved by this circuit using a saturable core transformer between line and field deflection coils (Mullard).

there are two main purity adjustments. A double-ring "purity" magnet round the tube neck (C in Fig. 1) controls all three beams in the gun structure at the same time and can be rotated until the whole screen is only one colour when only the corresponding gun is operating. These purity magnets are adjusted for best purity at the tube face centre. Where adjustment of the magnets alone cannot produce satisfactory purity, the other available adjustment is in the position of the deflection yoke. Normal procedure is to set up purity at the screen centre with the magnets, and clear up remaining impurity at the picture edges by moving the deflection yoke slightly back or forth along the tube neck.

Purity adjustment alone does not ensure a good black-and-white or colour picture. The three electron beams could still be hitting the correct colour of phosphor spots, but could be out of registration with each other. It is therefore necessary to adjust the three beams individually by external magnetic fields so that they overlap exactly over the whole screen. This is known as "convergence" and is carried out in two stages.

First, convergence at the screen centre "static" or "d.c." convergence is effected by adjusting four further permanent magnets on the tube neck near the electron guns. Three of these are in the radial convergence assembly (B in Fig. 1), one each controlling the red, green and blue guns. Adjusting them moves the related beams in or out radially from the tube axis. The fourth d.c. convergence magnet is in the blue lateral convergence assembly (D in Fig. 1) and moves the blue beam on its own laterally. Red and green thus have only one magnet adjustment each, and there is only one position of the magnets in which these beams coincide at the picture centre. Blue has two magnet adjustments so that the beam can be brought exactly to coincide with the already aligned red and green.

Because the three electron guns are offset from the tube axis, purity and d.c. convergence adjustments alone will not ensure that the beams remain in registration over the whole screen. When a gun (in this case the blue gun) is offset in the tube neck as shown in Fig.6(a), the scanning lines are bent upwards towards the gun. This is because the physical displacement of the beam off-centre means the line coils above and below the tube neck produce an unbalanced field acting on the beam. The red gun, set at 120° anti-clockwise from the vertical blue gun, produces raster distortion downwards and to the left as indicated for the red horizontal and vertical mid lines in Fig. 6(b). The diagram also shows the similar distortion down and to the right for the green raster, and the symmetrical upwards-distortion for the blue raster.

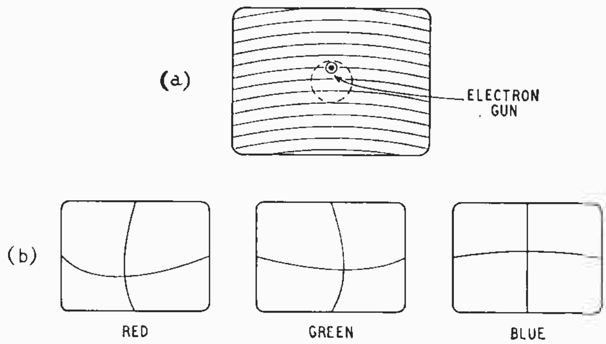


Fig. 6. Dynamic convergence of electron beams in colour tube; (a) effect of placing of single gun off centre in yoke (illustrated for vertical blue gun); (b) typical distortion of red, green and blue raster lines without dynamic convergence correction.

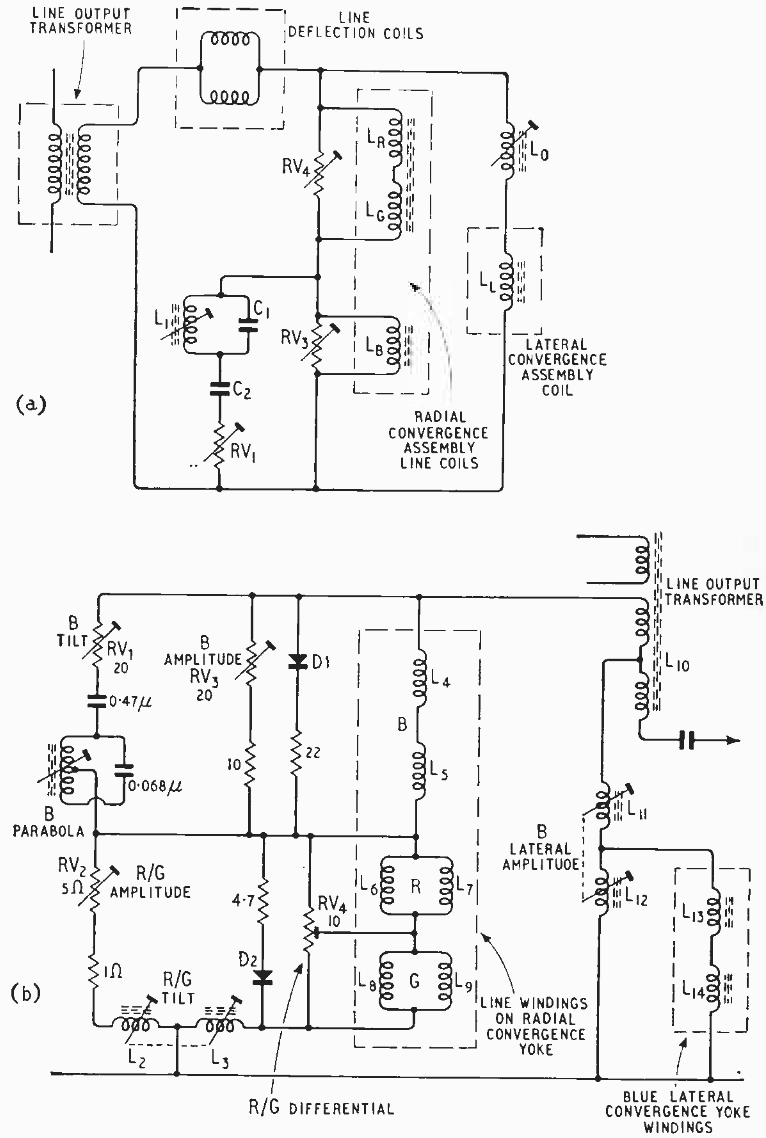


Fig. 7. Line dynamic convergence arrangements: (a) skeleton circuit of one method of providing correcting currents in radial and lateral convergence coil assemblies; (b) complete line convergence circuit (Mullard).

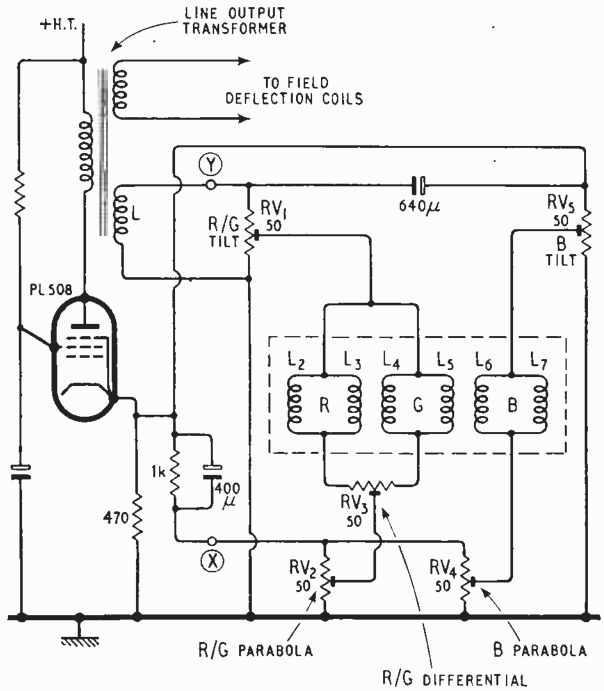


Fig. 8. Field dynamic convergence arrangements, illustrated in practical circuit (Mullard).

Dynamic convergence circuits correct these distortions by locating auxiliary coils outside the tube neck over each of the three guns and feeding parabola-like currents into them. In the radial convergence assembly a separate powdered-iron core, U-shaped coil lies over each of the three guns as shown last month. Line and fields coils are wound series-aiding on both legs of each core, and are driven with approximately parabolic currents from the line and field timebases to correct the mis-convergences arising from the offsetting of the guns from the axis.

Apart from the three radial convergence coil assemblies lateral convergence is further controlled for the blue beam only by a ferrite-cored coil over the blue beam gun near the cathode. This has *line* coils only on each outside leg. The centre polepiece is shaped to set up a magnetic field towards the coil axis, which controls the lateral displacement of the blue beam (see last month). Here again dynamic convergence is effected by feeding parabolic currents to the lateral convergence series coils from the line timebase.

LINE CONVERGENCE (DYNAMIC)

Fig. 7(a) shows in skeleton form the line convergence section of a colour receiver designed to provide adjustable parabolic currents at line frequency to the three sets of line coils of the radial convergence assembly and the one set of line coils of the lateral convergence assembly. You will see that these convergence coils are connected in series with the line deflection coils, which provide a near parabolic current suitable for the red, green and blue radial coils and the blue lateral coil. To give a more predominantly parabolic current for the blue radial coil, a circuit L_1, C_1 tuned at the second harmonic of the line frequency is shunted across it.

A practical version by Mullard of this basic arrangement is given in Fig. 7(b) and represents the circuits previously shown in block form as convergence networks in Fig. 3. The line output transformer passes line deflection earth return currents to earth through both the radial convergence assembly line coils on the left and the blue lateral convergence coils on the right. The pair of radial blue line coils are connected in series and the radial red and green coil pairs each in parallel. The blue lateral coils are series connected.

Across the blue radial coils, L_1, L_5 in Fig. 7(b), three adjustments are available. The shunt RV_3 with a 10Ω limiting resistor is used to set the current amplitude in the coils. An inductor controls the shape of the parabolic modification of coil current, and RV_1 its magnitude. Diode D_1 is added mainly to reduce the difference between 625- and 405-line operation to avoid need to reset d.c. convergence between standards.

Across the red and green radial coils in Fig. 7(b) three further adjustments exist. Shunt RV_2 controls the overall current amplitude in the two coils, while RV_4 connected between the coils enables the proportion of red and green current in them to be adjusted. A further balance correction is available in the preset split inductance L_2-L_3. Diode D_2 again is included to make adjustments less sensitive to changes between 625 and 405 standards.

Current into the series-connected blue lateral coils is controlled by the preset split inductor L_{11}-L_{12}.

In all, seven preset adjustable components for setting up satisfactory dynamic line convergence can be counted in Fig. 7 (b). In practice these are supplemented by the symmetry-adjusting inductance L_6, L_7 at the line deflection yoke in Fig. 3 (b), giving altogether eight dynamic convergence line adjustments.

FIELD CONVERGENCE (DYNAMIC)

Fig. 8 illustrates in the form of a practical commercial circuit the process of vertical (field) dynamic convergence. In this, a separate winding in the field output transformer, in conjunction with the valve cathode output, provides correcting currents in the three sets of field coils of the radial convergence assembly. It will be remembered that no correction at field frequency is applied to the lateral convergence assembly. The sawtooth-parabola voltage at (X) from the valve cathode is partially balanced against the opposite-phase sawtooth from the transformer at (Y). The resultant correcting currents in the coils at field rate are shaped into suitable near-parabolic form by a set of adjustable preset potentiometers. Three controls RV_1, RV_2 and RV_3 affect the paralleled red and green coils, and two, RV_4 and RV_5, the blue coils separately. These five presets are supplemented by a separate balance control (RV_6 in Fig. 4) to make six field convergence controls in all.

REVIEW

It can be seen that the problems of deflection and convergence in a colour receiver are more complex than in black-and-white. Setting up a satisfactory raster calls for careful design and painstaking adjustment.

To the newcomer to colour, convergence is especially difficult to understand. However, although achieving satisfactory convergence in a colour receiver calls for adjusting some 12-14 preset controls, six permanent magnets and three coils yokes (many of which interact on each other), service manuals normally set out exact adjustment procedures in a logical order. If these are carried out "according to the book," it is not difficult to achieve a satisfactory picture.

WORLD OF WIRELESS

Physics and Instruments Exhibitions

THIS year's Physics Exhibition, organized by the Institute of Physics & Physical Society, will again be held at Alexandra Palace, North London. It opens on April 17th for four days and admission is by ticket obtainable free from exhibitors or by sending a stamped addressed envelope to 47 Belgrave Sq., London, S.W.1. The exhibition will open at 10.00 each day, but on the first admission until 13.00 will be restricted to members. It closes at 18.00 on the first two days, and at 19.30 and 17.00 respectively on the other two days.

The emphasis is again on research and development, but new instruments "which fall short of the scientific interest which is sought for the Physics Exhibition" are being shown in an exhibition organized by the Scientific Instrument Manufacturers' Association to be held simultaneously in the Palm Court at Alexandra Place.

For some years a feature of the Exhibition has been the series of afternoon lectures. On the first day Professor W. M. Nestel, of Telefunken, will deliver a paper on "Some physical and technical considerations on the forthcoming European colour television." Dr. J. W. Drinkwater, of Shell Research, will deal with the development and use of equipment to monitor a ship's performance on the 18th, and Dr. R. W. G. Haslett, of Kelvin Hughes, will talk on "Underwater acoustics" on the 19th. Each of these lectures starts at 15.30.

U.S.A. Educational Television

FIVE television stations in New York state with educational programme content are to be interconnected via microwave links. New York City (WNDT), Schenectady (WMHT), Syracuse (WCNY), Rochester (WXXI), and Buffalo (WNED) are all existing community stations which are to co-operate with the state university in this venture. A committee of representatives of the five stations, the state education department and the state university will decide the network's programmes. Although the individual stations are at present carrying state university programmes the microwave network will eliminate the necessity to interchange recordings. The audience, which the state university is seeking is the general interest type which also watches commercial television. Education courses will be divorced from the classroom; they will be the kind that can be pursued entirely in the home. The microwave network of 449 route miles is to be supplied by the Raytheon Company.

Local Radio Stations

THE first local radio stations to be provided by the B.B.C. have been announced by the Postmaster General. The university cities of Leicester, Liverpool and Sheffield, are to be the first of the nine in this experiment. The sites will be chosen to give a maximum coverage of 8 to 12 miles radius in each of the cities. The running cost of a station is thought to be about £52,000 per annum and this in the case of Leicester could be paid for by approximately a 1d increase in the rates, according to the City's Council.

French Colour Television:—It has been announced by the French Government that colour television programmes will be introduced in October, initially for 12 hours a week. Transmissions using the 625-line SECAM system will be radiated from selected u.h.f. stations at present used for the second programme.

ESSA IV.—Another artificial earth satellite in the ESSA weather series was launched in January by N.A.S.A. and handed over to E.S.S.A. (Environmental Sciences Services Administration of the U.S. Department of Commerce) in February. A check of the various systems before the satellite was turned over to E.S.S.A. revealed a camera shutter malfunction in the a.p.t. (automatic picture transmission) system. Attempts to get the camera working properly have so far been unsuccessful but the satellite carries an additional camera for use in such circumstances. The ESSA IV a.p.t. system transmits cloud pictures over a narrow-band v.h.f. facsimile link to meteorological stations throughout the world. The operational frequency is 137.5 Mc/s—the same as used by ESSA II. The system and picture reception were described in detail in an article by C. E. Goodison entitled "Operational Weather Satellites" published in the December 1966 issue.

Among the subjects discussed at the first session of the **High Speed Guided Transport** symposium, held recently at the Borough Polytechnic, London, were modern signalling, traffic control, and train detection. A dissertation on train detection using guided-wave radar by Professor H. M. Barlow of University College, London, was of special interest. He stressed the need for continuous information about trains running at high speeds by employing uninterrupted coupling between trains and a circuit running along the track. Application of microwave techniques for this purpose has its problems, and although the possible use of a screened form of surface waveguide as a means of meeting some of these problems was being considered, this work was still in an experimental form. A demonstration of this microwave technique similar to that seen at the Physics Exhibition last year (*Wireless World*, May 1966, p. 229) was given.

A computer-composed music competition has been announced by the International Federation for Information Processing. The music may be based upon a theme supplied explicitly to the computer, but in any case the finished composition must be determined entirely by the action of the computer. Entries will be judged by a panel of expert musicians and computer programmers appointed by the president of I.F.I.P. Awards will be made for the best three compositions. The prizewinning entries are hoped to be performed during the 1968 I.F.I.P. Congress in Edinburgh from August 5th to 10th. The closing date for entry submission is January 31st, 1968, further information is obtainable from the Administrative Secretary, I.F.I.P. Congress Office, 23 Dorset Square, London, N.W.1.

An **international broadcasting convention,** to be held in London from September 20th-22nd, is being organized jointly by the Electronic Engineering Association and the Royal Television Society. It will be held at the Royal Lancaster Hotel, London, W.2, and will comprise an exhibition of broadcasting equipment, conference sessions and social functions. The E.E.A. is responsible for the exhibition and the R.T.S. for the conference.

A one-day conference on April 5th, having as its theme **Quality and Reliability and the Technician Engineer,** is to be held by the I.E.E.T.E. in collaboration with the National Council for Quality and Reliability. It will be at Queen Mary College, University of London, E.1. The fee to non-members is 30s. Enquiries should be addressed to the Secretary, the Institution of Electrical and Electronics Technician Engineers, 26 Bloomsbury Square, London, W.C.1.

The Consumer Products Division of S.T.C. which markets **K.B. and R.G.D.** receivers is to hold a trade show at Kensington Place Hotel, London, W.8, from August 21st to 24th.

PERSONALITIES

P. H. Spagnoletti, O.B.E., who is director of business development for Standard Telephones and Cables Ltd., has been appointed president of the recently formed Committee of European Associations of Manufacturers of Active Electronic Components. The main object of C.E.M.A.C. is to promote the compatibility of national specifications for active electronic components throughout Europe that will, through the International Electrotechnical Commission, be developed into world standards. The U.K. representative body is VASCA (Electronic Valve and Semiconductor Manufacturers Association), of which Mr. Spagnoletti has been chairman since last September. The other member countries are Belgium, France, Germany, Italy and the Netherlands.

G. J. McDonald, B.Sc., F.I.E.E., who has been the Marconi International Marine Company's technical manager since 1953, is appointed chief engineer. He will be concerned with forward planning and will also be able to devote more time to international meetings covering marine technical affairs. His position as technical manager is taken by **K. H. Potts,** A.M.I.E.E., A.M.I.E.R.E., who joins the company from the Central Electricity Generating Board. **J. R. Trost,** B.Sc., M.I.E.E., who joined the company in 1964 as deputy technical manager, now becomes technical administration manager responsible for day-to-day administrative matters. Mr. McDonald, who graduated at the University of Glasgow, joined Marconi's Wireless Telegraph Company in 1935. He was initially engaged in research and development work, concentrating especially on direction-finding techniques, and later on the development of marine radio equipment. He transferred to Marconi Marine as deputy technical manager in 1949 and was appointed technical manager in 1953. Mr. Potts, the new technical manager, began his career in 1945 as a student trainee in communications engineering with the Post Office in Manchester. During his national service he was engaged on ground radar development work with R.A.F. Signals Command. In 1950 he rejoined the Post Office and since 1953 has successively been with Plessey, Granada TV, Fielden Electronics, Anglia TV and Central Electricity Generating Board. Mr. Trost read for his degree at Brighton Technical College and in 1944 he joined Marconi's Wireless Telegraph Company as a design engineer. In 1958 he went into the Marconi Research Laboratories and transferred to Marconi Marine in 1964 when he was appointed deputy technical manager.

G. J. McDonald

K. H. Potts.

Wing Commander Dennis Abraham, B.Sc., M.I.E.E., at present head of the Electrical Engineering Department of the Royal Air Force College, Cranwell, has been appointed head of the Department of Electrical and Electronic Engineering at the Borough Polytechnic, London. A graduate of the University of Wales (Swansea), where he obtained first class honours in electrical engineering, Wing Commander Abraham served as a radar officer in the R.A.F. during the war, then spent some time in industry, followed by a period on the staff of the University of Aberdeen. He then took a two-year post-graduate course at the College of Aeronautics, Cranfield, specializing in electrical circuit theory.

C. A. R. Pearce, M.Sc.Eng., F.I.E.E., is appointed acting general manager of the Telecommunications Group of Associated Electrical Industries Ltd. in succession to **E. H. Ouston** who is leaving the company. Mr. Pearce, who joined A.E.I. in 1965, began his career with the G.P.O. and became chief engineer of the Factories Department. More recently he was director of manufacture of the Telecommunications Group of the Plessey Company.

The Fellowship of the City & Guilds of London Institute has been conferred on **Robert C. G. Williams,** Ph.D., B.Sc. (Eng.), D.I.C., F.I.E.E., for "eminence in the field of telecommunications and electronics and engineering administration." Dr. Williams, who is chief engineer of Philips Electronic and Associated Industries Ltd., is chairman of the council of the Institution of Electrical and Electronics Technician Engineers and the director for the European Region of the I.T.E.E. Dr. Williams studied at the City & Guilds Engineering College and was with Murphy Radio for 15 years prior to joining Philips in 1946.

Norman Bone, assistant projects engineer in the B.B.C. Sound Broadcasting Department, has been elected president of the Association of Public Address Engineers. This is the first time a professional broadcasting engineer has occupied the position. Mr. Bone, who joined the B.B.C. from the Post Office 31 years ago, has been a member of the A.P.A.E. council for some time and is well known for his lectures on acoustics and microphone characteristics.

N. Bone

E. C. Drewe, O.B.E., F.I.E.E., head of the B.B.C's Equipment Department, will retire in April, after nearly 37 years' service, and will be succeeded by **T. J. Allport,** at present engineer-in-charge, television outside broadcasts. Mr. Drewe joined the B.B.C. as an assistant research engineer in 1930. He held engineering posts at several transmitting stations from 1934 and in 1943 was appointed assistant head of the Engineering Secretariat. In 1945 Mr. Drewe went into the Research Department, where he became assistant head. He has been head of the Equipment Department since 1953. Mr. Allport joined the B.B.C. in 1946 as a recording engineer. In 1949 he transferred to the Engineering Information Department. He has been engineer-in-charge television O.Bs since 1963.

Colin S. Gaskell, D.Phil., B.Sc., has been appointed chief engineer of the Sanders Division of Marconi Instruments Ltd. at Stevenage, Herts. He graduated at Manchester University in 1957 and subsequently attended the Engineering Laboratory, Oxford, to conduct research into millimetre wave generation and applications of pulsed magnetic fields. For a thesis on this work he was awarded his doctorate. Since 1962 Dr. Gaskell has been engaged in research and development, in the field of solid state microwave devices and immediately prior to joining Marconi Instruments was deputy chief engineer of Microwave Associates, of Luton.

Dr. C. S. Gaskell

P. C. Ruggles

Dr. N. A. Slark

English Electric Valve Company has announced the appointment of **P. C. Ruggles,** M.B.E., B.Sc., as manager of the Image Orthicon and Photomultiplier Production Department, and of **N. A. Slark,** Ph.D., B.Sc., M.I.E.E., as assistant manager. Mr. Ruggles graduated in physics from Imperial College, London, in 1944 and joined the E.E.V. team developing reflex klystrons. He was responsible for making the first rugged types. His work in this field was recognized by this appointment as an M.B.E. in 1957. In 1958 he transferred to the camera tubes section. Dr. Slark, who also studied physics at Imperial College where he obtained his doctorate, joined the Camera Tube Research Department of E.E.V. in 1958.

Standard Telephones and Cables Ltd. has appointed **John M. Groocock,** Ph.D., D.I.C., M.I.E.E., company quality assurance manager. Dr. Groocock, who succeeds **R. H. Williams** who has left the company, joined S.T.C. in 1958 and for three years was concerned with transistor design. In 1961 he was appointed quality assurance manager for the transistor division and later assumed responsibility for quality and reliability at the Harlow and Footscray semiconductor manufacturing establishments. Immediately prior to joining S.T.C. Dr. Groocock was for seven years in the Ministry of Supply which he joined after undertaking research at Imperial College for his Ph.D.

Dr. J. M. Groocock

R. L. Grimsdale, M.Sc., Ph.D., M.I.E.E., assistant chief engineer of A.E.I. Automation since 1965, has been appointed professor of electronics at the University of Sussex. Dr. Grimsdale, who is 38 and was born in Sydney, N.S.W., was appointed to the staff of Manchester University in 1951 and was a lecturer in electrical engineering from 1954 until joining A.E.I.

Barry Holland, who recently left the Marconi Company and went to the U.S.A., has been appointed television systems engineer with Visual Electronics Corp., of New York. After studying at the Coventry Technical College, where he gained a City & Guilds Certificate in Electronics, and serving for two years in the R.A.F. as a radar instructor, he joined Marconi in 1961.

Graham Miller, B.Sc., a graduate of University College, Swansea, has been appointed marketing director of Dynamco Ltd. Mr. Miller, who is 36, was until recently sales director of Wayne Kerr having previously been general manager of their United States subsidiary.

J. C. Akerman is commercial product manager for semiconductor devices in the Industrial Markets Division of Mullard and not the Entertainment Markets Division as stated incorrectly in our announcement last month (p.129) of his appointment as a director of Associated Semiconductor Manufacturers Ltd.

OBITUARY

Victor James Cooper, B.Sc.(Eng.), A.C.G.I., F.I.E.E., M.I.E.R.E., deputy director of product planning of the Marconi Company since 1965, died on March 6th aged 56. Mr. Cooper, who was educated at the Sir Walter St. Johns School and at City and Guilds Engineering College, joined the Marconi Company in 1936 to do development work on m.f. and h.f. transmitters. During the war he was engaged in radio counter measures. In 1947 he became responsible for Marconi's television transmitter development. He was appointed chief engineer, advanced development in 1954 and became chief television engineer in 1956. The same year he was appointed a member of the Technical Sub-Committee of the Postmaster General's Television Advisory Committee, an appointment he still held at his death. Mr. Cooper was chairman of the Television Society for 1960/1 and was a member of a number of national and international organizations including the International Federation for Medical Electronics.

Manohar Balaji Sarwate, B.Sc., Ph.D., secretary-general of the International Telecommunication Union since October 1965, died on February 19th aged 56. Dr. Sarwate was a graduate of the University of Bombay and received his doctorate in radio engineering from Liverpool University. From 1938 to 1941 he was engaged on research and development of aircraft radio and radar equipment in the United Kingdom. He then became an officer in the Technical (Signals) Radio Branch of the Indian Air Force in which he rose to the rank of Squadron Leader. From 1946 to 1953, he was with the Civil Aviation Department of the Government of India. He was chairman of the Indian Government's Radio and Cable Board from 1953 until 1959 when at the I.T.U. Plenipotentiary Conference he was elected deputy secretary-general of the Union.

Peter Samwell, M.I.E.R.E., joint managing director of Samwell & Hutton, electronic equipment manufacturers of Goodmayes, Essex, died on February 21st aged 49. Prior to starting the company with G. Hutton in 1946, he was in the Test Gear Development Laboratory of the Plessey Company. For a number of years he had been working on precision r.f. measurement of attenuators for the Ministry of Aviation.

NEWS FROM INDUSTRY

SECOND AERIAL AND ASSOCIATED EQUIPMENT FOR GOONHILLY

THE design, production, installation, and testing of an extension to the existing satellite earth station at Goonhilly, Cornwall, is to be carried out by the Marconi Company through a £1.5M contract from the G.P.O. This extension will consist of a second aerial and associated equipment. The aerial, with a steerable reflector surface 90 ft in diameter, will cover a 210° arc in azimuth, to enable it to work both the Atlantic and Indian Ocean satellites. This 550-ton structure complete with transmitters, receivers and other equipment will pivot in azimuth and will be driven by four thyristor controlled d.c. motors developing a total of 60 h.p. Beam deflection is achieved by moving the 7 ft diameter sub-reflector about two axes by a hydraulic servo system, yielding a maximum deflection of ±½°. The aerial which has a quasi-paraboloidal profile can be moved from one satellite to another at a speed of 10° per minute in azimuth, and 5° per minute in elevation.

The transmitter will employ wideband t.w.ts to provide a final peak saturation power output of 10 kW. The gain of each t.w.t. stage is in the order of 30 dB throughout the civil satellite communications band of 5,925 Mc/s to 6,425 Mc/s. Transmitting facilities will be adequate for over 500 telephone channels and one television channel simultaneously, using a multi-access satellite of the Intelsat III type. The receiving system will be based on a low noise parametric amplifier mounted on the back of the dish structure. This amplifier consisting of three gallium arsenide varactor diode stages in cascade, is enclosed within a closed-cycle cryogenic system using gaseous helium at about −257 °C. This provides low noise performance and a bandwidth of 500 Mc/s. A low noise tunnel diode amplifier will form the second main amplifying stage in the receiver and this amplifier with the main and standby parametric amplifiers will be mounted in containers inside the low noise receiver cabin. The receiver system will cover the satellite communications band from 3,700 Mc/s to 4,200 Mc/s including all possible channels from Intelsat II and III (which will start service next year) type satellites, as well as from the Intelsat I (Early Bird) satellite.

PHILIPS OF EINDHOVEN ACQUIRE PYE OF CAMBRIDGE

THE battle for the Pye organization has ended with Philips of Eindhoven acquiring through a new U.K. subsidiary—temporarily called Philips Electronic Holdings Ltd.—all the 5s ordinary shares in Pye of Cambridge Ltd. Philips Industries and Philips Electronic Holdings Ltd., have stated that they will eventually apply to the Board of Trade for consent to change the new holding company's name to Pye Holdings Ltd. The numerous wholly or part owned Pye subsidiaries which are now part of the Philips empire include British Relay Wireless & TV Ltd., Cathodeon Crystals Ltd., Cathodeon Electronic Ltd., Faraday Electronic Instruments Ltd., Labgear Ltd., Newmarket Transistors Ltd., Pamphonic Reproducers, Pye T.V.T., Pye Telecommunications Ltd., Telephone Manufacturing Co. Ltd. and Unicam Instruments Ltd. It also includes E. K. Cole Ltd. and its subsidiaries (Dynatron Radio, Egen Electric, Ferranti Radio and Television); Ether Controls Ltd., and subsidiaries, and Unidare Ltd., and its subsidiaries. Philips are to arrange for Mullard Ltd. —a wholly owned subsidiary—to undertake the manufacture of cathode ray tubes and semi-conductors on behalf of Pye. Other wholly owned subsidiaries of Philips Industries are Peto Scott Ltd., Philips Electrical Ltd., and the M.E.L. Equipment Co. Ltd., whose telecommunication activities will be integrated with those of Pye, under the management of Pye. It has also been stated that the interest of both Philips and Pye would be best served if Pye continued to formulate and implement its own policies, at the same time taking advantage of the benefits of close association with the Philips Group in all spheres of activity. The board of the new company will have as its chairman the Rt. Hon. Peter Thorneycroft.

NEW TECHNIQUES FOR MICROCIRCUIT PRODUCTION

RESEARCH and development of new techniques for producing microcircuits is being carried out by Welwyn Electric Ltd. Total cost of research, and a new automated production line is said to be in the region of £750,000, and the National Research Development Corporation have agreed to contribute considerably to this sum. The basic products concerned are thin-film, thick-film, and hybrid microcircuits, and the production methods chosen by Welwyn are chemical deposition, and fired-on glazes. It is said that the reasons for preferring chemical deposition to other processes are that it is more effective, cheaper, and can be rigorously controlled for accuracy. The first project of this kind to appear in the North East development area (Bedlington, near Newcastle), it is expected that ultimate production rates of up to 200,000 micro-assemblies per week will be reached at a cost that will permit competitive terms in world marketing. Welwyn Electric Ltd. are of the opinion that film and hybrid units will eventually cost less than half the price of equivalent monolithics. Other advantages of thick and thin-films are their ability to handle higher power than the smaller monolithic micro-circuits, (permitting direct operation of relays and s.c.r. circuits without amplification), and higher voltage applications making them less sensitive to electrical noise in the circuit, or voltage peaks on the supply lines.

A **nuclear reactor simulator** is being used at the Central Electricity Generating Board's nuclear power station at Berkeley, Glos., to train its operators. It has been specially designed to C.E.G.B. specifications by the Flight Simulator Division of Redifon Ltd., Crawley, Sussex. Stated to be the only system in the U.K. to simulate both the standard Magnox-type reactor, and the gas cooled type "Dungeness B," it is made up of two interconnected units. The controls and facilities of a power station control room are duplicated on a reactor control desk. An analogue computer pre-programmed for both types of reactor, supplies the response for the desk. Both reactor types can be simulated in two modes, the axial mode (start, power running, and automatic or manual control) and the zonal mode (demonstrates interzonal disturbances at full power). Apart from its importance in thoroughly and accurately training reactor operators, this simulator may be programmed for research studies, such as reactor behaviour under varying temperature conditions. Automatic graph recorders are employed to indicate reactor performance, and fault conditions, which can be corrected on the desk controls subsequently affecting the computer.

Epoxy glass copper-clad laminate for conventional and multilayer printed circuit boards will be manufactured in the U.K. shortly by the Mica Corporation of California. This corporation has recently held preliminary discussions with the Board of Trade, and a suitable factory site is now being sought. Present distribution in the U.K. of these laminates is by Dage (Gt. Britain) Ltd., 1 Penn Place, Rickmansworth, Herts.

Crown Radio Co. Ltd. (England) has been formed to handle in the U.K. the products of the Crown Radio Corporation of Japan. Offices and servicing facilities are at 137-149 Goswell Road, London, E.C.1. (Tel: CLE 5531).

Sprague Electric (U.K.) Ltd., the marketing organization for components from Sprague Electric, U.S.A. is now operating from Trident House, Station Road, Hayes, Middlesex.

Design of Schmitt Trigger Circuits

FOR DEFINED THRESHOLD APPLICATIONS

By A. E. CRUMP*

Part 1 (last month) dealt with the design of the normal Schmitt trigger circuit, from the aspect of threshold conditions. A variant of the Schmitt circuit, with an additional emitter resistor, is dealt with in this concluding article. An example of the use of design procedure evolved is given at the end of the article

FIG. 10 shows a circuit which differs from Fig. 1 due to the inclusion of R_H. This additional circuit constant makes it possible to pre-set the value of $V_{IN(sat)}$ as part of the design sequence, and also offers greater scope where smaller backlash voltages are required. This is because V_{IN} no longer has to approach V_{B2} to turn Tr1 on (assuming Tr2 conducting). Due to the voltage drop across R_H, V_R is pushed closer to V_T. The value of V_T is unaffected by R_H.

There is of course a penalty to be paid in order that the above advantages may be obtained, and that is that R_H reduces the loop gain of the circuit (see Appendix 6).

The equivalent d.c. circuit of Fig. 10 for the case where Tr2 is conducting is shown in Fig. 12. The case where Tr1 is conducting is as shown in Fig. 6, due to the fact that R_H does not affect V_T.

Fig. 12 is analysed in Appendix 7 and an expression for V_R is obtained.

EVOLUTION OF DESIGN SEQUENCE

To find R_E. By inspection of Fig. 12:—

$$R_E = \frac{V_R - V'_{BE1}}{I_{E2}} \quad \ldots \quad 7$$

V_R, V'_{BE1} and I_{E2} are all design parameters and therefore R_E can be found by substitution.

To find R_2. This is done using the stability parameters as in the case of the basic trigger circuit (part 1), so equation B (Appendix 4) may be used except that R_{max} and R_{min} are defined differently:—

$$R_{max} = (1+\beta_{max})(r_{e2} + R_E + R_H) + r'_{bb2(max)} \quad \ldots \quad 8a$$

$$R_{min} = (1+\beta_{min})(r_{e2} + R_E + R_H) + r'_{bb2(min)} \quad \ldots \quad 8b$$

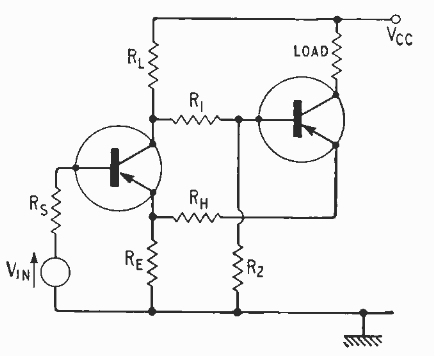


Fig. 10. Circuit of modified Schmitt trigger.

In order that R_{max} and R_{min} can be evaluated, R_H must be known.

(a) Put $R_H = 0$ and solve equations 8 and B (Appendix 4) for R_2;

(b) Progress with the calculation to find R_L, R_1 and R_H as described in the appropriate following paragraphs;

(c) Substitute the calculated resistor values in equation 9 to find the final stability value for V_R.

$$\Delta = \frac{\Delta_{RH=0}}{1 + \frac{R_H}{R_E}} \quad \ldots \quad 9$$

where Δ is the value of $V_{R(max)}/V_{R(min)}$ with R_H in-

*Plessey Automation Ltd., formerly with G.E.C. (Coventry)

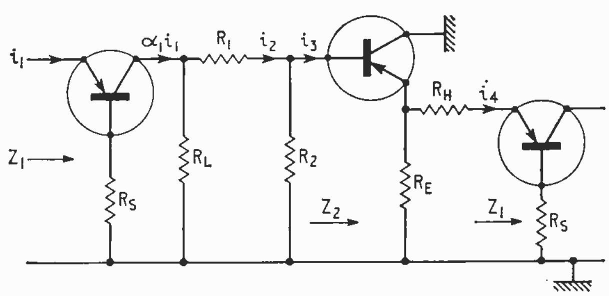


Fig. 11. Small-signal equivalent circuit for loop-gain calculation.

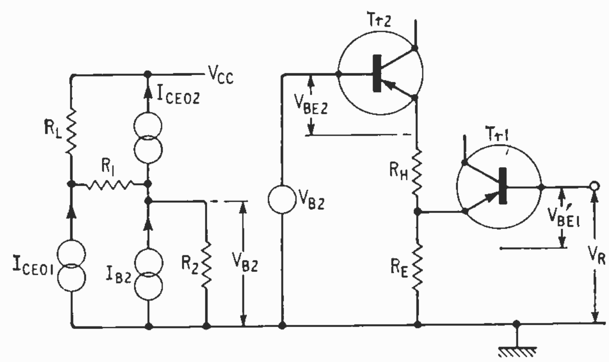


Fig. 12. D.C. equivalent circuit for V_R calculution.

cluded and $\triangle_{RH=0}$ the value with $R_H = 0$. The value of $\triangle$ will be less than that required by the specification and it is possible that this will place a limit on the γ_O value. In this case the design should be repeated using the calculated value of R_H in equations 8 and re-calculating the value of R_2. This will also affect R_1 which will have a new value, and also, using the new values, substitution in equation 11 will produce a new R_H value. (This process can be repeated to obtain a really accurate solution, but normally one repeat is ample. The procedure is illustrated in Fig. 13.)

To find R_L. The values remaining to be calculated are R_L, R_1, and R_H and their magnitudes are inter-related, so some assumption must be made to enable at least one of the resistances to be given a value. The other two can then be found by simultaneous solution.

The method used confines the error to the value of $V_{IN(sat)}$ which is assumed to be the least important design parameter, and this gives a safe solution in that the value of $V_{IN(sat)}$ will be slightly higher than calculated. Appendix 9 gives the resulting equation for R_L.

To find R_1. R_1 is found by transposition of the expression for V_T (equation 1 or Appendix 2). Using the simpler equation 1, this gives:—

$$R_1 = V_{CC} + \alpha_1 V_{BE1} \cdot \frac{R_L}{R_E} - V'_T\left(1 + \frac{R_L}{R_2} + \alpha_1 \frac{R_L}{R_E}\right) \quad .. \quad 10$$

To find R_H. This can be obtained by a somewhat lengthy transposition of equation C (Appendix 7). Neglecting leakage currents,

$$R_H = R_E\left[\frac{R_2}{R_2 + R_1 + R_L}\left(\frac{V_{CC}}{V_R - V'_{BE1}} - \right) - \frac{R_1 + R_L}{(1+\beta_2)R_E} - \frac{V_{BE2}}{V_R - V'_{BE1}} - 1\right] \quad .. \quad .. \quad .. \quad 11$$

If leakage currents are taken into account, $I_{CBO2}(R_1 + R_L) - I_{CEO1} R_L$ is added to V_{CC}.

Loop gain. See Appendix 6.

The foregoing design sequence is summarized in the panel. As in the earlier case various checks can be

SYMBOL DEFINITIONS

V_{CC}	Supply voltage	
$V_{B(sat)}$, V_{IN}	Input voltage which just causes trigger to saturate.	
V_T	Lower trip voltage	
V_R	Upper trip or restore voltage	
R_S	Source resistance	
α	$\beta/1 + \beta$	
β	Current amplification factor*	Common-emitter T-equivalent circuit
r'_{bb}	Internal base resistance	
r_e	Internal emitter resistance	
V_{BE}	Base-emitter voltage	
V'_{BE}	Knee voltage of I_B - V_B curve	
$V_{CE(sat)}$	Collector-emitter saturation voltage	
$V_{BE(sat)}$	Base-emitter saturation voltage	
I_{CEO}	Collector-emitter leakage current	
I_{CBO}	Collector-base leakage current	
S	Current stability factor ($\approx 1 + R_S/R_E$).	
*	In Y_O calculations put $\beta = h_{fe}$. In all other calculations put $\beta = h_{FE}$, if known.	

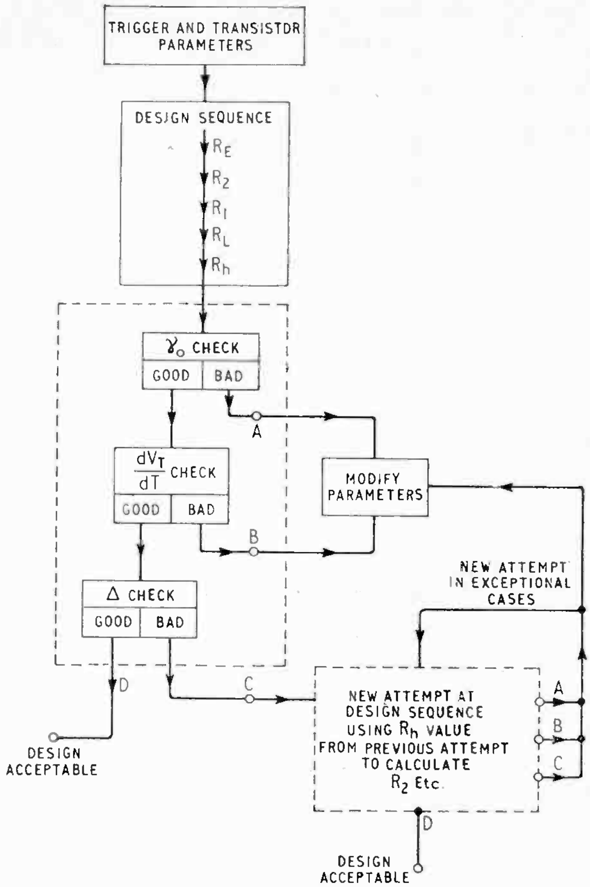


Fig. 13. Design sequence for close tolerance circuits.

made and these are enumerated below. An example of the use of the relations derived is given at the end of this article.

CHECKS

Temperature dependence of V_T and V_R. The dependence of V_T is identical to that for the basic circuit (equation 5). The equation for V_R is given in equation C (Appendix 7) and dV_R/dT can be evaluated from the expression in Appendix 8.

Dependence of V_T and V_R on supply voltage. V_T dependence is given by the relation for the basic circuit (part 1).

$$\frac{dV_R}{dV_{CC}} = \frac{1}{P\left(1 + \frac{R_H}{R_E}\right)}$$

where $P = 1 + (R_1 + R_L)\left(\frac{1}{R_2} + \frac{1}{(1+\beta_2)(R_E + R_H)}\right)$

Resistor tolerances. It is of course possible to obtain a set of equations describing the effect of resistor tolerances on V_R and V_T. The expressions are extremely cumbersome so it is recommended that the maximum and minimum values of the resistor tolerances should be substituted in the V_R and V_T expressions.

DESIGN SUMMARY

Find:—

1. R_E from equation 7.
2. R_2 from equations B (Appendix 4) and 8
3. R_L from equation D (Appendix 9).
4. R_1 from equation 10.
5. R_H from equation 11.
6. Check loop gain (Appendix 6).
7. Check $\triangle$ using equation 9 (see Fig. 13).

DESIGN EXAMPLE BASED ON BFY64

The example has been chosen to illustrate the design of a trigger with 0.6 V typical backlash, using silicon transistors.

This is quite a low backlash value and it is possible that the first calculation will not produce a satisfactory design—it will then be necessary to have a second attempt in the matter previously discussed, using the results of the first calculation as the basis for the second.

Circuit specification	BFY64 data
$V_T = 6 \pm 0.1$ V	$h_{fe} = 25$–100 at 5 mA
$V_R = 6.6 \pm 0.2$ V	$h_{FE} = 80$–200 ,,
$I_{C2} = 5$ mA	$V_{BE} = 0.7$ V ,,
$V_{B(sat)} = 8$ V	$V'_{BE} = 0.5$ V
$R_S = 100\ \Omega$	$V_{BE(sat)} = 0.75$ V ,,
$V_{CC} \leqslant 50$ V	$V_{CE(sat)} = 0.04$ V ,,
	$r'_{bb} = 300$–$500\ \Omega$
	$r_e = 5\ \Omega$

1. Set $V_{CC} = 20$ V.
2. Substituting in (7), $R_E = 1.22$ kΩ (1.2 kΩ preferred value)
3. Substituting in (B) and (8), $R_2 = 13{\cdot}7$ kΩ (12 kΩ)
4. Substituting in (D), $R_L = 2.29$ kΩ (2.2 kΩ)
5. Substituting in (10), $R_1 = 7.89$ kΩ
6. Substituting in (11), $R_H = 6.93\ \Omega$
7. From Appendix 6, $\gamma_O = 1.28$ (for $h_{fe(min)}$) or 1.59 (for $h_{fe(max)}$).

Note.—The use of preferred values is in order for R_E, R_2 and R_L provided that the preferred value of R_E is used in the R_2 calculation and the preferred value of R_2 used in the R_L calculation. When considering R_1 and R_H however, exact values should be used if the specification is to be met.

The value of loop gain is satisfactory as the transistor used will maintain its h_{fe} value down to very low currents such as those encountered at the commencement of the regeneration action.

Test results

$$\left.\begin{array}{l} V_T = 5.95\text{ V} \\ V_R = 6.70\text{ V} \end{array}\right\} +25^\circ\text{C}$$

$$\left.\begin{array}{l} V_T = 5.97\text{ V} \\ V_R = 6.82\text{ V} \end{array}\right\} +100^\circ\text{C}$$

$V_{B(sat)} = 8.6$ V at $+$ 25°C.

Acknowledgment is due to Mr. M. H. Williams and Miss J. P. Tipler of the General Electric Company (Coventry) for their practical assistance and useful discussion when the article was first conceived, and to G.E.C. for readily agreeing to publication.

APPENDIX 6

For the modified circuit loop gain is calculated from equation A (Appendix 1) using the following expression for Z_2:—

$$Z_2 = (1 + \beta_2)\left[re_2 + R_H + \frac{R_E Z_1}{R_E + Z_1}\right] + r'_{bb2}$$

APPENDIX 7

Derivation of expression for V_R. Applying the superposition Theorem to Fig. 12, in a similar manner to Appendix 2, we obtain an expression for V_{B2}.

$$V_{B2} = \frac{R_2}{R_1 + R_2 + R_L}\left[V_{CC} - I_{CEO1} R_L + (R_1 + R_L)(I_{CBO2} - I_{B2})\right]$$

Now $I_{B2} = \dfrac{V_{B2} - V_{BE2}}{(R_E + R_H)(1 + \beta_2)}$

$$V_R = V_{B2} - V_{BE2} + V'_{BE1} - I_{E2}R_H$$

and $I_{E2} = V_R - V'_{BE}/R_E$

Using these equations, the following relation for V_R can be derived:—

$$V_R = \left[\frac{V_{CC} + V_{BE2}R - I_{CEO1}R_L + I_{CBO2}(R_1 + R_L)}{1 + \dfrac{R_1 + R_L}{R_2} + R} - V_{BE2}\right]\left(\frac{1}{1 + \dfrac{R_H}{R_E}}\right) + V'_{BE1} \quad \ldots\ldots\ldots\ldots \text{C}$$

where $R = \dfrac{R_1 + R_L}{(1 + \beta_2)(R_E + R_H)}$

APPENDIX 8

The temperature dependence of V_R can be determined by evaluating the following expression:—

$$\left(\frac{\partial V_R}{\partial V_{BE2}}\right)\frac{dV_{BE2}}{dT} + \left(\frac{\partial V_R}{\partial I_{CEO1}}\right)\frac{dI_{CEO1}}{dT} + \left(\frac{\partial V_R}{\partial I_{CBO2}}\right)\frac{dI_{CBO2}}{dT} + \ldots$$

$$\ldots + \left(\frac{\partial V_R}{\partial V'_{BE1}}\right)\frac{dV'_{BE1}}{dT} + \left(\frac{\partial V_R}{\partial \beta_1}\right)\frac{d\beta_1}{dT} + \left(\frac{\partial V_R}{\partial \beta_2}\right)\frac{d\beta_2}{dT}$$

APPENDIX 9

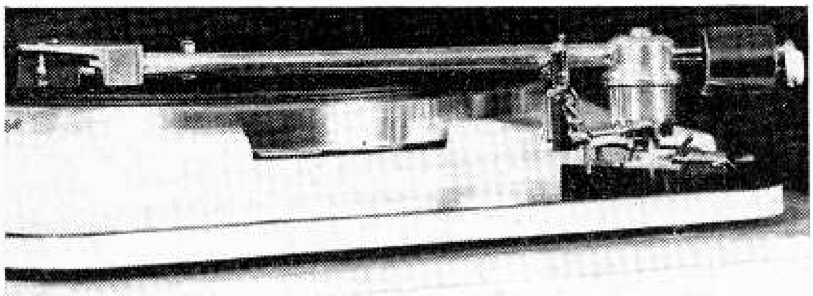
When Tr1 is saturated, the current through R_L can be assumed to be:—

$$I_{C(sat)} + V_{B2}/R_2 = \frac{V_{B(sat)} - V_{BE(sat)}}{R_E} + \frac{V_T - V_{BE1} + V'_{BE2}}{R_2} \quad \ldots\ldots\ldots\ldots$$

$$\therefore R_L = \frac{V_{CC} - V_{CE(sat)} - V_{B(sat)} + V_{BE(sat)}}{\dfrac{V_{B(sat)} - V_{BE(sat)}}{R_E} + \dfrac{V_T - V_{BE1} + V'_{BE2}}{R_2}} \quad \ldots \text{D}$$

Correction. In the denominator of equation 2 and of the equation for V_R in Appendix 3 and in the equation for A (p. 125) the term $R_1 + R_L$ should be in parenthesis. The dividing rule in the equation for V_R should not under-rule the last two terms. Brackets should also be placed around the right hand side of equation 7 to include all up to the multiplier dot. Finally, references to I_{CEO2} should be taken to read I_{CBO2}.

Electronic Laboratory Instrument Practice, by T. D. Towers. The subject matter of this book first appeared as a series of articles in *Wireless World* (in 1965) and therefore requires little introduction. It describes all of the more usual instruments to be found in the modern electronics laboratory together with practical instruction for their use. Written in an easily understood fashion this book should be of value to the engineer and student alike. Pp. 164. Price 35s. Iliffe Books Ltd., Dorset House, Stamford Street, S.E.1.



SOME THOUGHTS ON PICKUP ARMS AND A PRACTICAL DESIGN

AN APPROACH TO PICKUP ARM DESIGN

By J. S. WRIGHT

THE purpose of this article is to determine as clearly as possible a practical approach to tone-arm design with due consideration and integration of all the major factors concerned, rather than to consider any particular aspect in isolated detail. It must be remembered that a tone-arm should be purely a silent partner in the total reproducing chain, as also should be the turntable. From the point of view of an ideal pickup cartridge the tone-arm is merely a necessary evil. This cartridge has to follow the spiral on the disc and would perform at its best if it could float magically unsupported on this path. Apart from fulfilling the simple function of support, the tone-arm can do nothing but interfere with the cartridge's potential tracking capabilities. This is rather obvious, but in the present state of the art it is felt that we are in danger of losing sight of fundamental requirements and engulf ourselves in the intricacies of perfecting isolated aspects, sometimes to the detriment of the combined results.

Since the function of the tone-arm is to carry the cartridge across the surface of the disc in sympathy with the spiral groove engraved thereon it is necessary that before design parameters can be established we must consider the demands that the disc may make upon the system. The perfect disc would consist of an absolutely flat surface with a modulated spiral groove and a locating hole precisely in the centre so that it may be allowed to revolve concentrically at a predetermined speed. However, in practice discs are neither flat nor concentric by a greater or lesser extent and it will be seen that it is chiefly due to these imperfections that the most crucial demands are made of a tone-arm. We can therefore say that the tone-arm is required to carry the cartridge across the radius of the disc in a similar plane to that of the original cutter with the minimum of mechanical or dynamic impedance. The tone-arm for the ideal cartridge can be envisaged as an inertia-less parallel tracking device with zero friction. We therefore confront ourselves with three obvious design factors—tracking error, inertia and friction. Let us examine these factors and their inter-relationship to determine practical design parameters.

John S. Wright formed Audio & Design in 1963 and is now managing director of the group of companies. Prior to working professionally in audio engineering he was engaged in work among mentally handicapped and under-privileged children although for many years he has made a close study of disc recording and pickup design.

TRACKING ERROR

It is well known that tracking error should be kept low if distortion is to be avoided from this cause. This error can be reduced to negligible proportions compared with other weaknesses in the disc reproducing chain if the arm is designed on an offset and overhang principle. Furthermore its effect can be negligible if the design is arranged for minimum distortion in this respect rather than for minimum tracking error. Much has been published on this principle and it is unnecessary to enlarge upon this here. A pivoted radial tracking arm has considerable practical advantages of design and function for negligible additional distortion over a parallel tracking device. The chief sacrifice we must make for the adoption of this system lies in the introduction of side-thrust or inward skating force derived from the friction between stylus and groove wall when an overhang is employed. This can, fortunately, be compensated for, but under present techniques only approximately by external means. The only significant benefit to be derived from a parallel tracking device is the complete absence of this side-thrust. Assuming we accept the practical superiority of the pivoted arm designed on an offset and overhang principle, the longer the arm the lower the tracking error, side-thrust and effect of pivotal friction. However, we have to contend this fact with the increased moment of inertia of a long arm compared with a short one with regard to increased effective mass discussed below. Since we have to play discs up to 12 in dia., about 7 in is the minimum physical length of an arm to allow this, while 9 in is perhaps more convenient from the mechanical design point of view. It can be shown that whilst the reduction in effective second harmonic distortion due to lateral tracking error can be worthwhile, as the arm length is increased beyond 7 in a law of diminishing returns exists and little practical benefit is to be gained by an increase over 9 in. It will be appreciated that to manufacture a 12 in arm with the equivalent inertia of say a 9 in version the weight of the arm would have to be about one half of the latter.

The formula derived from Bauer's graph for determining the offset angle for minimum effective second harmonic distortion due to lateral tracking error is well known:

$$B = \frac{57.3\, r_1 \left(1 + \frac{r_1}{r_2}\right)}{L\left[\frac{1}{4}\left(1+\frac{r_1}{r_2}\right)^2 + \frac{r_1}{r_2}\right]}$$

where L is the arm length from stylus to pivot, r_1 and r_2 are the maximum inner and outer disc radii. Let L be 9 in as discussed above. Let the outer radius r_2 for a 12 in disc be 5.76 in (BS 1928: 1965). Inner radii naturally vary according to disc size and the length of material recorded. An average for 33⅓ rev/min discs of inner radius is around 2⅝ in but the minimum permissible inner radius is 2⅜ in (BS 1928: 1965). Since it is when discs are cut to this limit the groove speed is at its minimum it is in these cases that the greatest tracking difficulties are often encountered. It is therefore desirable to ensure that tracking error is at a minimum under these conditions. This does, however, ignore the fact that the minimum permissible inner radius for 45 rev/min records is 2 in, but it is felt that the majority of users of high quality systems most generally encounter l.p. records, both on grounds of value and quality. In any case the additional groove speed at 45 rev/min at this radius will to some extent reduce distortion from the tracking error under these circumstances. A sufficiently close value of r_1 is therefore 2.375 in particularly when errors that inevitably arise from misalignment of arm and/or cartridge are considered. Substituting these values in the equation given we have $B=23°$. This will provide us with an effective second harmonic distortion related to a recorded velocity of 10 cm/sec of less than 1% due to lateral tracking error. Since the other harmonics amount to less than 10% of this the total distortion can be considered as negligible, particularly when it is compared with distortion commonly arising from vertical tracking error.

INERTIA

In practice the pickup cartridge consists of a mass and a compliance from which a natural resonance must derive. Hence we have an inevitable and undesirable resonance, which should be placed beyond the useful audio range. As it is ludicrous to consider placing this above the audio range we are forced to accept it below, and theoretically the lower the better. For a given compliance the greater the mass the lower the resonance will be and since it would appear that the closer this resonance can become to zero frequency the better, we should in this respect aim at infinitely high cartridge and tone-arm mass. This would allow a pass-band from zero frequency upwards.

But as already discussed, discs are imperfect with regard to concentricity and flatness so if the tone-arm/cartridge resonance is approaching zero, the system will generate undesirable l.f. components from these sources. Furthermore in the case of modern high compliance cartridges gross over-flexing and possible damage can occur, together sometimes with "hiccuping" due to changes in stylus pressure. This resonance therefore should be in a range both below audibility and yet above frequencies where it may be excited by extraneous disc disturbances. For a cartridge of given compliance and mass a fairly critical effective tone-arm mass must be achieved to place this resonance where it is of least hindrance.

The resonant frequency is unrelated to, but not unaffected by, pivot friction as this may be considered resistive. It is true that the lower this resistance the higher the "Q" of the resonance, but if pivot friction were total (i.e. no freedom of movement were permitted) it would then be impossible to determine the location of the pivot and hence the device could no longer be considered in dynamic terms. It can be seen, therefore, that there is a critical damping factor that can lower the Q of this resonance.

In the case of a dynamic body such as a tone-arm, the effective moving mass can neither be computed nor considered without regard to the moment of inertia of the system and it is therefore necessary to determine this as a design parameter. Since moment of inertia is a function of length and mass, the tone-arm length cannot solely be considered from the point of view of permissible tracking error and available housing space.

We will concern ourselves here with the design of a tone-arm suitable to realize as fully as possible the potential tracking capabilities of some of the finest cartridges both available at the time of writing and to be anticipated in the near future. These, in general, are designed to track at a stylus pressure of 1½ gm and less, say a range from ½ to 1½ gm. To ensure this tracking capability, apart from other considerations, we expect to encounter a compliance range of about 15×10^{-6} to $40 \times ^{-6}$ cm/dyne respectively.

As discussed the low frequency resonance derived from the total moving mass and the compliance should fall below the audio range, at least say below about 20 c/s where rumble components can be dangerous, and preferably as low as about 14 c/s. On the other hand it must be above the frequency where it may be excited by disc ripples, but although these have been known to reach as high as 10 c/s, 6 c/s can be taken as the lowest "safe" frequency. We therefore wish to place our low frequency resonance between about 6 c/s and 14 c/s. Having determined our compliance range as above we are able to compute maximum and minimum total moving mass figures if this frequency band is not to be exceeded.

If we take the highest compliance figure and the lowest permissible resonant frequency, the maximum permissible effective mass is 18 gm ($1/4\pi^2 f^2 C$) and, if we take the lowest compliance figure and the highest permissible resonant frequency, the minimum permissible effective mass is 9 gm. If we wish to stay within this "safe" frequency range the total effective moving mass inclusive of cartridge mass should lie between 9 and 18 gm. However, the majority of cartridges in this compliance category have a weight of 2 to 8 gm. Therefore, by simple deduction we can accept an effective moving arm mass of from about 7 to 10 gm.

FRICTION

Imagine a perfectly flat and concentric disc with a single connected circular groove being repetitively played by a pickup arm and cartridge as it revolves. (In such an instance the friction or lack of freedom of the arm is immaterial to the tracking of the cartridge. Indeed, perfect tracking would be achieved even if the pivot were solidly locked in position.) Imagine now that the circular groove becomes a spiral as on a microgroove recording and that the cartridge has to travel radially across the disc for some few inches during the course of many minutes. The force which carries the cartridge across the record must be derived from this motion rather like a worm wheel driving a cog. Any friction imposed by the tone-arm can be considered as a force acting to oppose the inward motion of the cartridge, and this can only be overcome by additional stylus pressure if correct groove to stylus contact is to be maintained. Whilst the additional stylus pressure required to overcome this is undesirable, both from the point of view of translation loss and record and stylus wear, it is only likely to be exceedingly small even under adverse conditions of tone-arm friction since the gear ratio between groove (the worm) and the tone-arm pivot (the cog) is extremely low. From the point of view of traversing the record the pivot friction, whilst nevertheless undesirable, is of little consequence.

It will be remembered that when considering the low frequency resonance of the arm a degree of controlled damping can lower its Q. Both friction and damping may be considered as resistive and consequently it would appear that a controlled degree of friction would assist in minimising low frequency resonance problems.

Furthermore, as stated previously, a pivoted arm designed on an offset and overhang principle exhibits a tendency to skate inwards across the disc due to friction between stylus and groove wall. Pivotal friction can be considered as a force opposing this motion and therefore it would seem that a controlled degree of friction would assist in overcoming this.

Above are some arguments that would lead us to believe that a degree of pivot friction is unimportant, and in fact may be advantageous. It can be seen of course that run-in and run-out grooves place a greater demand on the freedom of a tone-arm but it can also be argued that there is no groove modulation to contend with at these times.

The reasons governing the desirability of low pivot friction are similar to those controlling tone-arm mass, i.e. disc warps and eccentricity. These irregularities usually exceed the maximum bass modulation. Since ideally the tracking weight should be set with relation to cartridge compliance to cope with the maximum anticipated low frequency modulation, any tone-arm friction will have to be compensated for by excessive stylus pressure, and it is not unreasonable to attribute a

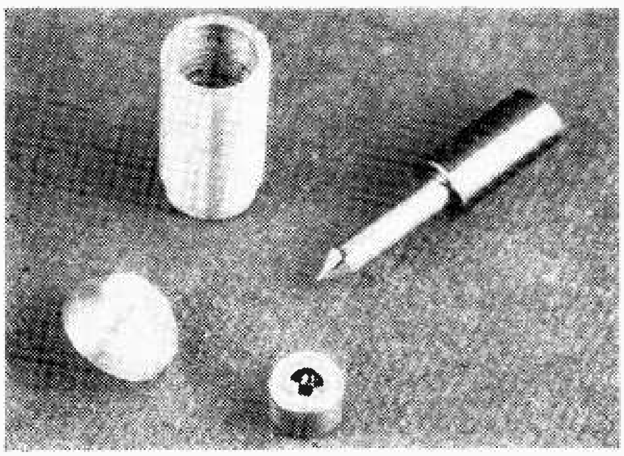


Fig. 1. Components of the unipivot. Left to right—retaining screw, bearing housing, microball race and pivot.

considerable proportion of the total stylus pressure to overcoming friction and inertia under common playing conditions. Although no figures or tolerances are laid down for disc flatness we are all familiar with discs having vertical warps and ripples easily visible to the eye. BS 1928: 1965 standards state that the distance from the centre hole of a disc from the centre of the groove spiral shall be within 0.005 in and furthermore that the diameter of the centre hole shall be nominally 0.285 in with a maximum of 0.2885 in. Concerning the reproducer turntable (BS 1928 : 1961), the turntable spindle should be a maximum of 0.282 in and a minimum of 0.2785 in and its centre with reference to the turntable centre shall be within 0.002 in. Accordingly an eccentricity of some 0.017 in can occur during playing and this will still be within specification. The importance of this can more readily be seen when it is remembered that the width at the top of a groove is about 0.002 in. For these practical reasons, therefore, it is vitally important to keep tone-arm friction to an absolute minimum.

Generally speaking from the practical and mechanical point of view the less the contact area of the moving surfaces compatible with bearing load, the lower the friction, so it is apparent that apart from magnetic or floating devices (which have been used experimentally under laboratory conditions) a unipivot device is likely to provide the lowest friction. However, a unipivot is a theoretical but impracticable device as we are imagining an infinitely small point locating on an absolutely flat surface which will not de-form under pressure. If this could be achieved the surfaces would bond together due to molecular attraction. Since the requirement is to reduce sliding friction to a minimum it is preferable to use a single rolling bearing with the minimum of slip between the contact faces and the bearing.

The advantages of resistive components at the arm bearing as discussed above cannot be ignored. The ordinary rubbing friction, although resistive, is useless for damping the Q of the low frequency resonance as it varies unpredictably with velocity. It would appear that we require a pure mechanical resistance in which the velocity of motion is proportional to the applied force. The resistance required to critically damp the resonance of the design is $B = \sqrt{4M/C}$ and we must substitute the maximum and minimum values of mass and compliance respectively to determine the resistance required for the most demanding conditions of use of the arm, giving $R_{max} \approx 2 \times 10^3$ mechanical ohms. Suppose a disc is revolving at $33\frac{1}{3}$ rev/min at a spiral pitch of 260 grooves per inch. The radial velocity will be $33\frac{1}{3}/260 \times 60 \approx 0{\cdot}005$ cm/s. The force required to move the arm at this velocity against R_{max} is therefore $2 \times 10^3 \times 0.005 = 4$ dynes, equivalent to 0.004 gm. This is obviously a sufficiently low figure for normal playing conditions of the modulated groove. The maximum radial velocity, is, though, to be encountered on run-out grooves and this is around 0.5 cm/s which under these resistive conditions would require undue stylus pressure to maintain groove contact under the playing conditions we have specified.

For this reason it is impossible to achieve critical damping of the arm and yet retain the freedom of movement required to deal with run-outs etc. by the use of pure mechanical resistance. We require the resistance to be frequency conscious and this is most readily achieved by the use of fluids. In the case of fluids impedance falls with frequency, thus lowering its effective resistance below the frequency of critical damping. In practice by damping with fluids a resistance of several times above the resistance required to critically damp the arm resonance would have to be used before it would interfere with tracking. The mechanical resistance offered by viscous damping fluids such as silicone is in proportion to the area of contact between the moving surfaces and approximately inversely proportional to the film thickness. With high viscosity liquids a degree of compliance accompanies the resistance and this can be helpful as it will permit the arm to follow grossly eccentric and warped discs more easily. Furthermore such damping assists to stabilize the arm against external shock as these are of a transient nature containing frequencies around the frequency of critical damping, i.e. in the case of the design under consideration at around 10 c/s.

From the above discussion it is clear that the side-thrust cannot be overcome by purely resistive means if the slightest degree of eccentricity exists. A force has to be applied by external means in equal and opposite motion to the inward skating force. Either of these factors is difficult to compute due to the variation with overhang, tracking error, stylus radius, shape and pressure, groove speed, lateral and vertical modulation, and with temperature, composition and cleanliness of the playing surface. Since no method has yet been finalized of automatically and simultaneously varying bias compensation during playing, it must be appreciated that any form of compensation must be very much of a compromise. We do, however, know from practical experiments combined with approximate calculations that the inward skating force is around 10% of the playing weight for the average spherical tip.

When applying an anti-skating force to the arm *via* an external device, great care must be taken to ensure that this device does not add friction of its own to impede the free movement of the arm. Mechanical devices are virtually bound to introduce some friction even if they are primarily designed on a rolling principle. If great care is not taken to avoid this it is quite feasible for more harm than good to occur particularly at the playing weights we are anticipating. A method which assists in overcoming side-thrust and which avoids these difficulties by the absence of moving parts is to apply correction with the use of a magnetic field.

ARM CONSTRUCTION

The following sections describe an arm that has been constructed and manufactured to the design parameters which have been outlined in this article.

Mass and balance. For practical reasons it was decided to use a counterweight, rather than springs, and restrict its range to cope with cartridges weighing 5 to 8 gm over the specified playing weight, as lighter cartridges could safely be "weighted-up" if used in this design. The moment of inertia (*M.I.*) is approximately 7×10^3 gm cm^2 inclusive of a cartridge weighing 5 gm. The effective mass at the stylus is $M.I./L^2 = 13.2$ gm, and the mass of the cartridge is subtracted to give an effective arm mass of about 8 gm—which is satisfactory. It should be remembered that some allowance must be made for tracking weight although this cannot directly be added or subtracted due to the change in position of the balance weight.

The counterweight was designed with the shaft hole eccentrically positioned sufficient to allow lateral balancing of the arm as required. This system of combined horizontal and lateral balancing places the centre of gravity of the system just below the pivot where the torsional resonance can be damped at record level.

Inaccuracies could occur in the fitting of the cartridge into the headshell, so to assist the user in minimizing this error parallel lines are engraved on the underside of the headshell. An alignment protractor enables the user to set for zero error at 2·375 in.

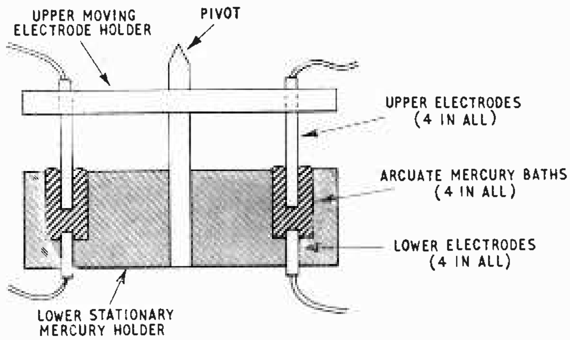


Fig. 2. Showing mercury lead-out principle.

Friction, damping and bias correction. Reference to Fig. 1 shows the basic components of the unipivot. A micro-ballrace engages a hardened steel pivot the angle of which is ground and polished to 60° inclusive to ensure a minimum of sliding friction. It can be seen that the major cause of sliding friction in this bearing will result from the bearing cage. In an attempt to minimise this the bearing and pivot is ultrasonically cleaned to an order of being chemically clean and is then treated with an epilam film. This is brought about by heating stearic acid in powder form until molten and the bearings are then suspended in the fumes for approximately one minute. This prevents the spread of oil away from the bearing surfaces.

One may be very careful to reduce friction in the bearings, but much of this is to no avail unless a method is found of bringing the electrical connections from the cartridge away from the arm without the addition of friction or torque. However fine a gauge of wire is used it is likely to interfere with the low friction values of the type of bearing discussed above. The torque will vary in relation to the stress imposed upon the wires during assembly and this will vary with aging and temperature. It was clear that wires should be avoided. Sliding contacts or lead-out through bearing surfaces is unsatisfactory due to its necessitating sliding friction. A method was adopted of overcoming this difficulty and is illustrated in Fig. 2 where four electrodes protruding from the moving upper arm make contact through accurate mercury baths surrounding the pivot. All electrodes are nickel plated with a gold flash which prevents corrosion during storage and ensures an immediate positive contact between the mercury and the electrodes. Where a solder connection is made it is covered with cellulose laquer paint to avoid its breakup due to the proximity to the mercury.

Resistive damping by silicone fluid is provided in a cup surrounding the pivot into which the bearing housing penetrates as shown in Fig. 3. By experimental means it was found that the required viscosity of this fluid was in the order of 600 stokes (cm^2/s). It will be noticed that a significant degree of torsional damping against external shock is provided by this method of application whilst it retains the maximum freedom of lateral movement. Confusion commonly occurs between torsional stability and torsional resonance. In fact there is no such concept as an independant torsional resonance seen by the stylus. The torsional mass appears as a mass in parallel with the

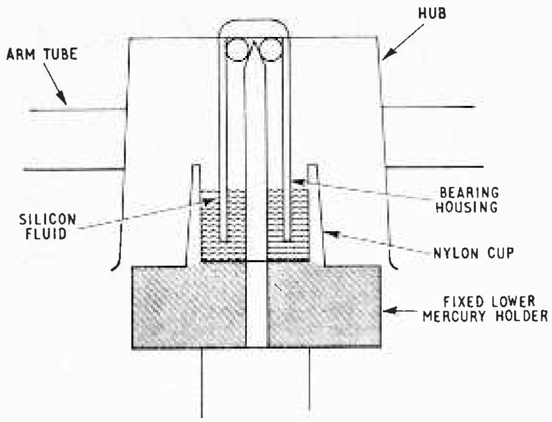
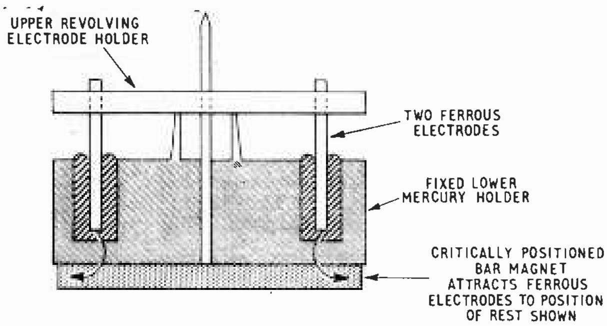


Fig. 3. Torsional damping arrangement.



▲ *Fig. 4. Magnetic anti-skating or side-thrust compensating device.*

Fig. 5. Complete lower nylon assembly showing magnet, murcury and silicone cups. ▶

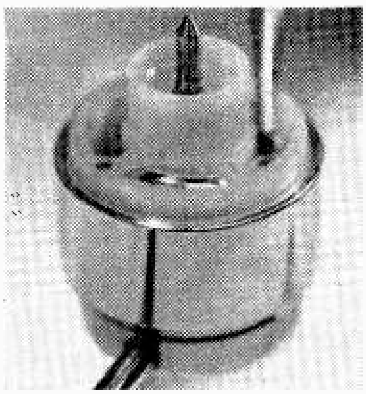
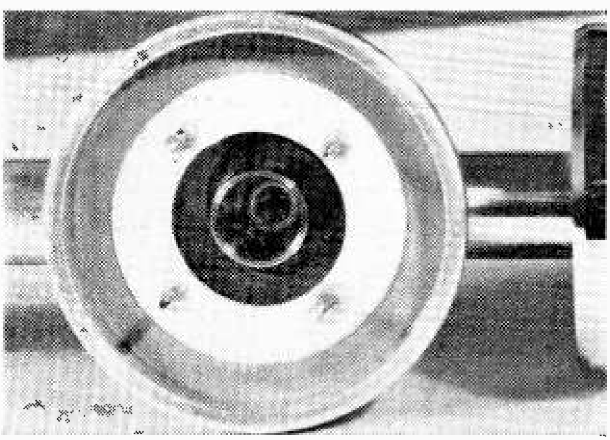


Fig. 6. Underside of upper hub with four nickel-plated electrodes and micro-band race in bearing housing. ▼



total mass thus slightly de-tuning the main arm resonance. A magnetic anti-skating device is inbuilt around this pivot assembly by the use of a high gauss Alcomax III magnet critically positioned in a recess directly under the mercury baths to attract the two of the upper four moving electrodes, which are manufactured from ferrous material, as the arm rotates inwards from the periphery of the disc. It can be seen that the strength of the magnetic field around the electrodes will reduce as the arm moves towards the centre of the disc where groove speed is at its minimum. This principle is illustrated in Fig. 4.

Fig. 5 shows nylon insert which accommodates the pivot, silicone fluid, mercury baths and magnet.

Fig. 6 pictures the underside of the hub of the upper carrying arm with the four electrodes in their nylon housing, and the micro-ballrace installed into the bearing housing.

Subjective listening tests have shown a noticeable ease of low frequency tracking together with an improved transient performance, the latter mainly due to the lower tracking weights attainable reducing the translation loss. The texture of the sound is particularly transparent and the location of the stereo image well defined. However, the importance of record and stylus cleanliness must be emphasised, particularly at the playing weights being discussed here. To a considerable extent these conditions will determine the fidelity of the sound and control the minimum playing weight of the system. Indeed it appears that until a method is available of retaining disc cleanliness in excess of normal standards there is little point in extending the design parameters discussed here.

APPENDIX

The author appreciates that some fine cartridges have been designed with a mass in excess of 8 gm. An alternative version of the arm with a heavier counterweight has therefore been designed to accommodate these, but the effective moving mass of this version is around 11 gm. A total effective moving mass of 18 gm is about the maximum that we can tolerate if we require to track down to $\frac{1}{2}$ gm. Since it is unreasonable to expect the tone-arm to add no mass a responsibility lies with manufacturers to keep cartridge mass in proportion to the compliance. The highest compliance we can safely accept from a cartridge weighing say 18 gm mounted in the alternative version arm is therefore 24×10^{-6} cm/dyne thus tracking at just under 1 gm.

The situation is somewhat eased in the case of a cartridge whose compliance is lower vertically than laterally. Here we obtain two resonances and since the lateral is likely only to be excited by disc eccentricity we can accept a much lower frequency here, say as low as 1 to 2 c/s. The vertical resonance will be higher than this and should be placed in the " safe " band discussed earlier. Since the vertical compliance is likely to be in the order of one third of the lateral, with reference to the design parameters above we may encounter compliances from 13×10^{-6} to 5×10^{-6} cm/dyne. Thus the maximum permissible effective mass is 54 gm $(1/4\Pi^2 f^{26})$ and the minimum permissible effective mass is 26 gm, from which the lowest lateral resonance may be 3 c/s. It would appear therefore that cartridges of a higher mass are more acceptable when designed with the vertical compliance lower than the lateral.

Acknowledgment. My sincere thanks and gratitude is extended to Mr. Frank Ockendon without whom this concept would never have been realized.

Go-Ahead for Colour TV

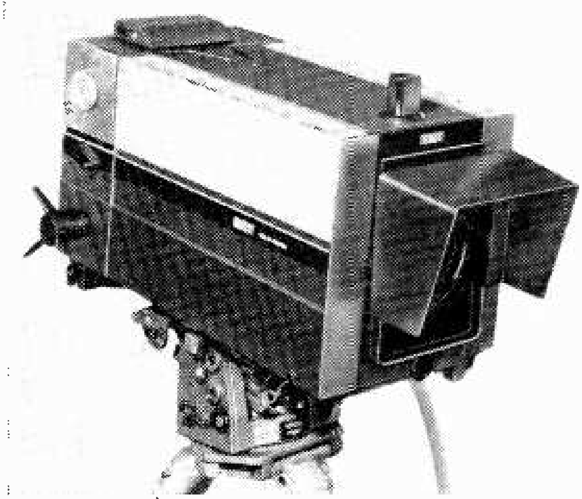
BBC-1 AND ITV TO GO ON TO 625 LINES AND TRANSMIT CHROMINANCE SIGNALS

A SINGLE standard for British television plus two more services in colour is what the Postmaster-General has now authorized, after recommendations by his Television Advisory Committee. By the end of 1969, BBC-1 and I.T.V. will be transmitting their programmes on 625 lines from u.h.f. stations in London, the Midlands and the North, and a substantial proportion of these programmes will be in colour (BBC-1, for example, will probably start with about 40 hours of colour a week). This, of course, will be in addition to the BBC-2 625-line/u.h.f. transmissions which will have already introduced colour (starting at the end of this year).

The present BBC-1 and ITV 405-line/v.h.f. transmissions will, however, continue for some years, so there is no prospect of existing 405-only receivers becoming obsolete overnight. To achieve this, the BBC-1 and ITV programmes, which will originate from 625-line cameras, will be standards-converted down to 405 lines and transmitted on the v.h.f. network—that is, "duplicated." (Already some programmes broadcast on 405 lines orginate from 625-line sources.

Eventually, when u.h.f. coverage is complete, the v.h.f. television bands (I and III) will be "re-engineered" to take 625-line transmissions, and will be able to accommodate two national services. Since the u.h.f. television bands, IV and V, will be carrying four services—BBC-1, BBC-2, ITV and the unspecified "fourth service"—ultimately there could be a total of six national services operating on the single 625-line standard.

All of this, although planned long ago, has been put into force rather suddenly and unexpectedly by the P.M.G's decision, after what seems like a rapid climb-down from official positions by both the Government and the independent television companies. In the White Paper on broadcasting published in December 1966 the Government lectured heavily on the cost of extending the broadcasting services, seeming to hint that all plans might be held up until the country was in a better economic position. The independent television companies, supported to some extent by the I.T.A., had been campaigning vigorously for colour on the 405/v.h.f. network—to such an extent that they had managed to give the impression that they thought colour on 625/u.h.f. was a retrograde step from an engineering point of view. What they really wanted, of course, was colour as quickly and cheaply as possible, and they saw the existing 405/v.h.f. service as the best vehicle for this purpose. Technical arguments supporting 405/v.h.f. colour now seem miraculously to have evaporated. The Government, in turn, appears to be justifying its *volte-face* on national economic grounds, pointing out (as the set manufacturers have pointed out to it) that the establishment of a single television standard will result in simpler and cheaper receivers and that the saving of, say, £5 each on millions of sets will outweigh the capital cost of the new transmitting equipment. This capital cost is, in fact, expected to be about £17M for the B.B.C. and £30M for the I.T.A.



Latest colour television camera is this EMI type 2001, which has four lead-oxide photoconductive tubes (red, green, blue and separate luminance) and a zoom lens built into the main case. A prismatic colour-separation system is used and the optical system is direct-imaging (without relay lenses). The electronic circuitry is solid-state throughout.

The new BBC-1 and ITV 625/u.h.f. services, including colour, are expected to be available to about 45% of the population from the outset and to about 70% by early 1971. At the time of going to press, stations and channels have not been announced, but it seems likely that the first group will be Crystal Palace (London), Sutton Coldfield (Midlands) and Winter Hill and Emley Moor (North). For each station in the u.h.f. network four channels have been allocated—BBC-1, BBC-2, ITV and one other. According to present planning formulas, the channel-number situation could be as follows (frequencies in Mc/s in brackets):—

	Crystal Palace	Sutton Coldfield	Emley Moor	Winter Hill
BBC-1	26(510-518)	46(670-678)	44(654-662)	55(742-750)
BBC-2	33(566-574)	40(622-630)	51(710-718)	62(798-806)
ITV	23(486-494)	43(646-654)	41(630-638)	59(774-782)
Other	30(542-550)	50(702-710)	47(678-686)	65(822-830)

Emley Moor and Winter Hill are, of course, shared by B.B.C. and I.T.A. transmitters, and have a common mast carrying the BBC-2 u.h.f. and I.T.A. v.h.f. aerials. Now, the new BBC-1 and ITV u.h.f. transmitters and aerials will be added. Crystal Palace and Sutton Coldfield, at present exclusively B.B.C. stations, will now be accommodating I.T.A. u.h.f. transmitters and aerials. There will be relay stations associated with the new transmitters, of course.

On the receiver side, the set manufacturers are naturally delighted with the new situation, which they have played no small part in bringing about. They realize, however, that the demand for receivers will probably rise very slowly at first because of their initial high cost (e.g. £279 or 36s 11d a week for Radio Rentals' cheapest 25-inch model) and the current hire purchase restrictions. B.R.E.M.A. estimate that production of colour receivers will be about 250,000 for the year 1970.

The kind of sets needed will vary with geographical area and with the successive phases of the broadcasting development. After 1969 in the service areas mentioned above it will be necessary to have only single-standard u.h.f. monochrome or colour receivers. But dual-standard receivers will continue to be needed, first for the 1967-69 period and secondly for the post-1969 period in those areas awaiting completion of the u.h.f. coverage. To cope with this situation, which will persist for some years, one big manufacturer, the Thorn group, will be running two production lines simultaneously, one for single-standard chassis and the other for dual-standard chassis. No doubt other manufacturers will do the same.

Although the single-standard receivers will initially need only u.h.f. tuners, nevertheless they will be designed to be "v.h.f.-ready," and a few years after 1969 will probably be supplied with combined v.h.f./u.h.f. tuners. This will ensure that they will be able to receive the two national services that will result from "re-engineering" of the v.h.f. bands.

CIRCULATORS AND ISOLATORS

RECENT EXTENSION TO THE LOWER FREQUENCY BANDS

By K. E. HANCOCK

IN the first article in this series we discussed the interaction between a magnetically biased ferrite material and a microwave signal, and then considered the mechanism of variation of r.f. signal absorption and phase shift with variation of the biasing magnetic field strength. The graph showing these changes as a function of applied magnetic field for a typical ferrite is reproduced again as Figure 1. In this article we will consider how this interaction is applied to give the two most common microwave ferrite devices, the isolator and the circulator.

First, the circulator. Apart from the variations due to optimization for frequency, bandwidth, size, number of ports and so on, there are three main types of circulators. The most common is the Y circulator, such as that shown in Fig. 2, which, when in waveguide form, is normally constructed in a T shape to make it easier to fit into a circuit.

Next we have the differential phase shift circulator, shown diagrammatically in Fig. 3. This is an earlier type, much larger but still used for high power applications. Finally there is the Faraday rotation circulator, shown diagrammatically in Fig. 4. This configuration is most commonly used in millimetre applications where material problems make it difficult to realize the other types, and where large proportional size is not usually a problem.

Let us consider first the action of the Y circulator. If we take a ferrite slab, put it in a waveguide and bias it suitably, the phase shift due to change of permeability at the point of circular polarization will slow down the wave at the point, moving the wavefront diagonally across the guide as shown in Fig. 5(a). A signal in the other direction will similarly be deflected but in the opposite sense.

From this it is a simple step to take three ferrite loaded waveguides and place them 120° apart to form a Y circulator as shown in Figs. 5(b) and 5(c). To amplify a little on what is meant by suitable bias, the ferrite is required to give phase shift, but to have low loss. Referring to Fig. 1, two bias points give this condition: point A below resonance and point B above resonance. For wide bandwidth it is preferable for the bias point to be in centre of an area of low slope, and generally speaking, with a low biasing requirement so that the magnet will be small. At low frequencies this area is narrow due to low field loss, so wide-band circulators are normally above-resonance devices. A narrow line width material is also preferred as this allows biasing closer to resonance. The subject of materials and optimum biasing is an extensive one, out of the range of this article, and the reader is referred to a bibliography to be given at the end of the next and final article for further reading.

As mentioned in the first article, so-called coaxial circulators are normally of strip-line form, a common configuration being that shown in Fig. 6(a). This particular layout has the advantage of being fully magnetically shielded, thus eliminating the need for special handling. One of the main problems of designing low frequency circulators is that of matching the ferrite to the line. One solution which has made 30 Mc/s circulators possible is the winding of coils around the ferrite, thus making it part of a lumped constant, tuned circuit, matching element as shown diagrammatically in Fig. 6(b).

Let us now consider the differential phase shift circulator. Examining first the effect of varying perme-

K. E. Hancock has been with the Canadian Marconi Company since 1962. He is senior project engineer in charge of the microwave components section of the telecommunications department. Mr. Hancock was educated at the South East London Technical Institute and joined the R.A.F., in which he was commissioned and worked on air radar. In 1960 he joined W. H. Sanders Ltd., at Stevenage, where he was deputy head of microwave development.

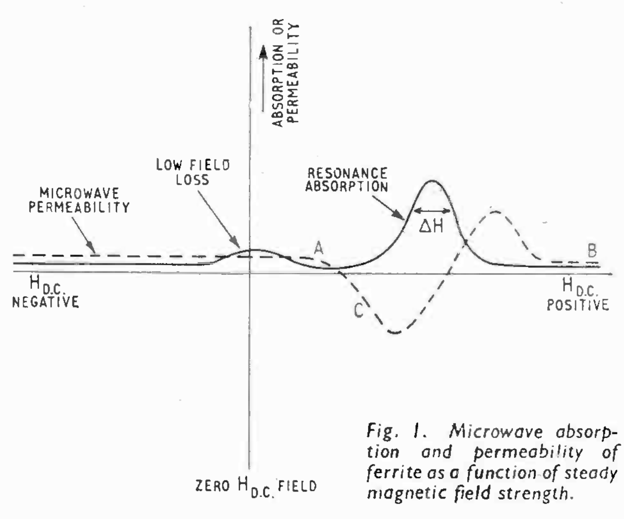
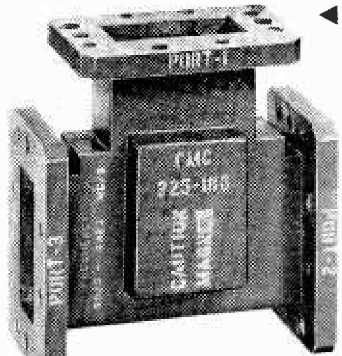


Fig. 1. Microwave absorption and permeability of ferrite as a function of steady magnetic field strength.



◀ *Fig. 2. Example of a "Y" circulator in waveguide form.*

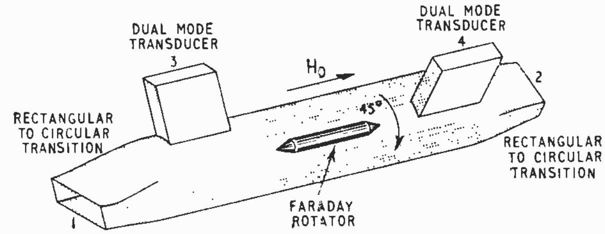
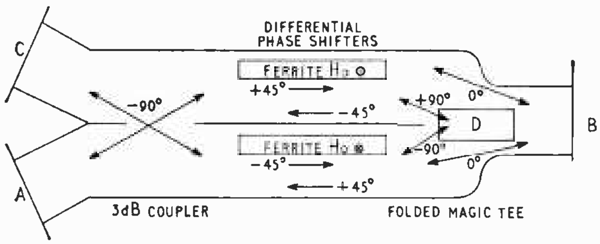
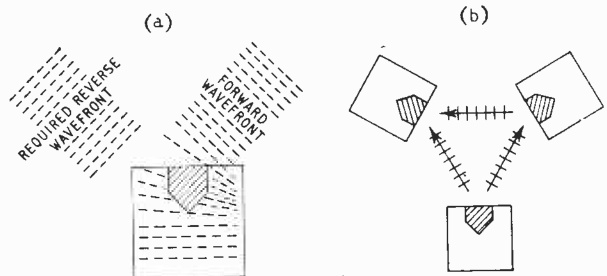


Fig. 4. The Faraday rotation circulator.

Fig. 3. Schematic diagram showing operation of a differential phase shift circulator.
▼





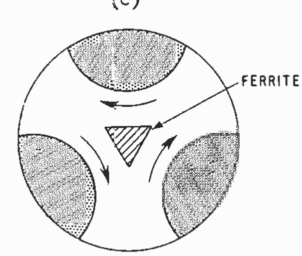


Fig. 5. Principle of field displacement or "Y" circulator: (a) wavefront deflection; (b) and (c) construction from three ferrite-loaded waveguides.

ability on the energy distribution in a material, we find that, as with a high dielectric material, the energy is concentrated in the region of high permeability. If a narrow slab of ferrite is mounted in a waveguide at the point of clockwise circular polarization, as shown in Fig. 7, and biased in the conventional direction, there is little or no interaction, virtually all the signal being slowed down, giving a phase delay through the device proportional to the length and type of ferrite. For a signal propagating in the opposite direction however interaction will occur. Referring again to our absorption and permeability curve, Fig. 1, suppose that our bias point is at point C. The r.f. loss is low, but the permeability is in the reverse direction. In this case, not only is there little energy passing through the ferrite but the effective width of the waveguide is reduced, increasing the velocity of propagation, and giving a negative phase delay. We now have a device which will give positive phase shift in one direction and negative in the other. To use this principle in a circulator let us refer again to Fig. 3.

A signal propagated into port A will be split into equal parts by the 3dB coupler, the coupled portion lagging by 90° in phase on the direct portion. The lower ferrite phase shifter will delay the direct signal by 45° so that it emerges at port B shifted in phase by −45°. The coupled portion will be advanced by 45° by the upper phase shifter, emerging at port B with a total phase shift of −90° +45°, i.e. −45°, and will thus be in phase with the direct portion, the total signal therefore appearing at port B.

A signal entering port B will be split equally by the magic tee into the upper and lower paths. The portion in the lower path will be advanced by 45° and then be divided into two equal parts by the 3 dB coupler, the coupled portion receiving a −90° phase shift to give an effective total delay of 45°. The portion in the upper path will be delayed by 45° and then split by the 3 dB coupler. The part coupled down to the lower path will be delayed by a further 90°, making a total of −135°, it now being 180° out of phase with the remaining lower

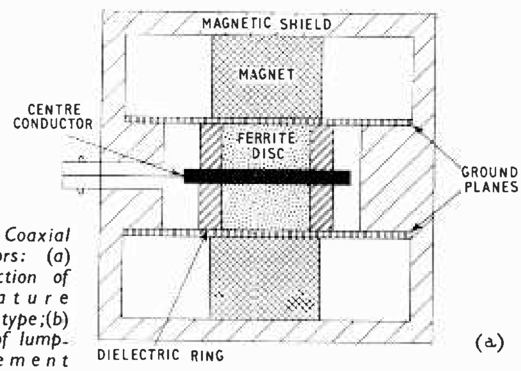
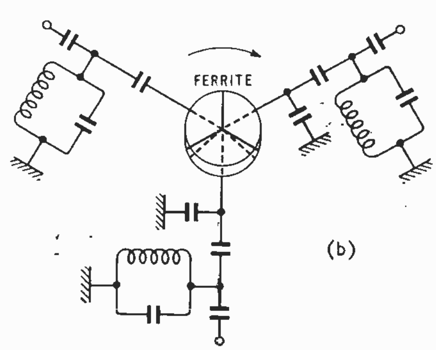


Fig. 6. Coaxial circulators: (a) cross-section of miniature shielded type; (b) circuit of lumped-element v.h.f. type.



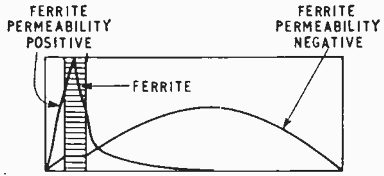
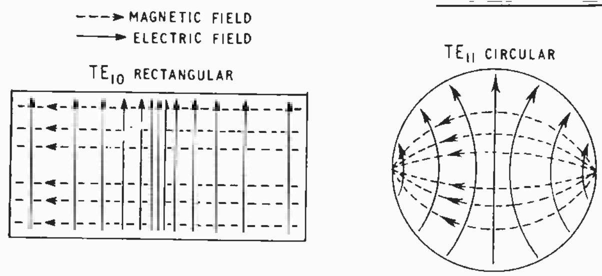


Fig. 7. Energy distribution in a ferrite-loaded waveguide as a function of permeability.

TABLE I. TYPICAL CIRCULATOR SPECIFICATIONS

Frequency (Mc/s)	Insertion loss (dB)	Isolation (dB)	v.s.w.r.	Size dia. (in)	Size h (in)	Remarks
30– 32	1.75	20	1.3	3	$1\frac{1}{2}$	Lumped constant type
140– 190	1.3	20	1.3	3	$1\frac{1}{4}$	Lumped constant type, high loss
150– 151.5	0.3	23	1.35	$8\frac{1}{2}$	$2\frac{5}{8}$	Low loss, larger size, narrow bandwidth
250– 300	0.5	18	1.25	8	$1\frac{1}{2}$	Wideband, higher loss
470– 630	0.7	18	1.3	3	$1\frac{1}{4}$	Lumped constant type
700–1000	0.5	71	1.3	$3\frac{1}{2}$	$1\frac{1}{4}$	Wideband
800– 835	0.5	20	1.25	2	$1\frac{1}{4}$	Lumped constant
750–1000	0.5	20	1.20	3	$3\frac{1}{4}$	Mechanically tunable (10% b.w.)
(Gc/s)						
2 – 4	0.5	18	1.25	$3\frac{1}{2}$	$1\frac{1}{8}$	Coaxial wideband
3.95– 5.85	0.3	20	1.20			Full waveguide bandwidth
4.4 – 5	0.3	20	1.15	4	3	Waveguide
5.9 – 6.4	0.3	20	1.2	$\frac{3}{4}$	$\frac{7}{8}$	Miniature coaxial
5.9 – 6.5	0.4	20	1.25	$1\frac{1}{8}$	$\frac{5}{8}$	Stripline plug-in
5.4 – 5.9	0.5	15	1.25	$2\frac{11}{16}$	2	Single junction 4-port coaxial
5.4 – 5.9	0.3	20	1.25	$22\frac{1}{2}$ long		5 kW c.w. differential phase shift w.g.
9.0 –12.0	0.5	20	1.25	3	2	1μs latching circulator switch
16 –18	0.3	20	1.25	$\frac{13}{16}$	$\frac{5}{8}$	Coaxial
12.4 –16	0.4	25	1.1	$1\frac{3}{4}$	$\frac{3}{4}$	Waveguide
34.5 –35.5	0.5	20	1.15	$1\frac{1}{2}$	$\frac{1}{2}$	"Y" Type w.g.
60 –62	1.0	20	1.3	2 × 3 × 6 Lg.		4-Port Faraday rotator

Fig. 8. Comparision of the TE_{10} rectangular and the TE_{11} circular waveguide modes.



path signal, cancelling it out. The uncoupled portion of the upper path signal will combine in phase with coupled lower path signal and appear at port C.

Similarly it can be shown that a signal applied at port C will appear only at port D, and one applied at port D will appear at port A. We thus have a four port circulator. As these phase shifters are operated at a low loss point and there is good thermal conductivity from the ferrite to the waveguide walls, this device can be operated at quite high power levels.

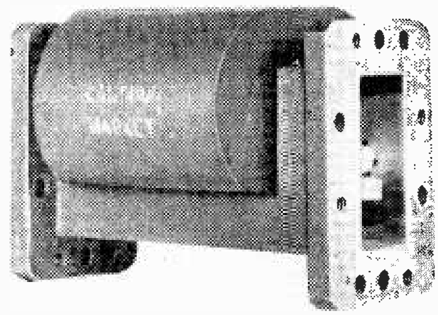
The final form of circulator we shall discuss is the Faraday rotation device, an outline of which is shown in Fig. 4. The heart of this circulator is the Faraday rotator, historically the first microwave ferrite device, built by Luhrs and Tull in 1949, although in 1845 the principle was demonstrated optically by Faraday. It may be proved* that a longitudinally polarized wave can be considered to be made-up of two circularly polarized waves, equal in magnitude, but rotating in opposite directions. These two circularly polarized waves can at all times be combined to give a linearly polarized wave. Let us consider the fundamental mode in a circular waveguide the TE_{11}. As can be seen in Fig. 8 this is more or less an extension of the TE_{10} rectangular mode. If we insert a rod of ferrite along the centre line of the circular waveguide and impose a longitudinal magnetic field such that the r.f. field is well below resonance, the two circularly polarized components are shifted in phase differentially since one wave aids electron precession and the other opposes it. The direction of the resultant rotation of polarization of the linear wave is determined by the direction of the magnetic field.

To see how this device is used in a circulator, let us turn again to Fig. 4. A TE_{10} rectangular mode signal applied to port 1 will be converted to the TE_{11} circular mode by the rectangular-to-circular transition, and will pass on to the Faraday rotator, port 3 having little or no effect as it does not significantly cut the electric field. The signal is rotated by 45° clockwise by the Faraday rotator and passes to port 2, being little affected by port 4 for the same reason as described above in relation to port 3. Taking a signal applied to any port and applying similar reasoning, it will be seen that circulatory action is obtained.

Having discussed how the three types of circulator work, let us consider the points that are of more practical interest to circuit engineers. When circulators can be used, what type to specify and what parameters should be considered. First, what type. In general the only advantage of the Faraday rotation circulator is that it can be achieved with current materials in the millimetre range. So if you are working in this field there is little choice but to use a Faraday rotation circulator. Again in current practice the differential phase shift circulator has the advantage only of power. If you are in the unfortunate position of wanting to diplex a receiver with a 150 kW c.w. transmitter at waveguide frequencies, use a differential phase shift circulator as the diplexing element.

But for frequencies between 30 Mc/s and 18 Gc/s and for power levels below around 100 W c.w., the Y circulator is the preferred device.

Fig. 9. Example of a resonance isolator.



* Chapter 7, Section 1 of "Microwave Ferrites and Ferrimagnetics" by Lax and Button. McGraw-Hill Book Co., 1962.

If we are using a Y circulator the next point will be, waveguide or coaxial? Obviously below about 1 Gc/s coaxial devices will normally be used, but above this, right up to 18 Gc/s we have a choice of waveguide or coaxial. As a generalization we can say that waveguide has the advantage of low loss, good matching and high isolation, whilst coaxial devices have wider bandwidth and smaller size. When we want to specify a circulator it is as well to remember that the main parameters, v.s.w.r., isolation and insertion loss are inter-related; generally, when one is good all are good. Unfortunately, however, in general the wider the bandwidth and the smaller the size the worse are all three.

So far no mention has been made of temperature characteristics. As with all semiconductors the performance of ferrites is temperature sensitive. However, in modern devices temperature compensation is normal, and, although temperature range should always be specified, if they are normal commercial or military specifications it is only in very broadband devices that any trouble is encountered in meeting them.

Having decided on the type of circulator required for a particular application we turn to the consideration of what parameters to specify. The following are those that are normally considered.

Configuration
Number of ports
Impedance of coaxial systems or waveguide size
Mid-point frequency and bandwidth
Isolation between adjacent ports and v.s.w.r. (inter-related)
Insertion loss between adjacent ports
Power handling
Temperature range
Size
Connector or flange type

The next obvious point is: what are obtainable specifications? As this will obviously vary with application, examples of currently obtainable performance at various frequencies and with various configurations are shown in Table 1. It should be noted however that microwave ferrite technology is rapidly changing and any particular design may be obsolescent almost as soon as it is put on the market.

Let us now examine isolators. There are four main types, only one of which makes use of a phenomenon we haven't covered. This is the most common, the resonance isolator shown in Fig. 9. The second most common is one type of field displacement isolator, or, under the name it is commonly known by, the terminated circulator. This is quite simply a three-port Y circulator with one port terminated with a matched load to make a two-port device. The advantage of this is mainly one of bandwidth, power, and in some cases, size or layout.

The third type is the Faraday rotation isolator, a miniature 13 Gc/s example of which is shown in Fig. 12. Recalling the action of the Faraday rotation circulator, we have a longitudinally magnetized ferrite rod in a circular waveguide which effectively rotates the polarization of the linearly polarized incident wave. Consider a similar structure with the addition of two resistive elements as shown in Fig. 10. The forward wave is unaffected by the first resistive element as the electric field is perpendicular to it, and after being rotated 45° the electric field is again perpendicular to the second resistive element. The reverse signal however will be rotated such that electric field is parallel to the resistive element and will be attenuated. This type of isolator has the disadvantages of comparative low power handling due to the limitations of the resistive elements, and an isolation limitation of around 30 dB due to variations from the ideal 45° of rotation and to less than perfect circular polarization.

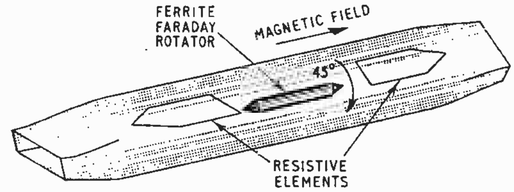
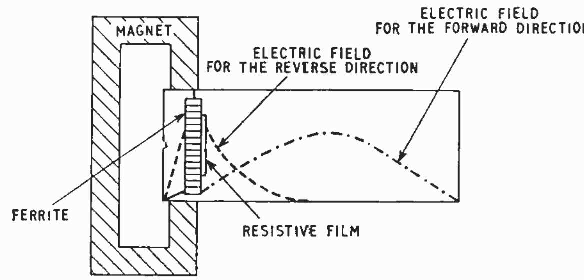
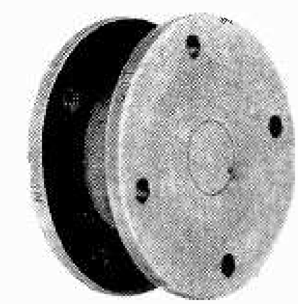


Fig. 10. Structure of the Faraday rotation isolator.



▲ *Fig. 11. The field displacement isolator.*



▶ *Fig. 12. Example of miniature Faraday rotation isolator*

The final type is again a field displacement device, this time a true isolator. Let us look again at the energy distribution in a ferrite loaded waveguide (Fig. 11), noting that the electric field at the inner face of the ferrite is very low in one direction but high in the other. If the inner face of the ferrite is coated with resistive film, the loss will be low in the low current direction and high in the high current direction giving us a non-reciprocal isolator. Again power dissipation is low due to the limitations of the resistive element.

Let us return now to the resonance isolator. Recalling once more our permeability and resonance curve (Fig. 1) let us bias for maximum loss at the centre of the resonance curve. If we put our biased slab of ferrite at the point of anti-clockwise polarization of the magnetic field for the reverse signal, we will get high loss in that direction and low loss in the opposite direction. The bandwidth of these devices depends basically on the line width of the material, and as mentioned before, if we get a wide line width material, in general the maximum resonance loss, and thence the isolation is reduced. However there are one or two techniques we can use to overcome this problem, the most common being the mounting of the ferrite slab on a wedge of very high dielectric constant material. This will concentrate the energy in the ferrite, making it more efficient. Incidentally it will shift the position of the point of circular polarization towards the centre of the guide. A further broadbanding technique in common use is a tapering of the magnetic field strength longitudinally along the line, effectively giving a number of isolators in cascade.

Of the four types of isolators discussed, by far the most commonly used types are the resonance isolators and the terminated circulators. Field displacement isolators are seldom seen now, and I personally know of no company marketing them. The Faraday rotation isolator is again limited to the millimetre end of the spectrum, the same reasons applying to the isolator as to the circulator.

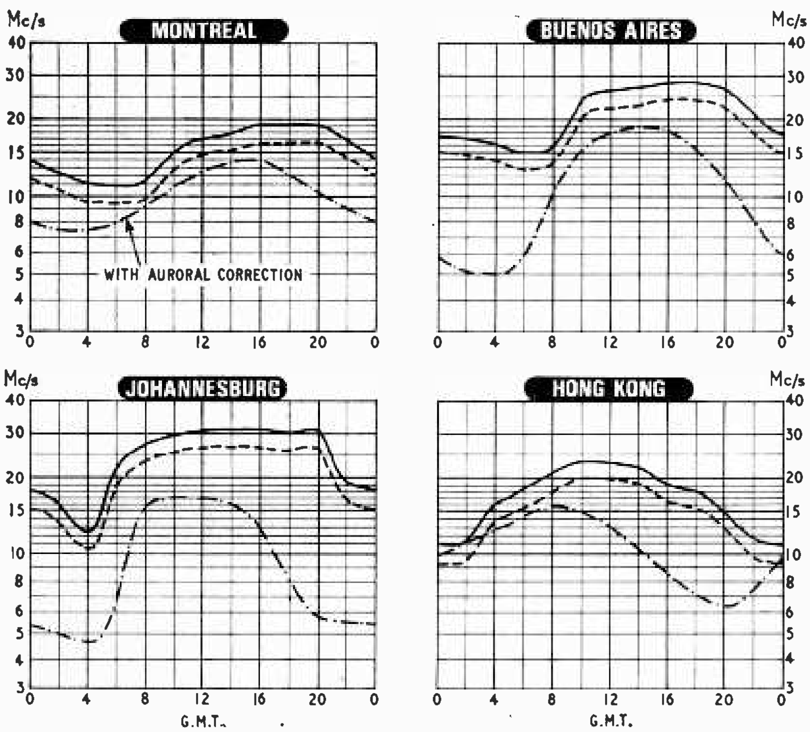
For specifying isolators generally, the same parameters should be considered as for circulators. Currently obtainable isolator performance figures are listed in Table 2.

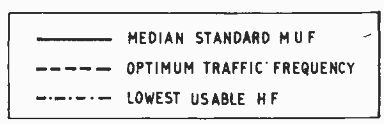
The next and final article in this series will deal with phase shifters of various types, the y.i.g. filters, and ferrite delay lines. It will conclude with suggestions for further reading on all devices covered in this series.

TABLE 2: TYPICAL ISOLATOR SPECIFICATIONS

Frequency (Mc/s)	Insertion loss (dB)	Isolation (dB)	v.s.w.r.	Size l × w × h (in)	Remarks
30– 32	1.75	20	1.3	$2\frac{3}{4} \times 3 \times 1\frac{1}{8}$	Terminated lumped constant circulator
250– 300	0.5	18	1.25	$8 \times 9 \times 1\frac{1}{2}$	Terminated circulator
390– 450	1.0	10	1.2	$7\frac{5}{8} \times 3 \times 1$	Narrow-band resonance type
404– 412	0.6	10	1.1	125in long	150kW c.w. w.g. resonance type
700–1000	1.0	12	1.35	$7 \times 1\frac{1}{8}$ dia.	Wideband resonance type
(Gc/s)					
2.0 – 4.0	1.0	20	1.2		
1.9 – 2.0	0.2	23	1.15	$2\frac{5}{8} \times 2\frac{11}{16} \times 1\frac{1}{4}$	Narrowband coaxial resonance type
6.05 – 6.35	0.5	20	1.4	$3\frac{1}{8}$ dia. $\times \frac{3}{4}$	Miniature w.g. terminated circulator
6.425– 6.875	1.0	50	1.1	$3\frac{1}{8} \times 3 \times 3$	W.G. resonance type
8.0 – 12	0.6	15	1.35	$1\frac{1}{8} \times 1\frac{1}{2} \times \frac{7}{8}$	Coaxial terminated circulator type
8.5 – 11.5	0.5	20	1.0	$4 \times 2 \times 2$	1kW c.w. power type
13.8 – 14.2	0.3	20	1.25	$1\frac{1}{2} \times 1\frac{5}{16} \times \frac{3}{8}$	Miniature w.g. terminated crculator
13.2 – 13.4	1.0	50	1.10	$5 \times 2 \times \frac{3}{4}$	Narrowband w.g. resonance
12.5 – 14.5	0.5	15	1.15	$2\frac{1}{2} \times 2 \times \frac{3}{4}$	Wideband w.g. resonance
18.0 – 26.0	1.0	24	1.15	$4\frac{1}{8} \times 1\frac{1}{2} \times \frac{3}{4}$	Wideband w.g. resonance
34 – 40	0.5	20	1.25	$3\frac{1}{2} \times 1\frac{1}{4}$ dia.	Faraday rotation type
128 – 130	1.5	20	1.3	$3\frac{1}{8} \times 87 \times 2$	Faraday rotation type

H. F. PREDICTIONS — APRIL





The prediction charts, which are prepared by Cable and Wireless Ltd., show the median standard MUF, optimum traffic frequency and lowest usuable frequency for reception in this country. They are generally applicable to the continental areas containing the locations specified.

With the advancing sunspot cycle MUFs are again some 20% higher than for the same month of last year. Diurnal variations continue to decrease, giving stable signals for longer periods, a trend which will continue on routes within the northern hemisphere. Curves for routes crossing the equator are roughly the same for all seasons, tending to the long flat shape during equinox conditions at present prevailing.

LUF curves, largely dependent on e.r.p. and s/n ratio, are shown for commercial telegraphy but will be similar for reception of high-power broadcasting stations.

Amateur S.S.B. Transmitter

THE FINAL DETAILS — POWER UNIT : LINING UP : OPERATION

BY C. J. SALVAGE

HAVING outlined in last month's issue the general circuitry and described in detail the various parts of the transmitter, it now remains to deal with the power supply unit. Lining up and operational instructions will also be discussed and elsewhere in this instalment a list of components for the complete transmitter is given.

Power supply unit (Fig. 6).—This is of small size, 10in×6in×7in, and contains the one transformer, with details as shown. The high voltage supply (1,500 V) has a mean rating of 200 mA and the 300 V winding a rating of 150 mA mean. The capacitors C_{65}—C_{72} are connected across the diodes in order to absorb switching peaks which would otherwise ruin them. R_{66} and R_{67} are also included to prevent heavy current surges. One of the heater windings could with advantage be reduced to 6.1 V in order to eliminate the necessity of R_{66}. This unit has attached a 12-core "Metvin" flexible cable, approx. 5ft long, terminating in a Plessey plug which connects with the socket at the rear of the transmitter. Several cores are connected in parallel for the heater leads.

LINING UP

The audio phase shift network can be adjusted by using an oscilloscope in a Lissajous configuration. This is accomplished by taking the outputs leading into the grids of the double triode V8 and applying them to the X and Y plates of a cathode-ray tube. If there is insufficient output from the grids of V8 pins 1 and 6 can be used. The test signal that should be fed into the microphone input socket should be from a variable frequency source giving 300-3,000 c/s. The final waveform should be a circular trace indicating that the two signals are 90° out of phase with each other. (Note: if the c.r.t. should by any chance not be symmetrical in its electrical characteristics an ellipse will appear, with its major and minor axes along the X and Y co-ordinates.) A simpler test is to apply a 1 kc/s tone and adjust VR_3 and VR_4, checking with a valve voltmeter that the potentials appearing at the grids are equal. In these operations VR_2 must be brought up from a minimum in order to avoid overloading the double triode V8.

The v.f.o. can be checked by listening on a receiver to make sure that the frequency and coverage are correct. V3 can also be checked by a receiver by making sure that the anode circuit is doubling or tripling as required in the various bands. L_2 is resonated to give maximum output in the centre of each band by adjusting the ferrite core. In like manner, L_1 is resonated for maximum centre band output. With the receiver picking up from L_1, C_{11} and C_{13} should be adjusted with VR_5 and VR_6 until maximum carrier suppression is achieved. The adjustment is made for each of the five bands in turn. When correctly adjusted, an audio signal applied to the microphone input and a small amount of r.f. signal taken from the anode circuit of the power amplifier (working into a matched load) will show as an unmodulated carrier on a c.r.o. As the audio is increased and decreased so the width of the band displayed on the c.r.o. will vary, showing a line when modulation is reduced to zero. Finally, the signal can be monitored with the receiver in the most selective position to make sure that the carrier

(*Continued on page* 191)

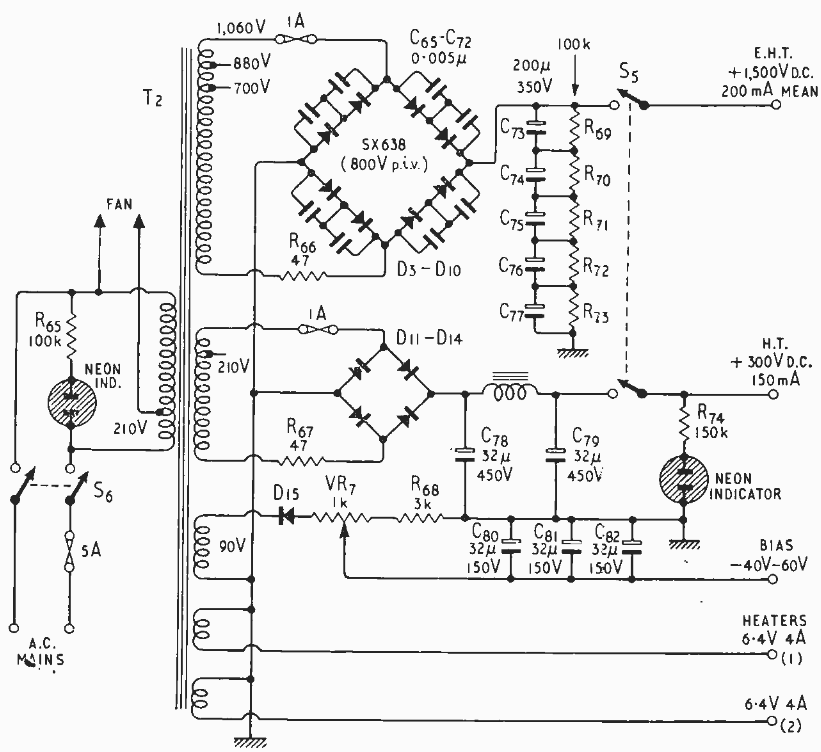


Fig. 6. The power supply circuit shown above provides the complete power requirements for the s.s.b. transmitter.

COMPONENTS FOR S.S.B. TRANSMITTER

CAPACITORS

C	Value F	WV	Type
1	10p	Gang Var.	See Note 1
2	20p		
3	See table	500	Silver mica
4	270p	500	„
5	100p	500	„
6	100p	500	„
7	0.01μ	350	Paper
8	0.002μ	350	„
9	100p	500	Silver mica
10	0.01μ	350	Paper
11	0.01μ	350	„
12	10p	500	Silver mica
13	0.01μ	350	Paper
14	See text	500	Silver mica
15	„	500	„
16	0.01μ	350	Paper
17	0.01μ	350	„
18	0.001μ	350	„
19	0.001μ	350	„
20	0.1μ	350	„
21	0.1μ	350	„
22	0.1μ	350	„
23	0.001μ	350	„
24	0.001μ	350	„
25	30p+30p	Var.	Note 1
26	0.01μ	350	Paper
27	0.01μ	350	„
28	100p	500	Silver mica
29	0.01μ	350	Paper
30	200p	500	Silver mica
31	4.7p	500	„
32	0.005μ	350	Paper
33	5.0μ	25	Elect.
34	0.1μ	350	Paper
35	0.1μ	350	„
36	430p	500	Silver mica
37	430p	500	„
38	680p	500	„
39	680p	500	„
40	16μ	6	Elect.
41	5.0μ	6	Elect.
42	0.2μ	100	Paper
43	0.2μ	100	„
44	0.2μ	100	„
45	0.5μ	100	„
46	0.2μ	350	„
47	0.005μ	25	„
48	0.5μ	100	„
49	100μ	6	Elect.
50	8μ	6	„
51	0.01μ	150	Paper
51a	0.003μ		inc. in valve holder V9
52	0.001μ	350	Paper
53	0.001μ	4kV	Silver mica or ceramic
54	0.01μ	350	Paper
55	260p	500	Silver mica
56	See table	500	„
57		500	„
58		500	„
59		500	„
60		500	„
61	0.01μ	350	Paper
62	0.001μ	350	„
63	0.01μ	350	„
64	0.01μ	350	„
65 to 72	0.005μ	350	Ceramic
73 to 77	200μ	350	Elect.
78	32μ	450	Elect.
79	32μ	650	„
80 to 82	32μ	150	„

Note 1—C_1 and C_2 "Polar" 30+30pF variable capacitor with plates stripped off to produce 10+20pF. C_{25} "Polar" 30+30pF.

Feed through capacitors—used wherever an h.t. or bias lead is brought through a screen. They act as extra decoupling and as anchor points.

C_{FT1} 500 pF. C_{FT2}—a grommet is adequate. C_{FT3} etc.—500 pF.

RESISTORS

R	Ω	W	R	Ω	W
1	47k	½	38	1.5k	½
2	1k	½	39	1.5k	½
3	10k	4½	30	3.3k	½
4	33k	½	41	3.3k	½
5	47k	½	42	270	½
6	1.5k	½	43	110k	½
7	470	½	44	47k	½
8	470	½	45	3.3k	3
9	100	½	46	6.7k	⅛
10	100	½	47	270k	⅛
11	1.2k	½	48	2k	⅛
12	1.2k	½	49	10k	⅛
13	33k	½	50	1k	⅛
14	33k	½	51	47k	⅛
15	33k	½	52	10k	½
16	33k	½	53	2.2m	⅛
17	33k	½	54	210k	⅛
18	47k	½	55	6.8k	⅛
19	See text and tables.				
20	180	½			
21	40mA		56	10k	½
22	470k	½	57	68k	⅛
23	33k	½	58	5mA	Shunt
24	33k	½	59	400mA	Shunt
25	2.2m	½	60	0.15	
26	770k	½	61	6.5k	½
27	487.5k	½	62	56	½
28	198k	½	63	1k	½
29	125k	½	64	5k	½
30	47k	½	65	100k	½
31	47k	½	66	47	½
32	270	½	67	47	½
33	270	½	68	3k	½
34	180	½	69	100k	½
35	47k	½	70	100k	½
36	47k	½	73	100k	½
37	47k	½	74	150k	½

All resistors are 10% tolerance, except R_9, R_{10} and R_{26} to R_{29} which are 1%.

R_{21}—15Ω 14in 40 s.w.g. d.c.c. Wound round resistor for support (Eureka).

R_{58}—1.54Ω 3.6in 36 s.w.g. d.c.c (Eureka).

R_{59}—0.15Ω 3.0in 24 s.w.g. d.c.c. (Eureka).

R_{60}—0.15Ω 14in 18 s.w.g. Eureka self supporting—with sleeving protection.

VARIABLE RESISTORS

VR_1—50k
VR_2—500k
VR_3—500Ω
VR_4—500Ω
VR_5—5k
VR_6—5k
VR_7—1k

VALVES

V1—EF80 (B9A.)
V2—OA2 (B7G.)
V3—6870 (B9A.)
V4—7360 (B9A.)
V5—7360 (B9A.)
V6—5763 (B9A.)
V7—12AT7 (B9A.)
V8—12AT7 (B9A.)
V9—4X250B (Special 8 pin).
4X150A will replace 4X250B providing e.h.t. is limited to 1250V.

DIODES

D1—OA81
D2—OA81
D3—D10—SX638 (800 p.i.v.)
D11—D14 approx. 80mA 300V r.m.s. diodes. or 160mA bridge rectifier complete.

TRANSISTORS

Tr1—OC72
Tr2—OC77
Tr3—OC77

SWITCHES

	Type	Function
S_1	Ceramic 5-way NSF	Waveband change.
S_2	6-way	Voice control and sideband selector.
S_3	3-way, 2-pole	Meter selector.
S_{4a}, S_{4b} with VR_2		
S_5	DPST high voltage	Netting switch "ON-OFF".
S_6	DPST high current	A.C. Mains "ON-OFF".

OTHER COMPONENTS

T1—4 to 6 : 1 Intervalve step down transformer. Any audio type will suit with 10mA rating in high impedance winding.

T2—Primary: voltage as required for a.c. mains supply, 210V tapping for fan. Secondary—1060V, 880V, 700V; 250V, 210V; 90V; 2×6.4V 4A.

The transformer is not critical. The author used a C core former. For the e.h.t. windings the insulation has to be reliable.

Fan—Airflow Developments Ltd., size 26BT 210 Volts.

RLA_1 3400Ω 1c/o Siemen type relay,
RLA_2 3400Ω 1c/o government surplus.

RFC_1—2.5 mH.
RFC_2—2.5 mH.

Remaining r.f.cs—30 s.w.g. d.s.c. copper wire wave wound on a Neosid former 2in high 0.3in diameter with five stacks 0.15in diameter 0.15in thick. Cores—900 grade.

M_1—1mA meter 60Ω
M_2—1 mA meter 60Ω
(note shunt resistors for this internal resistance only).

(*continued from page 189*)
and the unwanted sideband are on the correct side and adequately suppressed.

OPERATION

The bulk of the transmitter is switched with S_2; this should be in the "off" or VOX position and VR_2 should be turned completely anti-clockwise. This procedure, known as "netting," leaves the v.f.o. on in order to achieve frequency synchronization with incoming signals at the receiver by the beat frequency method.

With the switch S_2 at the "on" position, VR_2 is advanced to half way. The microphone is then made effective. The double ganged tuning capacitor C_{25} in the balanced modulator should be adjusted and simultaneously the drive control VR_1 advanced, until a reading on the meter (switched to p.a. current) shows approximately 0.7-0.8 mA (1 mA f.s.d. shunted for 400 mA). When speaking into the microphone, with a 70Ω load or a matched aerial connected to the output, C_{55}, the p.a. tuning capacity, can be tuned for maximum reading of aerial voltage on the voltmeter. When no audio is applied, balance controls VR_5 and VR_6 should be adjusted to give minimum reading on the aerial voltmeter, the sensitivity of which can be increased by turning VR_2 in an anti-clockwise direction if desired.

When the transmitter is set up for s.s.b. on any band and the control switch is set to VOX, netting is very swift, being achieved by turning VR_2 anti-clockwise to net and then back to normal. The receiver switches back on after a completed transmission, so checking for replies is made automatic. If the station called is also using VOX, it is possible to "call in" quite easily, making contact during a short pause in the other's transmission—in fact I have called in two New Zealand stations in contact during a very brief break in their transmissions.

Carrier insertion is achieved by unbalancing the balanced modulator with either VR_5 or VR_6, but in this event a steady direct current to the p.a. should not exceed 0.4 mA meter reading (160 mA actual current). This indicated current does include that taken by the screen of the 4X250B. With inserted carrier a steady current is indicated by the aerial voltmeter. The audio should be turned down to approximately half that normally used for s.s.b. as overloading and distortion will result.

INDUCTOR TABLE

L1	Band	V.F.O.		Change Mc/s	Turns	s.w.g.	C3
80 m	3.5- 3.8 Mc/s	f/2	1.75-1.9 Mc/s	0.15	3/16" wide 3/8" dia wave wound	40 sd..c.	47 pF
40 m	7.0- 7.1 Mc/s	f/2	3.5-3.55 Mc/s	0.05	24	36 en.	470
20 m	14.0-14.35 Mc/s	f/3	4.6-4.78 Mc/s	0.117	22	36 en.	226
15 m	21.0-21.45 Mc/s	f/3	7.0-7.15 Mc/s	0.150	11	30 en.	280
10 m	28.0-29.7 Mc/s	f/3	9.33-9.9 Mc/s	0.567	10	30 en.	130

L2	Turns	Link	s.w.g. en.	L3 Turns	s.w.g. en.	L4 Turns	s.w.g. en.	R 19
80 m	80	3	38 (22 pF in parallel)	110	42	90	42	2.7 k
40 m	50	5	36	60	38	52	38	3.9 k
20 m	28	5	30	28	30	21	30	6.8 k
15 m	14	3	30	18	30	12	30	8.2 k
10 m	8	3	30	13	30	9	30	12.0 k

Above: wound on Neosid type 358/8BA formers, 0.3in. dia; Grade 900 cores.

L5	Wound with 14 s.w.g. T/C wire 8TPI				
80 m	C55-180 pF	C56-1,200 pF	11.5 μH	14 turns.	2½in dia.
40 m	90 pF	C57-550 pF	5.7 μH	7.5	,,
20 m	45 pF	C58-270 pF	2.7 μH	4.0	,,
15 m	30 pF	C59-200 pF	2.0 μH	2.0	,,
10 m	23 pF	C60-130 pF	1.4 μH	6.0	1¼ in dia.

L6 and L7—Vinkor LA2303 220t 32 s.w.g. enamelled wire. Adjusted to 26 mH

Capacitor Table for RF Phase Shift Network C14 & C15

Capacitor to give Zo of 100Ω			
80 m	3.7 Mc/s	430 pF	390 pF silver mica + 30 pF (Philips trimmer)
40 m	7.1 Mc/s	224 pF	200 pF silver mica (Philips trimmer)
20 m	14.2 Mc/s	112 pF	82 pF silver mica (Philips trimmer)
15 m	21.2 Mc/s	75 pF	47 pF silver mica (Philips trimmer)
10 m	28.5 Mc/s	56 pF	22 pF silver mica (Philips trimmer) (strays account for 10/15 pF)

DATA ON VALVES USED

	Heater		Anode	Screen	Grid	Anode	Screen	Grid	Drive	Max.	RF	f	(Mc/s)
	V	I	V	V	V	mA	mA	mA	W	Diss	W	Full	Re-duce
6870 .. (SQ) B9A base	6.3	0.6	250	250	-30	28.5	8.0	1.4	7.15	6.3	3.2	75	150
5763 .. 6062 (SQ) B9A base	6.0	0.75	300	250	-60	50.5	5.0	3.0	0.35	12.0	8.0	50	175
7360 .. B9A base	6.3	0.35	150 150	250 max. 175 typ.					0.5 max.	1.5 1.5			
4X250B .. Special 8 pin base	6.0 Forced air cooled	2.6	2kV							250	400	175	500

International AUDIO FESTIVAL

THE demand from manufacturers for space at the annual Audio Festival and Fair held at the Hotel Russell, London, continues to grow and this year because a few more rooms have been made available the number of exhibitors has reached a new high—a total of 92. The majority of the manufacturers have booths in the exhibition areas and demonstration rooms. Despite the crowds which annually flock to this festival of sound, and the resulting difficulty of getting into the demonstration room of your favourite equipment manufacturer, the popularity of the Fair is unabated. The *pros* and *cons* of holding the Fair in an hotel have frequently been discussed and it is interesting to note that one conclusion from a survey of visitors to last year's show was that two-thirds of them preferred it to be held in the atmosphere of an hotel. It was considered essential for demonstrations to be given in rooms.

The Fair will open on each of the four days (March 30th-April 2nd) at 1100 and close at 2100 on the first three and at 2000 on the last day. Admission before 1600 on the opening day is restricted to specially invited guests. Tickets (for all but the preview) which admit two people are obtainable free from exhibitors, audio dealers or the editorial offices of *Wireless World* (please send a stamped, addressed envelope).

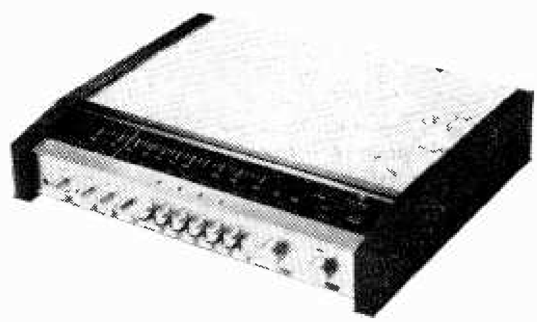
We list below the names of the exhibitors and where overseas manufacturers are represented by their U.K. agents we give the latter's name in parentheses. In the June issue we plan to include a review of the latest developments in audio techniques as seen by members of the staff of *Wireless World* at the Fair. As a foretaste we give on these pages illustrations of some of the latest equipment which will be exhibited and/or demonstrated.

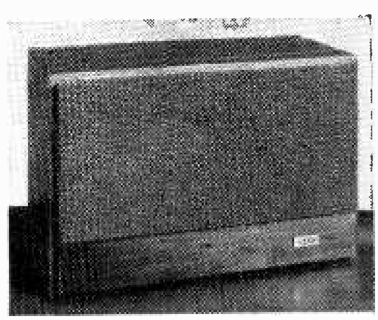
Plans are being made by the B.B.C. to radiate slightly extended periods of pilot-tone transmissions during the Fair to facilitate the demonstration of stereo equipment by exhibitors. On the 31st these will probably be from 1600-1700 and 1930-2010, on the 1st from 1040-1200 and on the 2nd from 1300-1700. The B.B.C. will not be giving stereo demonstrations this year but will have an information bureau at the Fair.

LIST OF EXHIBITORS

A.E.G.
A.K.G. (Politechna)
Acoustical Mftg. Co.
Agfa-Gevaert
Akai (Pullin)
Allan, Richard, Radio
Amateur Tape Recording
Ampex Corporation
Arena (Highgate Acoustics)
Armstrong Audio
Audio & Design
Audio & Record Review
Audio Technica (Shriro)
B.A.S.F.
B.B.C.
B.K.S.T.S.
B. & O. (Debenham)
B.S.R.
Beyer (Fi-Cord)
Boosey & Hawkes
Bosch
Braun (Fi-Cord)
Brenell Engineering Co.
Brown, S. G.
Celestion
Cosmocord
Decca Record Co.
Design Furniture
E.M.I.
Elcom
Euphonics (A. C. Farnell)
Fane Acoustics
Fed. of British Tape Recording Clubs
Ferguson
Ferranti
Ferrograph Co.
Fidela (Denham & Morley)
Field, N. & S. B., & Co.
Fisher Radio
Garrard Engineering
Goldring Mftg. Co.
Goodmans Industries
Gramophone
Grampian Reproducers
Grundig
H.M.V.
Hi-Fi News
High Fidelity Magazine
KEF Electronics
Leak, H. J., & Co.
Linear Products
Lowther Manufacturing Co.
Lugton & Co.
Lustraphone
Minnesota Mining & Mftg. Co.
Mikrofonbau (Denham & Morley)
Mullard
Ortofon (Metro-Sound)
Parmeko
Philips Hi-Fi
Philips Tape Recorders
Pioneer Electronics (Swisstone)
Radford Electronics
Radionette (Denham & Morley)
Rank Wharfedale
Records & Recording
Rectavox Company
Rogers Developments
S.G.S.-Fairchild
S.M.E.
Sansui Electric Co. (Technical Ceramics)
Scopetronics
Sennheiser (Audio Engineering)
Shure Bros.
Sonotone (Metro-Sound)
Sony (Debenham)
Standard Telephones & Cables
Stereosound Productions
Sugden & Co.
Tandbergs (Elstone Electronics)
Tannoy Products
Tape Recorder Developments
Tape Recorder Spares
Tape Recording Magazine
Thorens (Metro-Sound)
Truvox
Vortexion
Whiteley Electrical Radio Co.
Williman, K. H., & Co.
Willi-Studer (C. E. Hammond & Co.)
Wilmex
Wireless World and *Electrical & Electronic Trader*

Akai (Japan) silicon transistor stereo tuner-amplifier.
WW 332 for further details

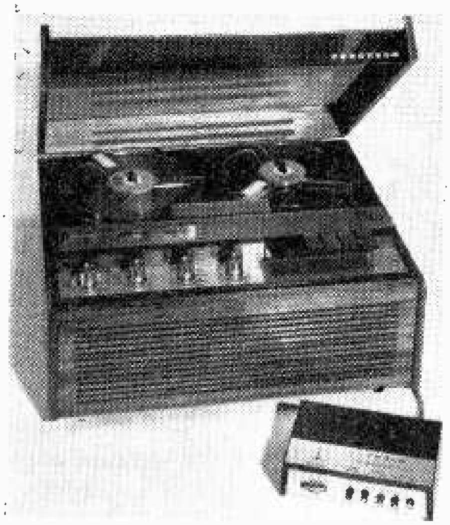




Cresta enclosure, with new drive units (B130 and T27) can be driven by amplifiers requiring a load impedance of 4-15Ω (K.E.F.).

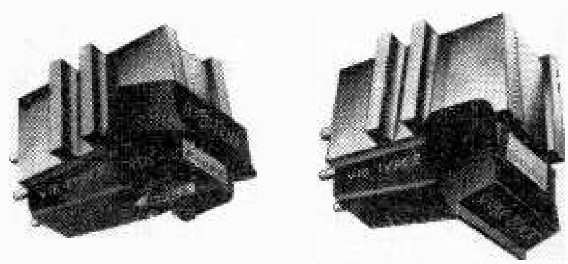
WW 333 for further details

& FAIR—London Mar.30 - Apr.2

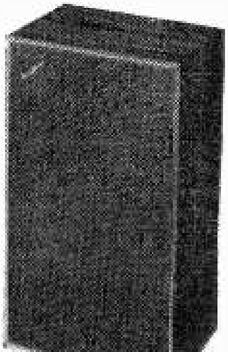


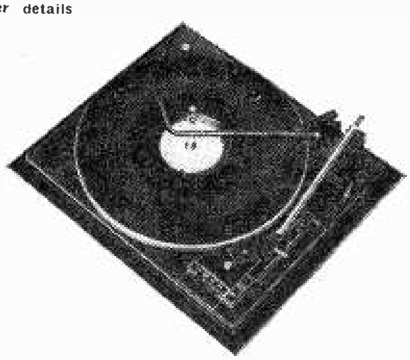
▲ Ferguson (B.R.C.) 4-track tape recorder is part of Unit Audio system and uses Thorn tape deck. Stereo operation is given by the Synchro-Amp unit in foreground. WW 334 for further details

Shure V15II pickup with protective stylus cover.
▼ WW 336 for further details

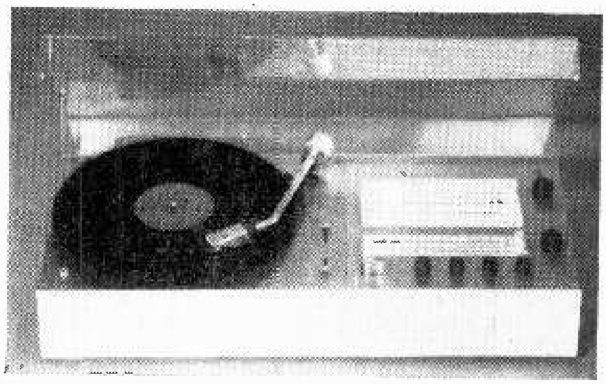


Latest Ionofane loudspeaker (model 604) comprises "ionic" h.f. loudspeaker plus a single l.f. driver (Fane Acoustics).
▼ WW 338 for further details

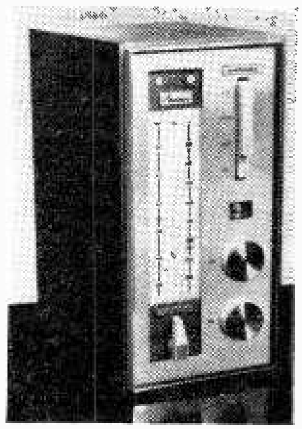




▲ UA 65 11 in automatic turntable with integral cueing device (B.S.R.). WW 340 for further details



▲ Audio 2 a.m./f.m. radiogram. Features include stereo decoder and bandwidth switch (a.m.). Separate loudspeakers are required (Braun, Germany). WW 335 for further details



◀ Stereomax a.m./f.m. tuner with stereo decoder and power unit (Goodmans) WW 337 for further details

2100 series recorder reviving bi-directional recording and including automatic reversing (Ampex). WW 339 for further details
▼

LETTERS TO THE EDITOR

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

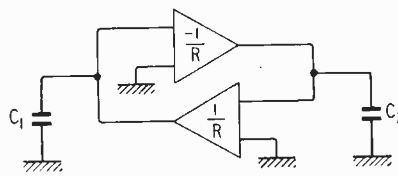
The Gyrator—Old Wine in a New Bottle?

I BELIEVE that some of the articles which have appeared in the recent burst of interest in gyrators are misleading, in that they could be taken to convey that a gyrator is a new sort of *circuit*; it seems to me that a gyrator is in fact a not-very-new concept, a novel—and possibly not always helpful—way of looking at certain well-established circuit configurations.

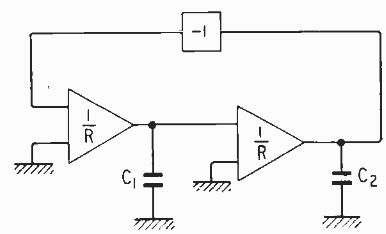
We may concisely define a gyrator by contrasting it with a transformer

transformer	*gyrator*
$v_2 = nv_1$	$v_2 = ni_1$
$i_2 = (1/n)i_1$	$i_2 = (1/n)v_1$

and in this way invest it with fundamental conceptual importance. When we look at many "gyrator circuits," however, we find some old friends. Thus if a capacitor C_1 is converted by a gyration resistance R into an inductance C_1R^2 and connected to another capacitor C_2, we should have an undamped parallel tuned circuit of resonant frequency $\omega = \sqrt{\dfrac{1}{C_1C_2R^2}}$. (Fig. A)



Alternatively, we may regard the set-up as a single-loop feedback system as shown in Fig. B.



B

Here the open-loop gain is $\dfrac{1}{pC_1R} \times \dfrac{1}{pC_2R} \times -1$

and on closing the loop we have

$$\frac{-1}{p^2R^2C_1C_2} = 1$$

so that $p = \sigma + j\omega = \sqrt{-1}\sqrt{\dfrac{1}{R^2C_1C_2}}$

Hence $\sigma = 0$

$$\omega = \frac{1}{R^2C_1C_2}$$

and if $C_1 = C_2 = C$

$$\omega = \frac{1}{CR}$$

So it seems ingenuous of Mr. Short to suggest in the March issue that a gyrator solves a problem of getting a 10 : 1 frequency range on an ordinary tuning capacitor. *RC* oscillators and filters have been doing it for years.

Mr. Sinclair's contribution in the same issue supports my point. If the positive end of the 100 μF capacitor in his Fig. 2 were earthed, one would call this a Darlington emitter-follower following a 1st-order low-pass filter; the output would be reasonably smooth even if the 2000μF output capacitor were omitted. Using the connection he actually does, one would—at first sight—expect the performance to be slightly degraded. On my lash-up of this circuit the peak-to-peak ripple is indeed greater in Mr. Sinclair's "gyrator" connection, though the ripple waveform is considerably improved, presumably because the simulated inductance raises the order of the filter from 1st to 2nd; which waveform has the more energy in the harmonics is exceedingly moot. It would be interesting to know Mr. Sinclair's thinking in arriving at this circuit.

P. E. K. DONALDSON

Physiological Laboratory, Cambridge.

In Defence of "Some" Electronic Organs

MR. MACHIN in his article in the February issue throws some light on why inexpensive electronic organs fail to convince musicians who are accustomed to the pipe organ, but does not do justice to the few good instruments designed to overcome all the defects he mentions.

First, one should not forget that the tonal properties of the simple divider organ have now been exhausted; therefore, to meet increasing competition, most commercial large-scale producers have to add effects such as rhythm, glissando, percussion and other circuit artifices foreign to the organ proper. This only underlines the gulf which has always existed between the theatre and the church or concert pipe organ and in such entertainment instruments, a few clicks or the inevitable degradation at the ends of the compass pass unnoticed.

When we come to the carefully thought-out organ, Mr. Machin is a little unfair. To deal with his points in turn, and taking the free phase organ first, then satisfactory examples such as the Miller, Gregorian and Allen all have oscillators of the highest stability, the performance of which over a number of years is entirely satisfactory. Some do generate sine waves with shaping circuits following, but some produce complex waves in the oscillator or buffer stage. The addition of upper harmonics to a fundamental can present difficulties with independent oscillators, but can, with care, be properly regulated; since, however, the 2nd is the octave of the fundamental, it is not so important as the 3rd and 5th, particularly in forming diapason tone. In an electrostatic organ, which was not mentioned, this regulation can be perfectly achieved. As Mr. Machin states, the cost of independent oscillators is high, but then if one is to imitate ranks of pipes one must have ranks of oscillators—there is no other way to obtain a true chorus or to form true mixtures.

In the matter of introducing wind noise, the ingenious circuits of the Allen Organ Co. (U.S. Patent 2,989,886) fully describe how to modulate organ tones with noise and also, how to achieve the "chiff" characteristic of stopped pipes. Noise generators have also been used in the Gregorian organs.

When considering transients, which are only objectionable if heard on keying a note, then of course the free phase organs are free from this defect but resistance switches, which are now used on a number of organs, are reasonably good and certainly with conductive silastomers they can be made to have a very long life, better than graphite. Keying is now accomplished through transistors rather than with diodes in the more exacting organs, one ingenious circuit which quite avoids any mutilation of the waveform being used by Copeman Hart & Co; incidentally in this case, the keying transistor is also used to convert a square wave from dividers to a sawtooth wave for tone forming. Again, keying is quite perfect in the electrostatic organ which, although virtually a divider system, keys only in the d.c. lines.

In the matter of tone circuits, the devices shown in U.S. Patent 2,649,006 are especially worthy of attention since it is thereby possible to tilt the response in any desired way. It is thus possible to balance the complete tonal spectrum as in the relative voicing of 16, 8.4 and 2ft pitches in a pipe organ. The correct overall balance is fully described by Thienhaus-Willms, "die lautstärke von orgelregistern", 1933, vol. 3. This voicing technique is also well illustrated in "Klangstruktur der Musik", verlag für radio-foto-kinotchnik, Berlin-Borsigwalde.

Reverberation has seen many ups and downs, cost being the usual excuse for unsatisfactory performance. However, the new tapered spring device disclosed in U.S. Patent 3,199,053, is, for the first time in a compact unit, frequency sensitive so simulating the natural process of physical decay of sound waves in an enclosed space. The unit is only 8in long and weighs 4 ounces. I would be happy to lend Mr. Machin this to try.

Finally, all good organ tone circuits are terminated in an isolating stage to preserve tonal fidelity; and in the matter of loudspeakers, I have often pointed out that it is essential to have a large area of air in contact with many cones, each operating at a low level per unit area. Only in this way can low notes, for example, simulate the breathing sounds so characteristic of large organ pipes. It is not a matter of power, but of propagation.

ALAN DOUGLAS

Radcliffe-on-Trent, Notts.

Symbols—Further Suggestions and More Comments

WHY change to "hertz" when "cycles per second" has been in use for so long? The reason is, in my opinion, that whereas "cycles per second" may in *writing* be rendered conveniently as "c/s," in *speech* it becomes too much of a mouthful. This then leads to the slipshod use of the term "cycles," when "cycles per second" is intended, so that when a lecturer really *does* mean "cycles" and not "cycles per second," he has to go first into a long speech to indicate that he really does mean what he is about to say, and not something else. This occurs frequently when describing scanning actions in television.

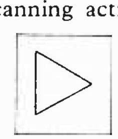
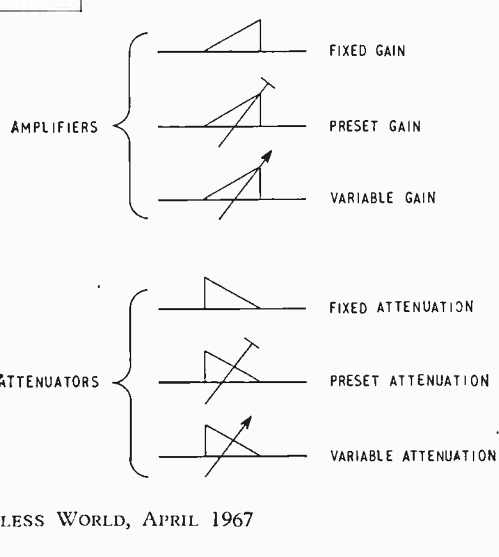


Fig. 1.
AMPLIFYING EQUIPMENT BS 530:212

(Below) Fig. 2. Symbols for amplifiers and attenuators suggested by R. C. Whitehead.



You may say that "hertz" does not directly indicate the property of frequency as does c/s." But does "knot" indicate directly a velocity in nautical-miles per hour? And does "ampère" indicate directly a current flow in coulombs per second?

Now could something be done about the two apparently unrelated words "pad" and "attenuator," that describe two closely related pieces of equipment? (BS 530:205). In this connection the B.S.I. committees might like to consider the practices of the Spanish language, wherein related objects and actions are commonly described by words which vary only in their endings.

Turning now to graphical symbols, BS 530:212 recommends the use of the symbol shown in Fig. 1 for an "amplifying equipment." Is this the same as an amplifier? Its relationship to the mathematical sign > suggests that the signal on the left-hand side (input) has a magnitude which is *greater* than that on the right-hand side (output). And is not the rectangle redundant? Of course a chaotic situation would develop if we became completely logical and used this symbol to represent a pad or attenuator, and a left-upon-right transposition of it as an amplifier.

Finally, may I suggest use of the symbols shown in my Fig. 2, and that we drop the use of the word "pad," because we don't find it necessary to use different terms to describe amplifiers of fixed and variable gains.

R. C. WHITEHEAD

Sutton, Surrey

Points from other letters

AS you apparently agreed to call condensers capacitors, there is no reason why you should not continue the farce and call cycles hertzes. As Bernard Shaw once remarked: Spelling does not matter so long as the meaning is understood. A stop has got to be made somewhere, otherwise an international incident might arise in an endeavour to rename the diode the Braun, Edison, or Fleming.

B. S. T. WALLACE

Littlehampton, Sussex.

YOUR January editorial mentions that "no international decision can be taken until 1970". Why? The I.E.C. officially adopted the hertz in 1937. It is not surprising that the Germans "and some Continentals" have been using the term for some time.

I agree the old term was fully descriptive, but only when written in one's own language or one very much like it. Hz means as much to a Japanese person as it does to one of those Continentals. Isn't it time the rear-guard action ceased in the interests of unanimity and easy international communication?

R. C. ELDRIDGE

Vancouver, B.C.

IF my opinion can help in avoiding two backward steps then pray note that I endorse your views, and vote for the use of the classical term c/s, and well-known symbol for a resistor. Let us hope logic and functionalism will prevail: after all, diagrams are made to be understood at a glance.

When electronics meets industrial electricity, as does happen in the varied field of automation, the lack of a really unified system of symbols is truly deplorable. Relay contacts depicted as capacitors (fixed and variable . . . . meaning normally open and normally closed contacts), relay coils shown either as a zig-zag, a rectangle or a thick black bar.

PAUL DE LATTRE

Tilff, Belgium.

"Battery Eliminator for Transistor Receivers"

IN your March issue on page 143, you give details of a battery eliminator for transistor receivers.

It should be pointed out that the use of such an eliminator renders the receiver liable to compliance with the safety standard, BS415, for which it is not normally designed. Also it is mentioned that the mains isolating transformer can be of the bell type, but to comply with the recognized safety standards any accessible parts (which in this case include the whole receiver) must be tested with a voltage of 2.5 kV.

D. P. DOO

B.R.E.M.A.,
London, W.C.1.

Single-beam Colour Tubes

MANY hundreds of thousands of pounds are currently being spent on colour television, and in the future many tens of millions will be spent on colour receivers.

These receivers appear to use shadowmask tubes almost exclusively. Since this tube has made the running for so long, are we not in danger of overlooking the changes in the "electronic art" which have occurred since its introduction? Recent cheap, reliable, high-performance transistors have made possible complex signal processing at low cost.

Should we not attempt to transfer some of our receiver costs from the expensive hardware of shadowmask tube and convergence circuitry to a simpler tube with, if necessary, complex, but cheap, transistor signal processing?

Surely the registration problems of the vertical phosphor stripe (Apple) tube could be overcome using modern transistor techniques, particularly since digital circuits can now be made so simply.

The final result of such research could well be a much cheaper receiver, and the elimination of convergence, and all that that implies. Nationally it could save millions of pounds.

R. G. AGGLETON

Selsdon, Surrey

HOW MANY TUBES DOES A COLOUR TV CAMERA NEED?

THE ultimate in colour television cameras will be one using a single pick-up tube, avoiding all the registration and balancing problems associated with three- or four-tube types, but meanwhile a two-tube colour camera has been built and successfully operated in Japan. It was described at a joint I.E.E./I.E.R.E./I.E.E.E./R.T.S. London colloquium on colour cameras in a paper by Mataji Komai and Kozo Hayashi, of Nippon Hoso Kyokai, Tokyo. The tubes are image orthicons, one giving a separate luminance signal and the other a chrominance signal. The chrominance tube receives light through a composite primary-colour filter made up of red, green and blue vertical stripes, and the electrical output is an R, G, B dot-sequential signal containing also black index pulses. The index pulses are used for gating the R, G, B samples so that the dot sequential signal is converted into three simultaneous R, G, B signals. Thereafter the luminance and chrominance signals are handled in the same way as those from conventional three- or four-tube cameras. Disadvantages of the technique are loss of light in the stripe filter and limitation of chrominance signal bandwidth (to about 500 kc/s) by the sampling process associated with the stripe filter.

Much of the colloquium was occupied with discussions on the relative merits of three-tube and four-tube (separate luminance) cameras. Speaking for four-tube designs were representatives of Marconi and E.M.I., and for three-tube designs representatives of Fernseh and Philips. C. B. B. Wood of the B.B.C. (which has purchased both kinds) felt that the four-tube camera had very little advantage over the three-tube type provided the last-mentioned was well designed and correctly operated. The question was, could the three-tube camera meet the necessary requirements? From Wood's account of tests at the B.B.C. Research Department, using criteria such as subjective picture sharpness, colour fringing and sensitivity, it appeared that there was little to choose between the two types and certainly nothing that the viewer at home would be aware of.

An American speaker, A. W. Malang, of General Electric, seemed rather impatient with the hair-splitting considerations of the performance comparisons, and remarked that factors such as cost, reliability and convenience of operation and maintenance played a more important part in the U.S.A. An over-riding factor was the variability of receiver colour reproduction in the U.S.A., partly resulting from the introduction of improved red and green tube phosphors. Also there was "milady's mood control" on receivers, which enabled viewers to have the colour temperature of white on the display tube set anywhere between a muddy brown and a crystal clear blue!

THE WORLD OF AMATEUR RADIO

The Continent Calls

WITH an ever-increasing number of administrations concluding amateur radio reciprocal operating agreements, the mobile enthusiast—of which there are nearly 2,500 in the U.K. alone—will find many opportunities this coming summer of continuing his activities while touring or visiting Continental Europe. Recently introduced regulations bring the Federal Republic of Germany into line with the several other countries which are prepared to offer a temporary licence to visiting qualified radio amateurs. Arrangements for dealing with applications for short-term German licences are in the hands of the German national amateur radio club (D.A.R.C.) who have authorized Mr. Herbert Picolin, DL3NE, to establish an International Affairs Office at Muelenweg 27, 5601 Doenberg, Germany. A copy of the full conditions can be obtained from him by sending an International Reply Coupon. The chief condition of the licence —which is valid for a maximum period of three months— is that the applicant shall hold a current licence in his own country of a standard equal to that of the German amateur licence. The fee for a short-term licence has been fixed at DM14, payable in Germany currency.

Foreign radio amateurs who wish to operate transmitting equipment in Austria must make written application at least one month in advance to the Post Direction in Vienna, Linz, Graz, Innsbruck or Klagenfurt according to the area in which the station will operate.

Applicants must give their full name and address, place and date of birth, address in Austria, class of licence required (class A, 25 watts; class B, 50 watts; class C, 100 watts). If portable or mobile operation is to be undertaken that fact must be stated, together with a request for permission to operate in all Austrian radio districts. A certified copy of the home station licence must accompany the application.

Portugal is another country which now offers mobile facilities to visiting radio amateurs. For stays of up to eight days a licence can be obtained by going personally to the office of the Director of Radio Services, Rua General Sinel de Cordes 9-50°, Lisbon, where the applicant's home station licence must be presented together with his passport. Those who wish to stay for longer periods must write, in advance, to the above address sending the station licence.

Australian Expedition Station.—VK8OX is the call sign of the amateur station now being operated by members of the Joint Services Expedition to West Central Australia. Earlier, when the station operated from Edinburgh R.A.A.F. Airfield, about 20 miles north of Adelaide, using the call VK8OX/5, more than 400 contacts with 80 countries were recorded. A ground plane aerial and a KW2000 transceiver were used. When on Service duties the station operates on 7·990, 14·455 and 20·465 Mc/s using the call VL5SX. R.A.F. Locking uses the call G8FC when working the Expedition station on amateur frequencies and GON when on Service duties. J. Etherington (G5UG) technical secretary of the R.A.F. Amateur Radio Society, R.A.F. Locking, near Weston-super-Mare, Somerset, is QSL manager for the Expedition.

International Weekend in Belgium.—A feature of amateur radio in Belgium is the close collaboration which exists between the Belgian national amateur radio society (U.B.A.) and the Belgian Red Cross. To mark the fifth anniversary of the formation of the National Amateur Radio Emergency Corps, which operates in collaboration with the Red Cross, an international weekend is to be held in Belgium during the period May 6th/7th. Activity will centre around the U.B.A. national station (ON4UB) at 80 Chausse de Vleurgat, Brussels 5, and the programme will include an international mobile rally and 144 Mc/s fox hunt.

New Italian Regulations.—New regulations make no provision for Italian amateurs to operate mobile—neither to they permit a licence to be issued to foreigners, although a qualified amateur who visits Italy can obtain a licence to operate from the station of any licensed Italian amateur. Italian amateurs are no longer authorized to operate on frequencies between 146 Mc/s and 21 Gc/s but it is expected that narrow segments around 432 Mc/s will be made available to them.

I.A.R.U. Growing.—With the election to membership of the national amateur radio societies in Algeria, Cyprus, Liberia and East Africa the numerical strength of the International Amateur Radio Union is now 72 with further applications from Malta and the Faroes now being considered. I.A.R.U. Region I Division, which exists to safeguard the special interests of radio amateurs in Europe, Africa and the Middle East, now comprises 24 member societies including the recently elected national organizations in East Africa, Nigeria and Czechoslovakia.

Radio Old Timers.—Sir Francis McLean, director of engineering, B.B.C., is to be the guest of honour at the ninth reunion of the Radio Amateur Old Timers' Association to be held at the Horse Shoe Hotel, Tottenham Court Road, London, W.C.1, on May 5th. The Association, with a membership now approaching 250, is open to all radio amateurs who have held a U.K. transmitting licence for an unbroken period of not less than 25 years, including the war years. Details from the Founder-Secretary, 16 Ashridge Gardens, London, N.13.

JOHN CLARRICOATS, G6CL.

Literature Received

Technical Data TF 2604 is a four-page sheet on the Marconi **electronic voltmeter** TF 2604. A brief explanation of the circuit is followed by descriptions of a.c., d.c., and resistance measurements. A full technical specification is given. The frequency characteristics of the a.c. probe are displayed, and there are photographs and details of four optional extras. From Marconi Instruments Ltd., St. Albans, Hertfordshire.
WW 328 for further details

Issued by DISA Electronik A/S. Herlev, Denmark, the 30-page DISA information booklet No. 3, has been sent to us by their U.K. branch at 116 College Road, Harrow, Middlesex. This particular issue is devoted to the **electronic measurement of mechanical events,** and included among the titles of the various papers are "Measuring angular vibrations in an engine shaft," "Measurement of turbulence characteristics," and "Tubular hot-wire probe for fluid-system experiments."
WW 329 for further details

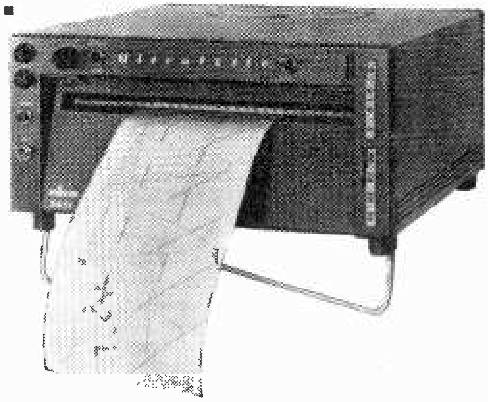
Full details of the Controlox **matrix programme board** by Oxley Developments Co. Ltd., Priory Park, Ulverston, North Lancs., are published in the four-page leaflet MB/11/66. Suggested applications, electrical and mechanical characteristics, and other relevant data are included.
WW 330 for further details

A 7-page data and price list for **power semiconductors** has been received from AC-Delco, 244 Brompton Road, London, S.W.3. As well as data on high-voltage silicon power transistors, germanium Nu-base and alloy base transistors, there are details on silicon rectifiers, heat sinks and accessories. A list of thirty-nine application notes (which are available on request) is printed on the back.
WW 331 for further details

NEW PRODUCTS

equipment systems components

Recording u.v. Oscillograph



WITH a simultaneous recording capacity of 30 channels d.c. to 10 kc/s the Ultralette 5651 has 16 paper drive speeds from 2.5 mm/minute to 100 cm/sec. This direct writing mirror galvanometer oscillograph by Svenska Diamant (Sweden) is available in the U.K. from the Instrument division of Claude Lyons Ltd. A wider range of speeds may be obtained by using a 25.1 reduction gear, thus enabling the machine to record at 1 mm/minute to 10 m/second. A reverse drive for oscillogram rewind, a flash timer, preset record length and selectable event release, together with remote control facilities are incorporated. Using a 30-cm optical arm and high quality optics the fine trace gives a high resolution. The galvanometers available have a natural frequency from 20 c/s to 10 kc/s with sensitivities from 0.00058 mA/cm to 46.5 mA/cm. The 5651 takes paper 3 in to 12 in wide and the overall dimensions of the machine are $15\frac{3}{4} \times 15\frac{3}{4} \times 7$ in (height).

WW 301 for further details

TIMER COUNTER

THE type TC7 0-2 Mc/s timer counter has been added to the range of instruments by Advance Electronics, of Hainault, Essex. This instrument, which costs £130, will also measure period and time and will count random or regular pulses. Weighing less than 9 lb and having overall dimensions of 11 × 11.25 × 5.25 in, it employs silicon transistors throughout, and hinged printed circuit boards. The display unit uses a read-out circuit which applies a strobing technique and cycles the counting stages; this avoids the need for more expensive separate decoding matrices. The frequency/sensitivity specifications are: 10 c/s to 2 Mc/s, <150 mV r.m.s. (typically <100 mV r.m.s.); d.c. to 50 kc/s, <+2 V d.c. or 4 V pk-pk sine. The input can safely handle up to 250 V r.m.s. maximum up to 10 kc/s, and up to 10 V r.m.s. maximum up to 2 Mc/s. The input impedance is 10 kΩ shunted by 20 pF (approx. 50 kΩ for 1 V r.m.s.). Single periods of signal up to 1 kc/s are measured using clock units of 10 μs, 1 ms and 100 ms. Multiple periods of 10 or 100 are measured by using clock units of 10 μs and 1 ms respectively. The reset control is either automatic, fixed display of approximately 1 s or manual reset by depressing a spring-loaded front-panel switch. External reset is by positive going pulses between 3 V peak and 6 V peak of minimum width 10 μs and rise time 1 μs; or external closing contacts. The internal standard frequency is controlled by a 100 kc/s crystal: set to ± 1 part in 10^5 at room temperature and stable to ± 3 parts in 10^5 from + 10°C to + 40°C. The unit will accept an external standard of 0 to 1.5 Mc/s negative going 1 V pk to approximately 6 V pk pulse waveform of approximately 0.1 μs rise time, or sine wave input 100 kc/s to 1.5 Mc/s 1 V r.m.s. minimum.

WW 302 for further details

Flip-Chip Capacitors

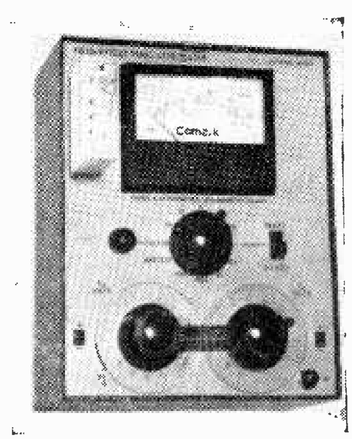
MONOLITHIC chip capacitors introduced by the United Insulator Co. Ltd., Oakcroft Road, Chessington, Surrey offer a wide range of capacitance values to designers. Later in 1967 the range of values, which is from 3,300 pF to 47,000 pF, will be extended. Tolerances of ±20 % are standard, but ±10 % tolerance capacitors are available by selection. The effective working temperature is from −60 °C to +150 °C. The maximum working voltage is 50 V d.c. Extra termination robustness is claimed due to the use of sintered palladium. The size is 3.3 mm square, giving a greater capacitance for a given area than that available by conventional thin film or i.c. techniques. Consisting of up to 25 layers of dielectric each 0.001 in thick, these "flip-chip" capacitors are stated to be in advance of any comparable product being made in Europe.

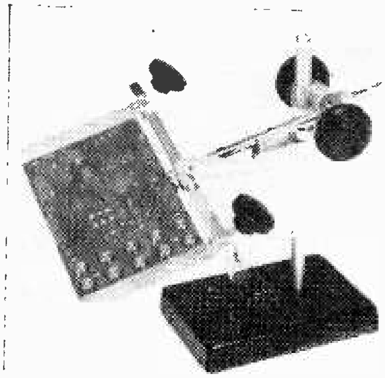
WW 303 for further details

F.E.T. Tester

A PORTABLE battery powered instrument designed for measuring the static and dynamic characteristics of f.e.ts and m.o.s.ts is believed to be the first of its kind in this country. This instrument, by Comark Electronics Ltd., Gloucester Road, Littlehampton, Sussex, will measure drain current, pinch-off voltage and mutual conductance at various settings of drain and gate voltage or current. Breakdown voltages may also be checked. The polarities of the drain and gate supplies are separately reversible so that both enhancement and depletion f.e.ts and m.o.s.ts of the n-channel and p-channel variety may be tested. Overload protection has been built in to reduce the risk of damage to the tester and tested component through misuse.

WW 304 for further details





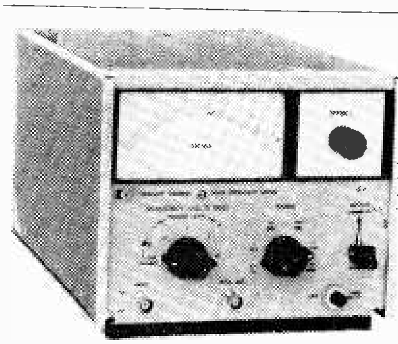
Circuit Board Holder

AVAILABLE from Technical Representation Ltd., Ravenoak Road, Cheadle Hulme, Stockport, this circuit board holder features spring loaded arms to securely hold work, instant release with light pressure on lever and a universal joint to facilitate the positioning of the board. It will hold boards varying in size from ¾ in to 7 in square and from $\frac{1}{32}$ to $\frac{3}{32}$ in thick. An extension can be fitted to accommodate larger boards.

WW 305 for further details

Frequency Meter/F.M. Discriminator

A NEW direct reading frequency meter/f.m. discriminator, Model 5210A, which measures frequencies in the range of 3 c/s to 10 Mc/s is available from Hewlett Packard Limited, 224, Bath Road, Slough, Bucks. It can function as a wideband discriminator, being able to demodulate signals at frequencies of up to 1 Mc/s. Its linearity in the capacity of discriminator is 0.025% of full scale up to the top of the 100 kc/s range, 0.05% in the 1 Mc/s range and 0.1% in the 10 Mc/s range. As a frequency meter its accuracy is of the order of 1% of the reading. It is claimed that an expanded scale feature it possesses, enables an accuracy of 0.1% of the reading to be achieved in frequency difference measurements, as well as improving the resolution by a factor of 10. Major features of this instrument include plug-in discriminator output filters and low-noise outputs for recording, observing and analysing f.m. and frequency data. The sensitivity of the instrument is 10 mV for the frequency band 20 c/s to 10 Mc/s. A four-step decade attenuator allows the sensitivity to be reduced to prevent false triggering on noisy signals. The

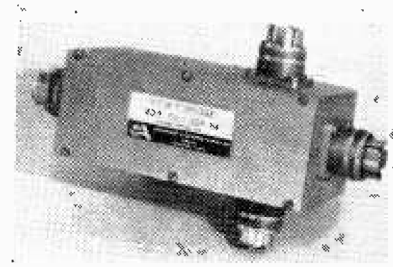


input impedance is constant at 1 MΩ shunted by 30 pF. The meter scale is linear from zero to one-tenth of full scale but from there on up to full scale it is logarithmic.

WW 308 for further details

Standing Wave Ratio Bridge

TWO models of standing wave ratio bridges made by Anzac Electronics Inc., featuring high accuracy at both high and low ratios are now obtainable in the U.K. from Wessex Electronics Ltd., Royal London Buildings, Baldwin Street, Bristol 1. In either fixed or swept frequency set-ups the new bridges enable rapid measurement of standing wave ratio and return loss. These models RB-1 and RB-3 have frequency ranges of 0.5—50 Mc/s and 3-1500 Mc/s respectively. The stated accuracy of RB-1 is 1% for v.s.w.rs up to 1.5 and 2% at 2. For the RB-3 the figures are 1.5% maximum below 1 Gc/s, and 2.5% maximum at 1.5 Gc/s for v.s.w.rs up to 1.5. Typical errors are half these values and the error at an apparent v.s.w.r. of 1.00 is <1% be-



low 1 Gc/s and <1.5% at 1.5 Gc/s. Low v.s.w.r. adaptors to nearly all commonly used connector types are available. Each unit includes a short-circuit termination and a table for converting return loss to v.s.w.r.

WW 306 for further details

Low Resistance F.E.Ts

ULTRA-LOW "on"-resistance field-effect transistors by Crystalonics Inc. are available through G.E. Electronics (London) Ltd., Eardley House, 182-4, Campden Hill Road, Kensington, W.8. Claimed to be the lowest "on" resistance f.e.ts at present available, the CP650 power series, in TO-5 cans, and the 2N4445 (CM650) switching series, in TO46 cans, exhibit 5 Ω maximum "on" resistance (R_{DS}). Brief details of the CP650 and 2N4445 respectively are as follows: dissipation, 8 W and 0.4 W maximum; breakdown voltage, 25 V; capacitance, 8 pF and 18 pF typical; drain current, 1.2 A and 0.4 A. The transconductance of the CP650 is 250 mA/V and junction temperature operating range is −65 to +200°C. In quantities of 100 to 999 the price of the transistors ranges from £7 19s to £15 5s each, delivery being from four to five weeks. The low power requirements of the CP650 and CP651 enable them to operate efficiently in supply regulators. In r.f. amplifiers they have exhibited, it is claimed, a dynamic range of 140 dB. The CP652 and CP653 can be used for the same purposes as low-current silicon controlled rectifiers, with the advantage of a turn-on/turn-off time of 20 ns from a 50 Ω driving source.

WW 307 for further details

PNP Silicon Epitaxial Planar Transistors

A SERIES of p-n-p silicon epitaxial planar transistors, 2N4058 to 2N4062, is announced by Texas Instruments. These are complementary to the n-p-n series 2N3707 to 2N3711 and are contained in the TO 92 case. The 2N4058, with typical noise figure of 1.7 dB and maximum 5 dB under test conditions of (h_{FE} 100-550) 15.7 kc/s noise bandwidth, $V_{CE} = -5$ V, $I_{CE} = -100\mu$A and $R_G = 5$ kΩ, has low-level, high gain applications. All exhibit the following maximum rating values: collector-base voltage, −30 V; collector-emitter voltage when the base-emitter diode is open-circuited, −30 V; emitter-base voltage, −6 V. Continuous collector current is −30 mA and continuous dissipation at or below 25°C in free-air is 250 mW. Permissible lead temperature $\frac{1}{16}$ in from case for 10 seconds is 260°C. The forward current transfer ratios for the 2N4059-62 types with $V_{CE} = -5$ V and $I_{CE} = -1$ mA are 45 to 800, 45 to 250, 90 to 450, and 180 to 800 respectively.

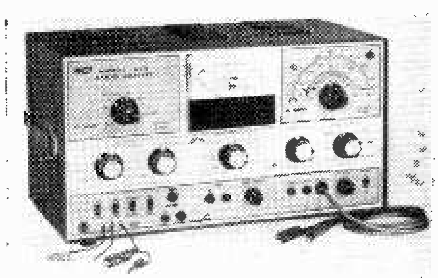
WW 309 for further details

Single Channel Noise Measuring Equipment

RECENT developments in the field of solid-state signal sources and general purposes klystrons have brought with them the need for an assessment of the purity of their c.w. outputs. A recent instrument, type 60, will measure amplitude modulation of a carrier expressed in terms of the r.m.s. frequency deviation produced in a 70 c/s bandwidth of noise (alternative bandwidths available are 30 c/s, 100 c/s, 500 c/s). It will also measure a.m. signal-to-noise ratios of the order of 126 dB-130 dB and, in the absence of overriding a.m. noise, it will measure f.m. r.m.s. deviations down to values of the order of $\frac{1}{2}$ c/s in a 70 c/s bandwidth. This equipment is particularly suitable for the evaluation of solid state sources having f.m. noise and spurious modulations of a high order (e.g., tens of c/s r.m.s. deviation). This instrument is in a range of equipment available from James Scott (Electronic Engineering) Ltd., Carntyne Industrial Estate, Glasgow, E.2.

WW 310 for further details

Domestic Equipment Tester

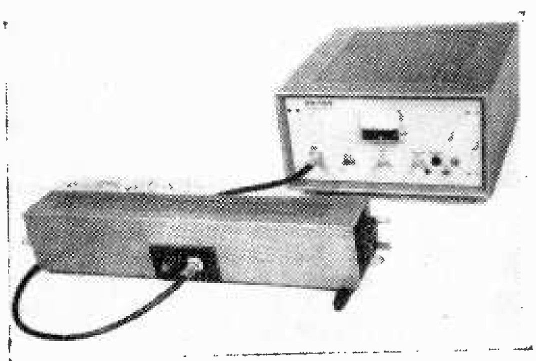


TRANSISTOR a.m. and f.m. sound receivers, television sets and audio amplifiers can be routine tested with the B. & K. Model 970 transistor equipment analyser designed by Empire Exporters Inc., 123 Grand Street, New York, N.Y., U.S.A. The quiescent current drawn by the receiver or amplifier under test can be quickly balanced. Then a.c. or d.c. signals are injected at test points without disconnecting components, permitting diagnosis of fault conditions. This model also provides for out-of-circuit transistor testing. It includes a built-in power supply, a volt-ohm milliammeter claimed to be burn-out proof, and a 400-c/s audio output or modulation for the r.f. signals. It generates 250 kc/s (a.m.); 10 Mc/s to 11.4 Mc/s (a.m. or f.m.) and 88 Mc/s to 108 Mc/s (f.m.). This model is available for 115-230 volts 50 c/s or 60 c/s mains supply.

WW 311 for further details

Helium Neon Gas Laser

A HELIUM neon gas laser which can be used for a variety of experiments and applications is one of a range being manufactured by System Computers Ltd., of The Fossway, Newcastle-upon-Tyne 6. This r.f. excited laser, designated model G2, operates on 6328Å at a guaranteed 0.4 mW in single mode and 1.0 mW in multi mode. It has a 50 cm discharge tube and an excitation frequency of 27.1 Mc/s. Accessories available include a power output meter and an amplifier loudspeaker unit.



WW 312 for further details

Tantalum Capacitors

DESIGNATED the Z Series, metal-cased miniature solid tantalum capacitors offered by Union Carbide Ltd., 8 Grafton Street, London, W.1, are suitable for printed-circuit board mounting where high component packing density is required. The capacitors have working voltages from 6 V to 125 V and capacitance values from 0.0047 μF to 22 μF with standard tolerances of ±20%, ±10% and ±5%. They are said to have a long shelf and operating life at temperatures within the range −80°C +125°C. The two case sizes in which these capacitors are supplied are 0.085in diameter, 0.25in long and 0.127in diameter, 0.375in long.

WW 313 for further details

R.F. Coil Assembly

A MINIATURE coil assembly has been introduced by Aladdin Components Measuring 0.722 in high overall and 0.415 in square, this assembly, CA100, enables i.f. transformers and variable inductors to be produced rapidly. The assembly consists of a small Makrolon former which is a push-fit into a synthetic resin bonded plastic base. This s.r.b.p. base is 0.375 in square and is available with up to six 0.030 in diameter pins. A ferrite pot core covers the windings to increase induction and to provide magnetic screening when required. The assembly can be tuned from either end by a ferrite or iron-dust screw core, of which a range of different grade and length of core are available.

WW 314 for further details

PREFORMING TOOLS

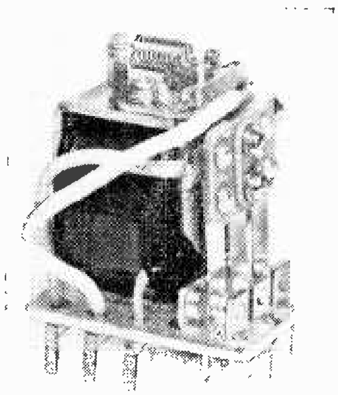
THE Kingham transistor preforming tool is the first of a series to be produced by Kingham Electronics Ltd., 17 Briary Wood Lane, Welwyn Heath, Herts. The leads of TO5 transistors (or other types with three lead 0.2in bolt circles) are joggled and cropped to a pre-determined length in one smooth operation. The transistor is then manually removed and snapped into position in the printed circuit board.

WW 315 for further details

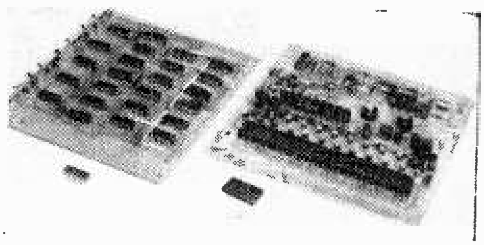
MINIATURE RELAY

A MINIATURE relay, MK 3-0, available from Keyswitch Relays Ltd., 120-132 Cricklewood Lane, London, N.W.2, has been designed for direct insertion in printed circuits. The characteristics are similar to the basic MK 3 (three pole, double throw). The switching current of the MK 3-0 is 7.5 amperes per contact, with maximum contact voltage 440 V a.c. or 250 V d.c. Coil consumption is not more than 2.5 VA a.c. or 1 W d.c. The relay has a life in excess of 5 million operations and a fast operating time of 15 ms (a.c.) or 25 ms (d.c.) Release times are 20 ms (a.c.) and 30 ms (d.c.) and insulation is 1,000 V a.c.

WW 316 for further details



Analogue-to-Digital Converter



AN analogue-to-digital converter designed to meet B.S.2G100 specifications and withstand severe conditions is available from Epsylon Industries Ltd., North Feltham Trading Estate, Middx. This converter has been incorporated in the latest flight data recording equipment. The analogue range is 0 V ±3 mV to ±6 V ±3 mV, and the input impedance 10 kΩ. The command is a pulse going from +6 V to earth, or earth short circuit, duration 10 μs. The command pulse clears the previous output. Conversion time is 100 μs. Resolution is 1 part in 1024. Accuracy is ±0.1% of full scale and ±half the least significant digit over the temperature range 0 to +70°C. The maximum conversion rate is 10 kc/s. The output is a parallel ten-bit word, in which "0" is represented by +12 V in series with 4 Ωk, and "1" is represented by <0.3 V. Serial output: an output carrying the serial reject pulse of amplitude +6 V ±1 V over worst case loading (10 kΩ, 100 pF) and temperature. Maximum noise on the serial output line is <1 V. The power supply requirements are −12 V ±0.25 V at 50 mA max.; +12 V ±0.25 V at 100 mA max; and +6 V ±0.25 V at 300 mA. The converter is contained on two printed circuit boards 6 in × 6.5 in × 0.75 in and 6 in × 6.5 in × 0.35 in, and it weighs less than 16 ounces.

WW 318 for further details

Frequency Generator

A SUBSTANDARD frequency generator type 7C-V-3OT manufactured by Contronics Ltd., Deepcut, Camberley, Surrey, is a development of an original valve design. This new instrument employs semiconductors and a Chronoscope tube and gives up to 30 watts continuous output (60 watts intermittent) at seven crystal controlled fixed frequencies between 46 and 52 c/s, or at variable frequencies in the range 44 to 54 c/s. The variable oscillator stability is claimed to be better than 0.01% in 30 seconds. In the Chronoscope (synchroscope) the deflector plates can be switched to either a.c. from the mains, an external source or the internal variable oscillator. A voltmeter and ammeter monitor the output. The equipment is housed in two metal cases with carrying handles, electrical connections being made by a flying lead. Power consumption is approximately 100 watts. Outputs of 63.5 V, 110 V, 240 V nominal are available. The generator unit weighs 36 lb and is 18 in wide, 12.5 in high and 12 in deep. The stabilized power supply weighs 26 lb and is 10 in by 12.5 in and 12 in deep.

WW 319 for further details

OPERATIONAL AMPLIFIER

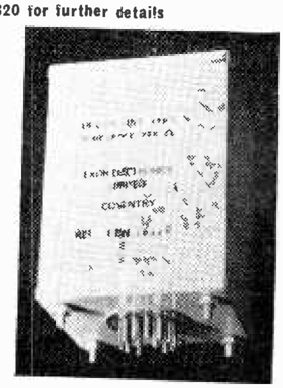
A DIFFERENTIAL d.c. operational amplifier, model 4009, by Opamp Labs., 172 S.Alta Vista Blvd., Los Angeles, U.S.A., is contained in a modified low profile microminiature TO-5 case. It can be used as an a.c./d.c. amplifier, oscillator, voltage or current regulator, active filter, modulator-demodulator and comparator. Featuring a unity-gain bandwidth of 30 Mc/s and to be useable with supply voltages from ±6 V to ±36 V, this device utilizes a hybrid construction of planar silicon transistors and cermet resistors. Using a power supply voltage of −36-0-+36 V, the current consumption is ±8 mA, the operating temperature range −55 °C to +70 °C and the internal power dissipation 600 mW. The open-loop voltage gain is 800, the input impedance 20 kΩ, and the output impedance 2.5 kΩ. Using a ±36 V power supply the output voltage swing for a 50 kΩ load is ±30 V; the swing for a 10 kΩ load is ±20 V and that for 2 kΩ load ±10 V.

WW 317 for further details

CODING DELAY LINE

A WIDE range of delay times and impedances are available in delay lines from Lexor Electronics Ltd., 25/31 Allesley Old Road, Coventry. New methods of construction are said to enable units of quite long delay to be accommodated in compact enclosures while preserving the facility of tapping points of high setting accuracy and fast rise-time. A typical unit, as shown, has a total delay exceeding 20 μs at an impedance of 220 Ω and an overall rise-time of less than 400 ns. Eleven taps are provided, each having a setting accuracy of ±10 ns. The temperature coefficient is better than 100 p.p.m./°C and the enclosure dimensions are 3¼ in × 2⅞ in × 2¼ in. These types of delay line are said to meet the exacting requirements of coding and decoding equipment for colour television and other applications.

WW 320 for further details



ANALOGUE INSTRUMENTATION HEADS

A RANGE of high-density ferrite magnetic heads for recording and replaying in multi-track analogue instrumentation recorders is now available from Mullard Ltd., Mullard House, Torrington Place, London, W.C.1. Glass/ceramic constructional techniques have been used to produce a tape contact area claimed to be of long life. The resulting consistent performance eliminates the adjustments to frequency-compensation circuits which are necessary when other types of head are used. The heads feature precise gap alignment and improved h.f. performance, the latter being due to the low inherent core losses of the ferrite material. Low core losses also ensure excellent performance at low signal levels and establish the bias required for optimum performance at a much lower level than normal. Conforming to the I.R.I.G. recommendations for direct and f.m. operation, these heads are compatible with those used in all existing I.R.I.G. system recorder equipments. Pairs of the 7 track heads can be doubled up on a suitable mounting base to provide a 14-track one-inch interlaced system to I.R.I.G. standards, whilst the 3- and 4-track heads can be similarly arranged in a 7-track 0.5 inch I.R.I.G. interlaced system. Record heads are ER7300, ER7302, ER7304 for, respectively, 1 in tape giving 7 data tracks +1 annotation track, 0.5 in tape giving 3 data tracks +1 annotation track, and 4 data tracks. ER7301, ER7303 and ER7305 are the replay heads for the above three record heads.

WW 321 for further details

Core Store

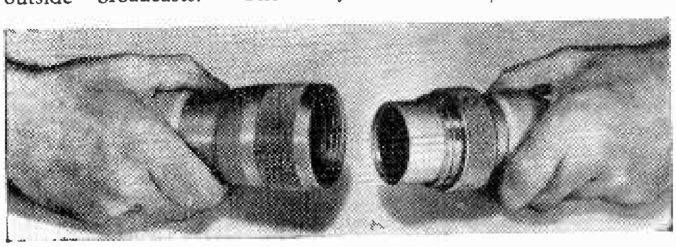
A FERRITE core store has been introduced by A.P.T. Electronics Limited, Chertsey Road, Byfleet, Surrey. The store module comprises a 32 × 32 (1024) bit ferrite core matrix, fitted with address decoders, read/write drive circuit and a sense amplifier, all on a single printed circuit card measuring 11in × 11½in. The depth is 5$\frac{1}{16}$in. Its input and output are controlled by the selection of two 5-bit address codes and when selection has been established, a read pulse is applied, followed by a short strobe pulse. The output then appears at standard logic level, coincident with the strobe pulse and the sense amplifier output. The state of a particular code is set by gating the write pulse appropriately after address selection. Switching is by read/write drive circuits gated appropriately. Stores may be connected in parallel or series as required to a maximum of 1024 words of 8 bits each, or 4096 bits. A power supply of ± 12V is required. The price is £135.

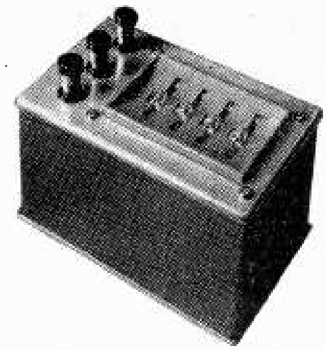
WW 322 for further details

101-way Coupler

A COLOUR television camera cable coupler concentrating as many as 101 contacts into a casing approximately 2 in (5 cm) in diameter has recently been introduced by British Insulated Callender's Cables Ltd. Already featured on many leading cameras, in studios and in outside broadcast vehicles, it facilitates cable interchanging and the rapid connection, extension and recovery of camera links. Claimed to be robust and weatherproof, it is designed to withstand the rough treatment inevitable during outside broadcasts. The beryllium copper plug and socket contacts have gold on silver plating, core connections are soldered and the assembly is integrally moulded to the cable. This moulding is protected by an aluminium bronze alloy body, dull nickel plated to resist corrosion. Straight couplers or couplers with flanges for securing to panels are available to suit the four types of colour television camera cables supplied by B.I.C.C.—two lightweight for short runs and two heavy duty for runs up to 2,000 ft.

WW 323 for further details





R and C BOXES

THREE types of resistance boxes and one type of capacitance box by Elliot Instrument Co. Ltd., Bigods Hall, Dunmow, Essex, cover the ranges 1 Ω to 10 kΩ, 10 Ω to 100 kΩ, 100 Ω to 1 MΩ and 100 pF to 1 μF. The low ranges of resistance use high-stability cracked carbon resistors and the upper ranges metal oxide resistors. The capacitance box incorporates silver mica capacitors in the low ranges and polyester film capacitors in the higher ranges. The voltage rating of the capacitance box is 60 V. The screened case containing the resistors and capacitors is provided with a separate earth terminal. Spring terminals or screw terminals with 4 mm sockets are available.

WW 324 for further details

Megohm Meter

A PORTABLE direct reading insulation resistance meter, type 2565, is being manufactured by Allied Electronics Ltd., 28 Upper Richmond Road, Putney, London, S.W.15. It is self-contained and mains-operated, and its readings are virtually independent of mains fluctuations. The test potentials are in two groups 250 V, 500 V, 1 kV and 150, 250, 500 V, these being applied by depressing a non-locking key. Measurement of current is by an electrometer technique (maximum value between 125 nA and 50 μA). The megohm scale of the meter is calibrated non-linearly, such that one decade covers 90% of full scale compared with the 50% usually found in ohmmeters. The ranges are 20 MΩ to 500 MΩ, 200 MΩ to 5 GΩ, 2 GΩ to 50 GΩ. The mains power consumption is 45 watts, on 200-250 V a.c. The instrument is contained in a heavy gauge steel case 12½ in × 8¼ in × 9 in. All ferrous parts are plated and transformers are vacuum impregnated. No electrolytic capacitors are used.

WW 325 for further details

D.C. Amplifier

DESIGNED for input voltages of 2, 5 and 10 mV is a d.c. amplifier manufactured by Norma of Vienna. The output current for the maximum input on any range is 10 mA, with a permissible output load resistance of 100 Ω to 500 Ω. The input resistance is 400 kΩ/mV and the offset current is not greater than 3 pA. The unit works by converting a d.c. input voltage into a square wave using a transistor chopper and then amplifying the result by a five stage transistor amplifier. Rectification is achieved by two switching transistors driven synchronously with the chopper. The modulation frequency of approximately 2 kc/s gives a short rise time. The d.c. amplifier is available in the U.K. from Croydon Precision Instrument Co., of Hampton Road, Croydon.

WW 326 for further details

VOLTMETER BRIDGE

THE Electro Scientific Industries (U.S.A.) Portametric Voltmeter Bridge, Model 300, now made in Britain, will measure volts from 1 μV to 511.1 V d.c., current from 10 pA to 5.111 A d.c. and ohms from 10 μΩ to 511.1 MΩ with an accuracy of 0.02%, as well as being able to indicate ratios. Plug-in adaptors extend the facility of the instrument so that measurements can be made of temperature, pH, a.c. voltage and high d.c. voltages, thus covering a wide range of application. It is battery operated and weighs 18½ lb, making it usable for field as well as laboratory measurements. The instrument is available from Livingston Electronics Ltd., Greycaine Road, North Watford, Herts.

WW 327 for further details

INFORMATION SERVICE FOR PROFESSIONAL READERS

To expedite requests for further information on products appearing in the editorial and advertisement pages of *Wireless World* each month, a sheet of reader service cards is included in this issue. The cards will be found between advertisement pages 16 and 19.

We invite professional readers to make use of these cards for all inquiries dealing with specific products. Many editorial items and all advertisements are coded with a number, prefixed by WW, and it is then necessary only to enter the numbers on the card.

Postage is free in the U.K. but cards must be stamped if posted overseas. This service will enable professional readers to obtain the additional information they require quickly and easily.

APRIL MEETINGS

Tickets are required for some meetings: readers are advised, therefore, to communicate with the society concerned

LONDON

3rd. Royal Institution.—Film "The world of semiconductors" based on the 1961 Faraday lecture by L. J. Davies at 5.30 at 21 Albemarle St., W.1.

5th. I.E.E.T.E.—"Quality and reliability and the technician engineer", conference organized in collaboration with the National Council for Quality and Reliability at 10 a.m. at Queen Mary College, University of London, E.1.

6th. S.E.R.T.—"Recent developments in semiconductors," at 7.0 at London School of Hygiene and Tropical Medicine, Keppel St., W.C.1.

10th. I.E.E.T.E.—"Electricity and electronics in aircraft" by Sir Robert Cockburn at 6.0 at Savoy Pl., W.C.2.

11th. I.Mech.E.—"Novel instrumentation in fluid mechanics and thermodynamics" conversazione at 5.30 at Queen Mary College, Mile End Rd., E.1.

12th. I.E.E.—"The future use of solid-state devices in the microwave field" by Dr. J. E. Carroll at 6.0 at Savoy Pl., W.C.2.

12th. I.E.R.E.—"Circuit design using digital computers" by E. Wolfendale at 6.0 at 9 Bedford Sq., W.C.1.

14th. I.E.E.—"A survey of semiconductor materials" by S. E. Bradshaw at 5.30 at Savoy Pl., W.C.2.

21st. I.E.E.—Colloquium on "Electric cars" at 2.0 at Savoy Pl., W.C.2.

21st. I.E.E. & S.I.T.—Discussion on "The dynamic measurement of stress using strain gauges" at 5.30 at Savoy Pl., W.C.2.

21st. R.T.S.—Fleming Memorial Lecture "The strange journey from retina to brain" by Dr. R. W. G. Hunt at 7.0 at The Royal Institution, Albemarle St., W.1.

24th. I.E.E.—Discussion on "Heterojunctions" at 5.30 at Savoy Pl., W.C.2.

25th. I.E.E. & I.E.R.E.—Symposium on "Processing of biological signals" at 10.0 at Savoy Pl., W.C.2.

25th. I.E.E. Grads.—"Video recording" by D. D. P. Leggatt at 6.30 at Willesden College of Technology, Denzil Rd., N.W.10.

26th. I.E.R.E.—Symposium on "Ultrasonic methods in non-destructive testing" at 2.30 at London School of Hygiene and Tropical Medicine, Keppel St., W.C.1.

28th. I.E.E.—"Attenuation of 8.6 mm-wavelength radiation in rain" by T. W. Harrold and "The prediction of attenuation by rainfall on line-of-sight microwave paths" by B. J. Easterbrook and D. Turner at 5.30 at Savoy Pl., W.C.2.

ARBORFIELD

11th. I.E.R.E.—"Infra-red detection" by Dr. S. D. Smith at 5.0 at the School of Electronic Engineering, R.E.M.E.

BIRMINGHAM

13th. I.E.E.—"Impact of the Industrial Training Act on education and training" by T. H. Kelsey at 6.15 at the University of Aston.

19th. R.T.S.—"Colour television: The PAL system" by Ian Macwhirter at 7.0 at Broadcasting House, Carpenter Rd., Edgbaston.

24th. I.E.E.—"Visual displays for data communication," by A. Hartley-Smith at 6.0 at M.E.B. Offices, Summer Lane.

BOLTON

12th. I.E.E.T.E.—"The use of closed circuit television in technical courses" by E. T. Blakeman at 7.0 at the College of Education (Technical), Chadwick St.

BRIGHTON

6th. I.E.E.T.E.—"Post Office Tower, and its place in the national telecommunications network" by T. Kilvington at 7.30 at College of Technology, Moulsecoomb.

BRISTOL

26th. I.E.R.E. & Inst.P.Phys.Soc.—"Super-conductivity" by Dr. J. G. C. Milne at 7.0 at the University, University Walk, Clifton.

CARDIFF

20th. S.E.R.T.—"U.H.F. tuners" by B. M. Godwin at 7.30 at Llandaff Technical College, Western Avenue

COVENTRY

10th. I.E.R.E.—"Parametric amplifiers" by D. P. Howson at 7.15 at the Lanchester College of Technology, Priory St.

DIDCOT

26th. I.E.R.E.—"Instrumentation for high-energy physics experiments" by P. Wilde at 7.30 at the Rutherford High Energy Laboratory, Chilton.

DURHAM

26th. I.E.E.T.E.—"Post Office Tower, and its place in the national telecommunications network" by T. Kilvington at 7.30 in the Science Laboratories, the University, South Rd.

EDINBURGH

19th. I.E.R.E.—"Engineering development in B.B.C. external services" by Dr. K. R. Sturley at 7.0 at the Department of Natural Philosophy, The University.

EVESHAM

3rd. I.E.E.—"Colour television" by H. V. Sims at 7.0 at B.B.C. Engineering Training Centre, Wood Norton.

18th. I.E.R.E. & I.E.E.—"Central Electricity Generating Board communications system" by K. S. Hooper at 7.0 at the B.B.C. Club, High St.

FARNBOROUGH

18th. I.E.E.—"An experimental investigation into radio propagation at 11.0 to 11.5 Mc/s" by D. Turner, B. J. Easterbrook and J. E. Golding at 6.30 at Technical College, Boundary Rd.

GLASGOW

12th. S.E.R.T.—"Medical electronics" by D. L. Thomas at 7.30 at the Y.M.C.A. Club, Bothwell Street.

20th. I.E.R.E.—"Engineering development in B.B.C. external services" by Dr. K. R. Sturley at 7.0 at the Institution of Engineers and Shipbuilders, 39 Elmbank Cres., C.2.

HARLOW

26th. I.E.R.E.—"Waveguides" by Professor A. L. Cullen, at 7.0 at Harlow Technical College, The High.

LEEDS

20th. I.E.E.T.E.—"Ultrasonic sensing and switching" by K. F. Mason at 7.30 at the University.

25th. I.E.E. "Computer processing of radar information" by Dr. P. J. C. Child at 6.30 at the University.

LEICESTER

18th. R.T.S.—"Amateur television" by a member of British Amateur TV Club at 7.15 at Vaughan College, St. Nicholas St.

LIVERPOOL

12th. I.E.R.E.—"Electronic melodic instruments" by K. A. Macfadyen at 7.0 at the Liverpool College of Technology, Byrom St.

NEWCASTLE-ON-TYNE

5th. S.E.R.T.—"Television transmission techniques" by L. Roworth at 7.15 at Charles Trevelyan Technical College, Maple Terrace.

12th. I.E.R.E.—"Radio astronomy" by I. Morison at 6.0 at the Institute of Mining and Mechanical Engineers, Neville Hall, Westgate Rd.

PLYMOUTH

5th. R.T.S.—"Radiophonics" by F. C. Brooker at 7.30 at Studios of Westward Television Ltd.

PORTSMOUTH

18th. I.E.E. Grads.—"The present state of fuel cells" by Dr. A. B. Hart at 6.30 at Highbury Technical College, Cosham.

RUGBY

4th. I.E.E.—"The B.B.C. radiophonic workshop" by F. C. Brooker at 6.15 at Rugby College of Engineering Technology.

SOUTHAMPTON

20th. S.E.R.T.—"Hospital broadcasting" by G. A. Allcock at 7.30 at the College of Technology, East Park Terrace.

WOLVERHAMPTON

26th. I.E.R.E.—"Masers and lasers" by Dr. D. C. Laine at 7.15 at the College of Technology, Wulfruna St.

29th. R.S.G.B.—Midlands u.h.f./v.h.f. convention at 10 a.m. at Park Hall Hotel, Goldthorn Park.

LATE MARCH MEETINGS

LONDON

29th. Inst. of Navigation.—Papers on "Performance of airborne invertial navigation systems" at 2.15 at the Royal Institution of Naval Architects, 10 Upper Belgrave St., W.1.

29th. R.S.G.B.—"Aerials" by F. J. H. Charman at 6.30 at the I.E.E. Savoy Pl., W.C.2.

31st. I.E.E.—"Acoustic behaviour of materials" by Dr. R. W. B. Stevens at 5.30 at Savoy Pl., W.C.2.

31st.—R.T.S.—"A history of television equipment" by G. R. M. Garratt at 7.0 at the Science Museum, South Kensington, S.W.7.

THE QUEEN'S AWARD TO INDUSTRY 1966

The world's finest cored solder

ERSIN Multicore 5 CORE SOLDER

- Contains 5 cores of non-corrosive high speed Ersin flux. Removes surface oxides and prevents their formation during soldering. Complies with B.S. 219, 441, DTD 599A, B.S.3252, U.S. Spec. QQ-S-571d.
- Savbit alloy contains a small percentage of copper and thus prolongs the life of copper soldering iron bits 10 times. Liquidus melting temperature is 215C°—419°F. Ministry approved under ref. DTD/900/4535
- Solder Tape, Rings, Preforms and Washers, Cored or Solid, are available in a wide range of specifications.
- Liquid fluxes and printed circuit soldering materials comply with Government specifications. Ask for special details.

FOR THE FACTORY

STANDARD GAUGES IN WHICH MOST ALLOYS ARE MADE AND LENGTHS PER LB. IN FEET.

S.W.G.	INS.	M.M.	FT. PER LB. 60/40	FT. PER LB. SAVBIT
10	.128	3.251	25.6	24
12	.104	2.642	38.8	36
14	.080	2.032	65.7	60.8
16	.064	1.626	102	96.2
18	.048	1.219	182	170
19	.040	1.016	262	244
20	.036	.914	324	307
22	.028	.711	536	508
24	.022	.558	865	856
26	.018	.46	1292	1279
28	.014	.375	1911	1892
30	.012	.314	2730	2695
32	.010	.274	3585	3552
34	.009	.233	4950	4895

STANDARD ALLOYS INCLUDE

TIN/LEAD	B.S. GRADE	LIQUIDUS MELTING TEMP C.	F.
60/40	K	188	370
Savbit No 1	—	215	419
50/50	F	212	414
45/55	R	215	419
40/60	G	234	453
30/70	J	255	491
20/80	V	275	527

HIGH AND LOW MELTING POINT ALLOYS

ALLOY	DESCRIPTION	MELTING TEMP. C.	F.
T.L.C.	Tin/Lead/Cadmium with very low melting point	145	293
L.M.P.	Contains 2% Silver for soldering silver coated surfaces	179	354
P.T.	Made from Pure Tin for use when a lead free solder is essential	232	450
H.M.P.	High melting point solder to B.S. Grade 5S	296-301	565-574

See us at the Paris and London Electronic Component Shows

There are interesting developments applicable to soldering, and our technical staff will be happy to give you full details and information of all our products. At each Exhibition our stands are near the main entrance.

PARIS
April 5th-10th
Hall 40, Allée C,
Stand No. 50.

LONDON Olympia
May 23rd-26th
Stand No. 154, immediately on the right as you enter.

MULTICORE SOLDERS LTD., HEMEL HEMPSTEAD, HERTS. PHONE HEMEL HEMPSTEAD 3636. TELEX 82363

M 40