" Wireless World "
Iliffe Electrical Publications Ltd.,
Dorset House, Stamford Street,
London. S.E.1

Managing Director:
W. E. MILLER, M.A., M.I.E.R.E.

Editor-in-Chief:
W. T. COCKING, M.I.E.E.

Editor:
H. W. BARNARD

Technical Editor:
T. E. IVALL

Editorial:
D. C. ROLFE
G. B. SHORTER, B.Sc.

Drawing Office:
H. J. COOKE

Production:
D. R. BRAY

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

VOLUME 71 No. **7**
PRICE: 3s. 0d

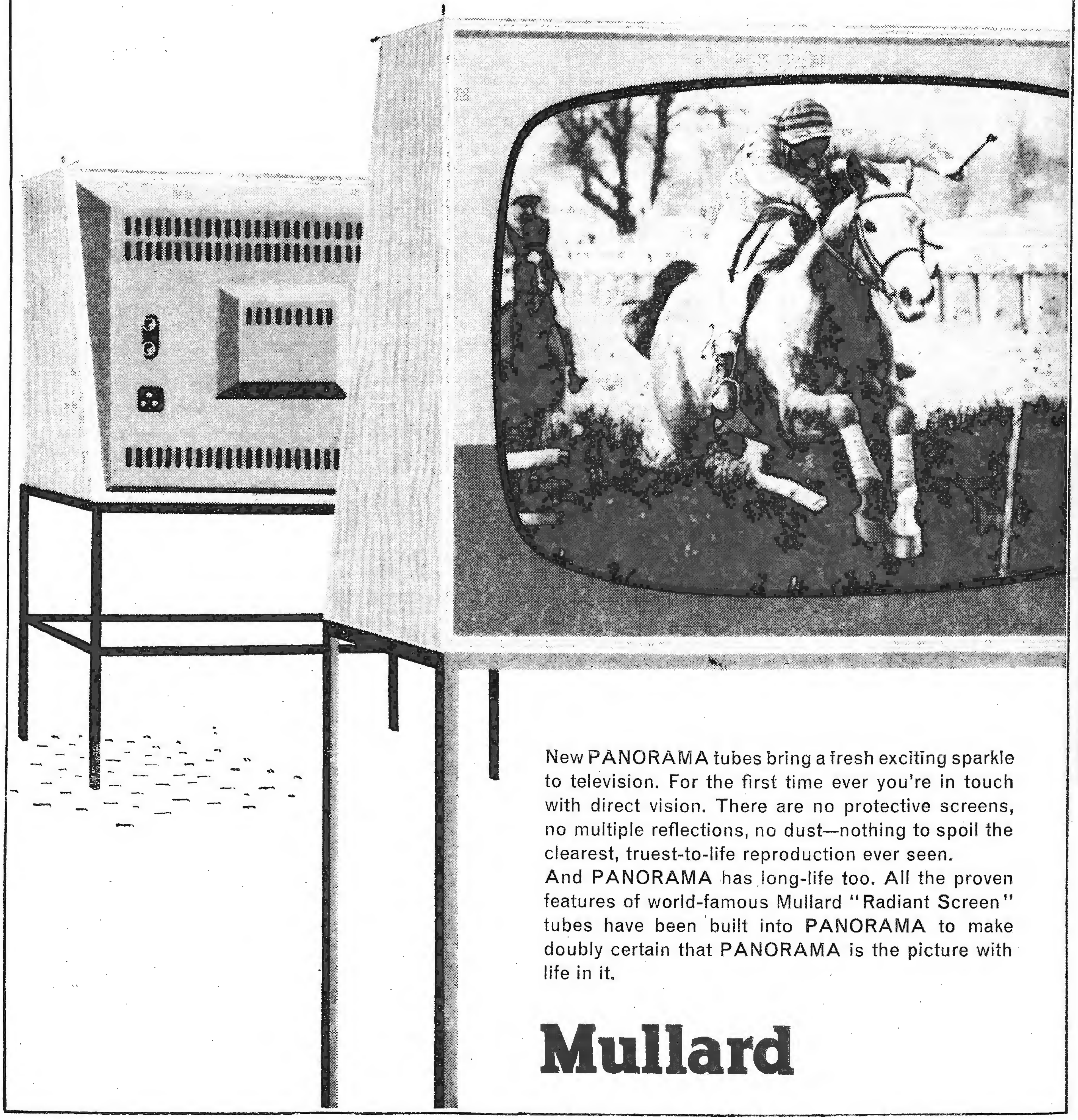
FIFTY-FIFTH YEAR
OF PUBLICATION

Wireless World

ELECTRONICS, TELEVISION, RADIO, AUDIO

JULY 1965

PUBLISHED MONTHLY (4th Monday of preceding month). *Telephone:* Waterloo 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:* King Edward House, New Street, 2. *Telephone:* Midland 7191. *BRISTOL:* 11, Marsh Street, 1. *Telephone:* Bristol 21491/2. *COVENTRY:* 8-10, Corporation Street. *Telephone:* Coventry 25210. *GLASGOW:* 123, Hope Steet, C.2. *Telephone:* Central 1265-6. *MANCHESTER:* 620, Deansgate, 3. *Telephone:* Blackfriars 4412. NEW YORK OFFICE U.S.A.: 111 Broadway, 6. *Telephone:* Digby 9-1197.



Wireless World

ELECTRONICS, TELEVISION, RADIO, AUDIO

The Industry and the Show

"WHY is it that British manufacturers cannot stage a radio show?" This question has been prompted by the announcement from International Trade Fairs that the "65 Show" proposed for the autumn will not now take place. Comparisons were immediately drawn with the successful shows of the German radio industry and with the international shows staged in Paris.

The failure of the Show to get off the ground was certainly not for the want of effort on the part of the organizers who took over the task from the industry's own exhibition company—Radio Industry Exhibitions Ltd. The real problem was lack of support from the members of the industry. Three of the major companies—Thorn, G.E.C. and Philips, which together account for thirteen brand names—announced that they would hold independent trade shows and would not be participating in the Show. A dozen or so overseas manufacturers had promised to participate and many others had shown interest in the project but only two or three British companies promised support.

Some feel that British manufacturers are afraid of overseas competition and therefore do not wish to encourage imports by participating in this the first international show. Others suggest that because the radio industry is in something of a trough at the moment manufacturers cannot afford the expense of exhibiting. Both may be right in part but it is possible that the root cause of the failure of the British radio industry to put on a show comparable with the Continental counterparts is the fact that in this country there is no one organization, as in Germany and France, to co-ordinate the efforts of the *whole* industry. In France, the associations for the various sections of the industry—components, receivers, valves and semiconductors, audio equipment and professional radio and electronic equipment—are co-ordinated by the Federation Nationale des Industries Electroniques (F.N.I.E.). Similarly in Germany the Verband Deutscher Elektrotechniker (V.D.E.) is the whole industry's co-ordinator. This cannot be said of the U.K. Each association appears to be intent on maintaining its influence in its own particular sphere of activity and the Radio Industry Council lacks either the power or the necessary authority to act as a co-ordinating body.

To revert to the question of foreign competition. It is recorded in the annual report of the British Radio Equipment Manufacturers' Association that U.K. production of domestic receivers has declined during the last three years "and it is a matter of grave concern to the industry that in an expanding market the U.K.-produced element continues to diminish in the face of low-cost competition from Hong Kong and Japan. Radio receiver imports, which, it is estimated, already account for about 50 per cent of the total home market numerically and about 20 per cent by value, will almost certainly increase both in volume and range and it is the view of the Association that they constitute a major threat to the future viability of the industry." It would seem, however, that the life blood of some B.R.E.M.A. members is actually being maintained by a "transfusion" from the source of this so-called threat as several of them are now importing complete sets and marketing them under their own trade names. Maybe their motto is: "If you can't beat 'em, join 'em."

VOL 71 NO 7
JULY 1965

Silicon Transistor Tape Recorder

1. DESIGN CONSIDERATIONS

By D. L. GRUNDY* and J. COLLINS*

For use with Collaro Studio or Wearite 4B tape deck ■ 7W low-distortion playback power amplifier, 20 c/s—20 kc/s ■ recording level indicator ■ good regulation power supply ■ silicon semiconductors throughout ease temperature compensation ■ unit construction

IN the past, a considerable amount of information has been published on the design of high quality transistor audio amplifiers. A high quality transistor tape recorder is perhaps a natural sequel. This two-part article outlines the design of such a recorder developed by the authors.

Silicon transistors have been employed throughout. They offer the outstanding advantages of indefinite life and elimination of the need for temperature compensation, and permit a flexibility of design not always possible with their germanium counterparts.

Regarding the choice of passive components in the circuits, the playback and record amplifiers have been so designed that they do not contain any unwieldy, inconvenient inductive components in the form of chokes or transformers. It is the authors' opinion and experience that the disadvantages associated with such components in audio circuits far outweigh their advantages, which in the majority of cases are merely superficial. An exception is the erase/bias oscillator, where large amplitude oscillations have to be derived from a relatively low supply voltage, and which therefore necessitates a transformer. The alternative method would be an RC oscillator and power amplifier fed from a high supply voltage. This has been discarded at present because of the lack of availability of an inexpensive transistor with a sufficiently high breakdown voltage.

The electronic circuitry, i.e. high-gain amplifiers, erase/bias oscillator, and record level indicator, has been designed for use with a Collaro Studio tape deck, record/playback head type C1, and erase head type CE1. Every effort, however, has been made in the design to accommodate other manufacturers' decks with the minimum amount of modification. This has been accomplished by presenting the record/playback head with a high input impedance (100 kΩ) on playback, so that the frequency

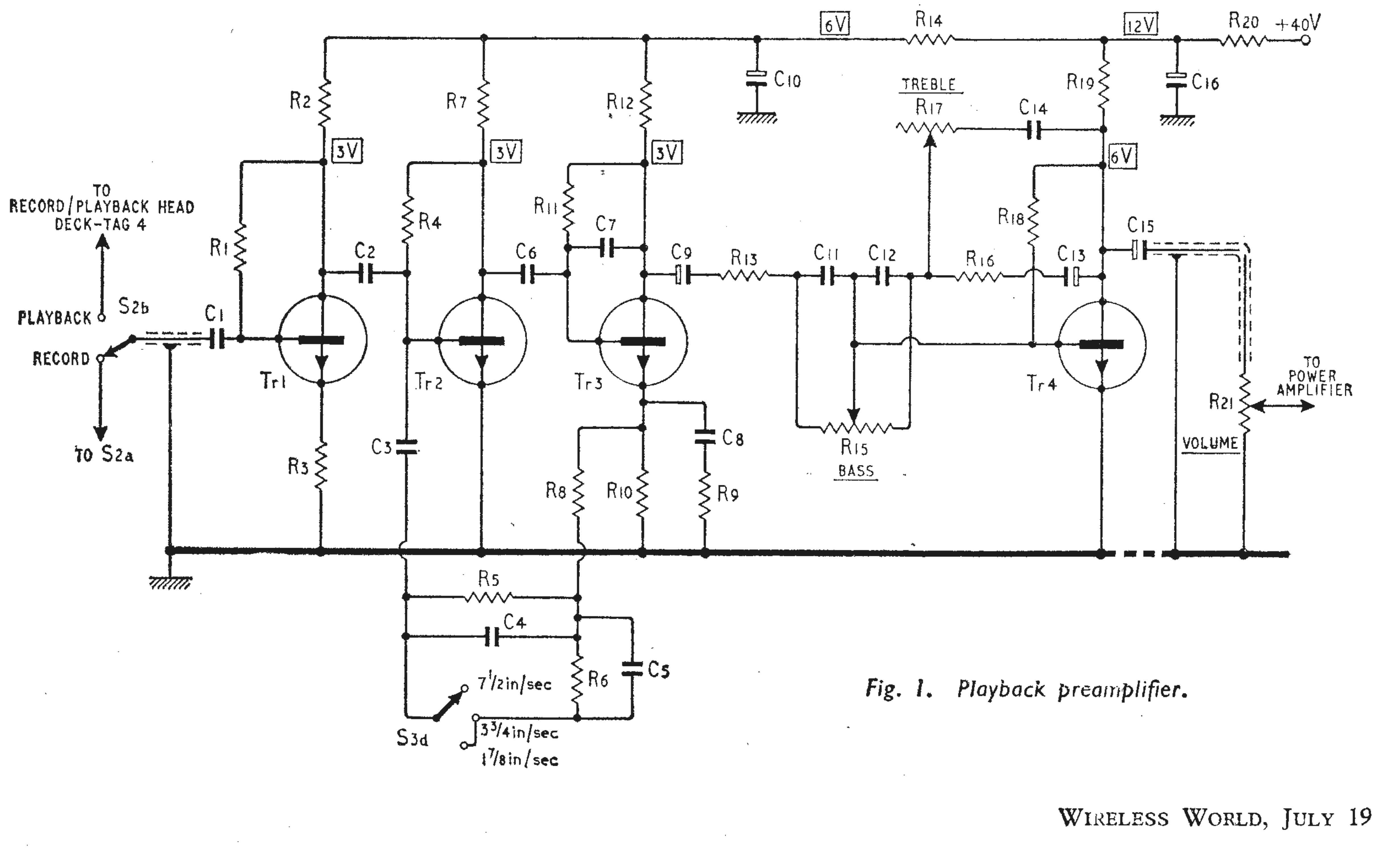


Fig. 1. Playback preamplifier.

---

*Applications Laboratory, Ferranti Ltd.

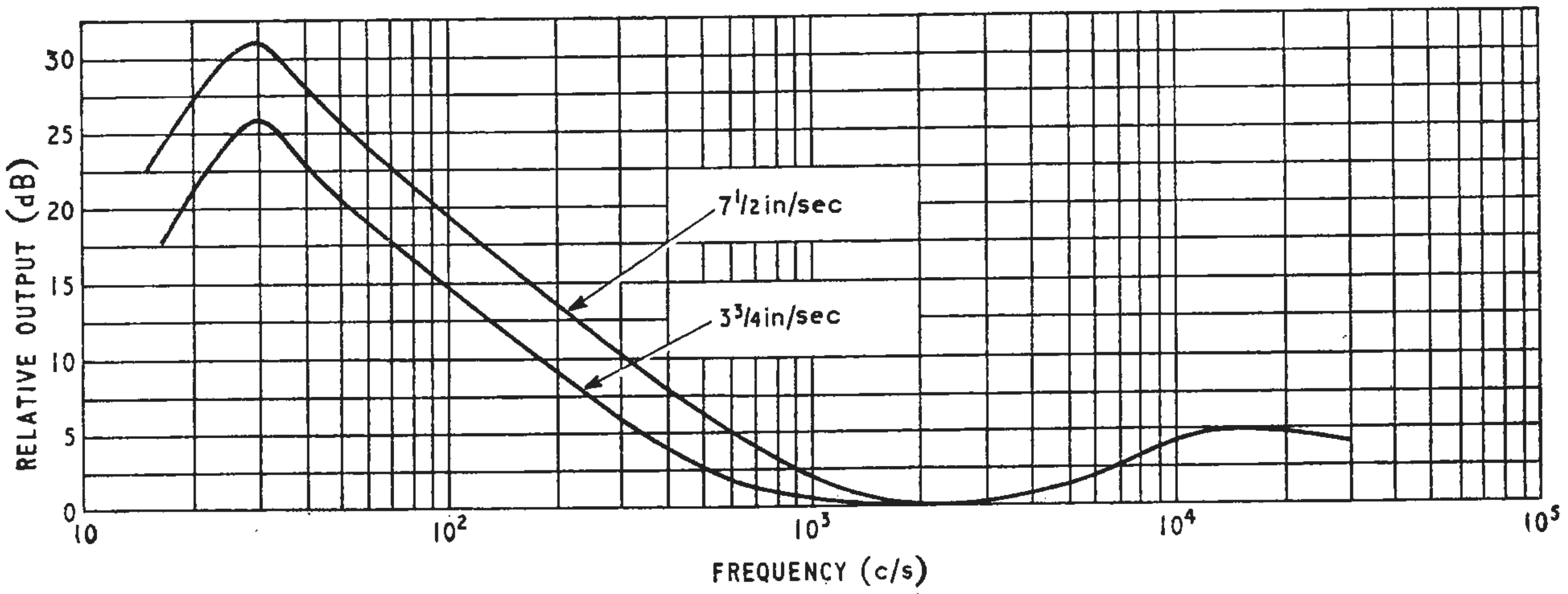


Fig. 2. Playback preamplifier amplitude-frequency response.

response of the playback preamplifier throughout the audio range is unaffected by the source inductance. For recording the head is fed from a high series resistance (180kΩ), which effectively constitutes a constant current source. The value of this resistance may be adjusted accordingly to supply most medium to high impedance heads with sufficient signal current to fully saturate the tape.

The playback and recording systems may be subdivided as follows:—

Playback System

(i) A 4-stage equalized preamplifier including tone controls.
(ii) A series-type 7W transformerless power amplifier.

Recording System

(i) A 4-stage equalized high-gain amplifier, with microphone and radio inputs.
(ii) A recording level indicator.
(iii) A push-pull oscillator performing both functions of erase and bias.

A high-stability power pack provides the necessary supply.

PLAYBACK SYSTEM

(i) Playback Preamplifier

This is shown in Fig. 1. Tr1 and Tr2 are low noise, high gain silicon planar transistors. Compatible with low noise requirements, Tr1 is run at a low quiescent emitter current of 50 μA, and has an input impedance of approximately 100kΩ which ensures that the break frequency associated with the input impedance and record/playback head inductance (600mH at 1 kc/s) is outside the audio range. Sufficient emitter degeneration is contained in the stage for a low total harmonic distortion content.

Equalization.—The fully equalized playback response for tape speeds of 7½ in/sec and 3¾ in/sec is shown in Fig. 2. Bass equalization is accomplished by frequency-selective negative current feedback from the emitter of Tr3 to the base of Tr2. At low frequencies negative feedback is reduced and a controlled amount of positive feedback is developed due to phase-shift introduced by coupling capacitors C_2 and C_6. At 7½ in/sec this gives a corresponding fall in response with frequency very nearly equivalent to a combination of series capacitor and resistor having a time constant of 75 μs and turnover frequency at 3 kc/s. The response is within 1 dB of the recommended C.C.I.R. test tape. A 150 μs time constant has been adopted for 3¾ in/sec giving a turnover between 1 kc/s and 2 kc/s. The combined effect of positive and negative feedback produces a desirable rapid rate of attenuation below 30 c/s.

In order to compensate for head losses at high frequencies it is necessary for some degree of treble lift to be applied. This has been accomplished by the network C_8, R_9 and R_{10}, in the emitter of Tr3 which provides about 6 dB of lift up to 15 kc/s, after which high frequency roll-off commences due to C_7. The same fixed amount of lift is employed for both 7½ in/sec and 3¾ in/sec.

Tone controls.—These are of the continuously variable type allowing independent control of bass and treble and situated in a feedback loop from collector to base of Tr4. The bass control, R_{15}, will provide 10-12 dB of boost and cut (at 50 c/s relative to 1 kc/s) from the flat position to the extremities of the potentiometer. R_{17} is a treble cut giving a 14 dB variation from 1 kc/s to 10 kc/s. The mid-frequency gain will be affected ±1 dB by each control, interaction between the two being negligible. Tr4 provides the necessary amplification to raise the signal to the input level of the power amplifier.

Noise and signal handling capacity.—The volume control has been situated at the preamplifier output to maintain a constant signal-to-noise ratio for all settings. This also fulfils the condition that with the control set to minimum the overall system noise is inaudible. Care has been taken throughout to ensure that the signal levels presented to each stage input are large enough not to impair the general signal-to-noise ratio (50 dB), which will be determined principally by first stage noise.

To accommodate variations in the tape-head output due to different levels in recording it is necessary that the preamplifier is capable of withstanding some degree of overload on its normal sensitivity of 1.5 mV r.m.s., without the introduction of severe harmonic distortion. This imposes a problem on the restricted signal handling capacity of Tr1 due to its very low quiescent current. Emitter degeneration, however enables it to accept an input signal overload of 4:1 resulting in a 0.3% increase in harmonic distortion content.

Stability.—The preamplifier would normally require a 12 V supply and have a current consumption of approximately 8 mA, making it ideally suitable for battery use. It is perhaps more convenient to take the supply from the positive rail of the power supply as shown, in which case adequate decoupling must be employed especially because of the large amount of bass lift present in the circuit.

(ii) Main Amplifier

This features a series-type transformerless class B amplifier capable of delivering 7W into a 15Ω resistive load from 20 c/s to 20 kc/s with an average overall efficiency of 60%. It is therefore suitable for use with most types of 15Ω loudspeakers. RC coupling has been employed throughout, in preference to direct coupling, to minimize drift and facilitate the setting up procedure while still preserving the lower audio frequencies. Silicon transistors hold distinct advantages over their germanium counterparts in power stages in that they are inherently capable of operating at higher ambient temperatures, and their low leakage makes temperature compensation almost unnecessary. Provided suitable biasing is employed therefore, at high audio frequencies problems like drift and thermal runaway are less likely to occur. The frequency response of silicon power transistors is also very often superior.

The output stage is basically asymmetrical, Tr10 is connected as an emitter follower and Tr11 is in common-emitter configuration. The drivers, Tr8 and Tr9, are both emitter followers. Asymmetrical drive conditions are therefore required for upper and lower halves, and the split-load phase inverter is ideally suited for this purpose. Positive bootstrap feedback, developed across R_{31} *via* C_{23}, is necessary to equalize the power gains of the two halves so that the maximum voltage swing across the loudspeaker load is attained. The presence of diodes D_1 and D_2 assists in providing a stable bias source for the drivers which being directly coupled to the output stage produces a standing current between 10 and 20mA in the output transistors for the elimination of crossover distortion. Harmonic distortion is minimized and the high frequency response enhanced

LIST OF COMPONENTS

Resistors

R_1	2.2MΩ
R_2	56kΩ
R_3	2.2kΩ
R_4	2.7MΩ
R_5	560kΩ
R_6	560kΩ
R_7	39kΩ
R_8	8.2kΩ
R_9	47Ω
R_{10}	120Ω
R_{11}	100kΩ
R_{12}	1kΩ
R_{13}	390Ω
R_{14}	1.8kΩ
R_{15}	5kΩ*
R_{16}	1.5kΩ
R_{17}	5kΩ*
R_{18}	150kΩ
R_{19}	1.5kΩ
R_{20}	3.9kΩ
R_{21}	5kΩ*
R_{22}	39kΩ
R_{23}	680Ω
R_{24}	10Ω
R_{25}	22kΩ
R_{26}	560Ω
R_{27}	1.5kΩ (1W)
R_{28}	27Ω
R_{29}	15kΩ
R_{30}	1.5kΩ
R_{31}	820Ω
R_{32}	220Ω
R_{33}	220Ω
R_{34}	2.7kΩ
R_{35}	150Ω
R_{36}	100Ω†
R_{37}	2.7kΩ
R_{38}	150Ω
R_{39}	100Ω†
R_{40}	270Ω
R_{41}	56Ω
R_{42}	56Ω
R_{43}	0.5Ω (2W)
R_{44}	0.5Ω (2W)
R_{45}	120kΩ
R_{46}	330kΩ
R_{47}	6.8kΩ
R_{48}	50kΩ*
R_{49}	5.6kΩ
R_{50}	6.8kΩ
R_{51}	180kΩ
R_{52}	15kΩ
R_{53}	15kΩ
R_{54}	2.7kΩ
R_{55}	3.9kΩ
R_{56}	8.2kΩ
R_{57}	330Ω
R_{58}	680kΩ
R_{59}	6.8kΩ
R_{60}	180kΩ
R_{61}	100kΩ
R_{62}	50kΩ*
R_{63}	27kΩ
R_{64}	33kΩ
R_{65}	3.9kΩ
R_{66}	39Ω
R_{67}	330kΩ
R_{68}	3.3kΩ
R_{69}	120kΩ
R_{70}	1kΩ
R_{71}	3.3kΩ
R_{72}	470Ω
R_{73}	680kΩ
R_{74}	22kΩ
R_{75}	680kΩ
R_{76}	22kΩ
R_{77}	1.5kΩ
R_{78}	82kΩ
R_{79}	27kΩ
R_{80}	1kΩ
R_{81}	4.7kΩ
R_{82}	100kΩ*
R_{83}	50Ω (preset)
R_{84}	2.7kΩ
R_{85}	50Ω (preset)
R_{86}	33Ω
R_{87}	25kΩ*
R_{88}	47Ω
R_{89}	2.7kΩ
R_{90}	2.7kΩ
R_{91}	330Ω
R_{92}	200Ω (3W)
R_{93}	2.2kΩ
R_{94}	330Ω
R_{95}	390Ω
R_{96}	5kΩ*
R_{97}	3.3kΩ
R_{98}	150Ω (3W)

Notes:—

All resistors ½ watt ±10% unless otherwise stated.

*Linear carbon types.

†Preset types which may be replaced by fixed resistors after setting up, see text.

Transformers

T_1 Mullard Ferrite core, FX2242.
L_1, L_3, 4 turns 34 s.w.g. (enamel covered).
L_2 15+15 turns 34 s.w.g. (enamel covered)
L_4 45+125 turns 34 s.w.g. (enamel covered)

T_2 Mullard nylon bobbin, DT2012.
Primary: 200 turns 36 s.w.g. (enamel covered), 11Ω, 1mH, centre tapped.
Secondary: 400 turns 36 s.w.g. (enamel covered), 17Ω, 3mH.

T_3 Douglas MT3AT or Gardner TP1002.
Primary: 0-230V, secondary 0-20V.

Capacitors

C_1	0.5μF
C_2	0.04μF
C_3	0.1μF*
C_4	0.02μF
C_5	0.02μF
C_6	0.1μF*
C_7	2200pF
C_8	0.25μF*
C_9	25μF, 12V
C_{10}	100μF, 25V
C_{11}	0.5μF*
C_{12}	0.5μF*
C_{13}	25μF, 12V
C_{14}	0.08μF
C_{15}	25μF, 12V
C_{16}	500μF, 25V
C_{17}	25μF, 12V
C_{18}	470pF
C_{19}	25μF, 25V
C_{20}	25μF, 12V
C_{21}	25μF, 12V
C_{22}	680pF
C_{23}	250μF, 12V
C_{24}	100μF, 12V
C_{25}	100μF, 12V
C_{26}	2000μF, 25V
C_{27}	100μF, 50V
C_{28}	0.1μF
C_{29}	25μF, 12V
C_{30}	1μF
C_{31}	1μF
C_{32}	0.1μF*
C_{33}	680pF
C_{34}	680pF
C_{35}	680pF
C_{36}	680pF
C_{37}	1500pF
C_{38}	1500pF
C_{39}	1μF
C_{40}	100pF
C_{41}	0.1μF*
C_{42}	0.1μF
C_{43}	1μF
C_{44}	1μF
C_{45}	68pF
C_{46}	50μF, 50V
C_{47}	1μF
C_{48}	25μF, 12V
C_{49}	1μF
C_{50}	1μF
C_{51}	100pF
C_{52}	4700pF
C_{53}	0.04μF
C_{54}	0.5μF
C_{55}	3300pF
C_{56}	220pF
C_{57}	220pF
C_{58}	1μF*
C_{59}	0.02μF
C_{60}	0.5μF
C_{61}	0.1μF, 1000V
C_{62}	5000μF, 50V
C_{63}	5000μF, 50V
C_{64}	250μF, 100V
C_{65}	0.01μF
C_{66}	25μF, 25V
C_{67}	50μF, 50V

*Non electrolytic.

Fuses

F_1, F_2	1A fast acting fuse, Belling Lee type L1510.

Semiconductors

D_1—D_9	ZS70, ZR60, ZS700, ZR600, ZDR1*
D_{10}, D_{11}	ZS130, ZS142, ZDR4*
D_{12}, D_{13}	ZR12, ZDR3*
D_{14}	ZS70, ZR60, ZS700, ZR600, ZDR1*
ZD_1	KS44B, ZKS3*
ZD_2	KS36B, ZKS2*
ZD_3	KS33A, ZKS1*
ZD_4	KR54, ZKR2*
Tr_1, Tr_2	ZT1711, ZTR18*
Tr_3—Tr_6	ZT80, ZT81, ZT83, ZTR11*
Tr_7	ZT44, ZT84, ZTR16*
Tr_8, Tr_9	ZT2270, ZT90, ZTR14*
Tr_{10}, Tr_{11}	ZT1701, ZT1483, ZTR13*
Tr_{12}, Tr_{13}	ZT80, ZT81, ZT83, ZTR11*
Tr_{14}, Tr_{15}	ZT44, ZT84, ZTR16*
Tr_{16}	ZT80, ZT81, ZT83, ZTR11*
Tr_{17}—Tr_{20}	ZT81, ZT43, ZT83, ZTR12*
Tr_{21}, Tr_{22}	ZT1701, ZT1483, ZTR13*
Tr_{23}—Tr_{25}	ZT81, ZT43, ZT83, ZTR12*
Tr_{26}	ZT2270, ZT90, ZTR14*
Tr_{27}	ZT1701, ZT1483, ZTR13*

Items marked thus * are included in two semiconductor kits available from Ferranti Ltd. The kits are designated TR100W for the Wearite deck version and TR100C for the Collaro deck version.

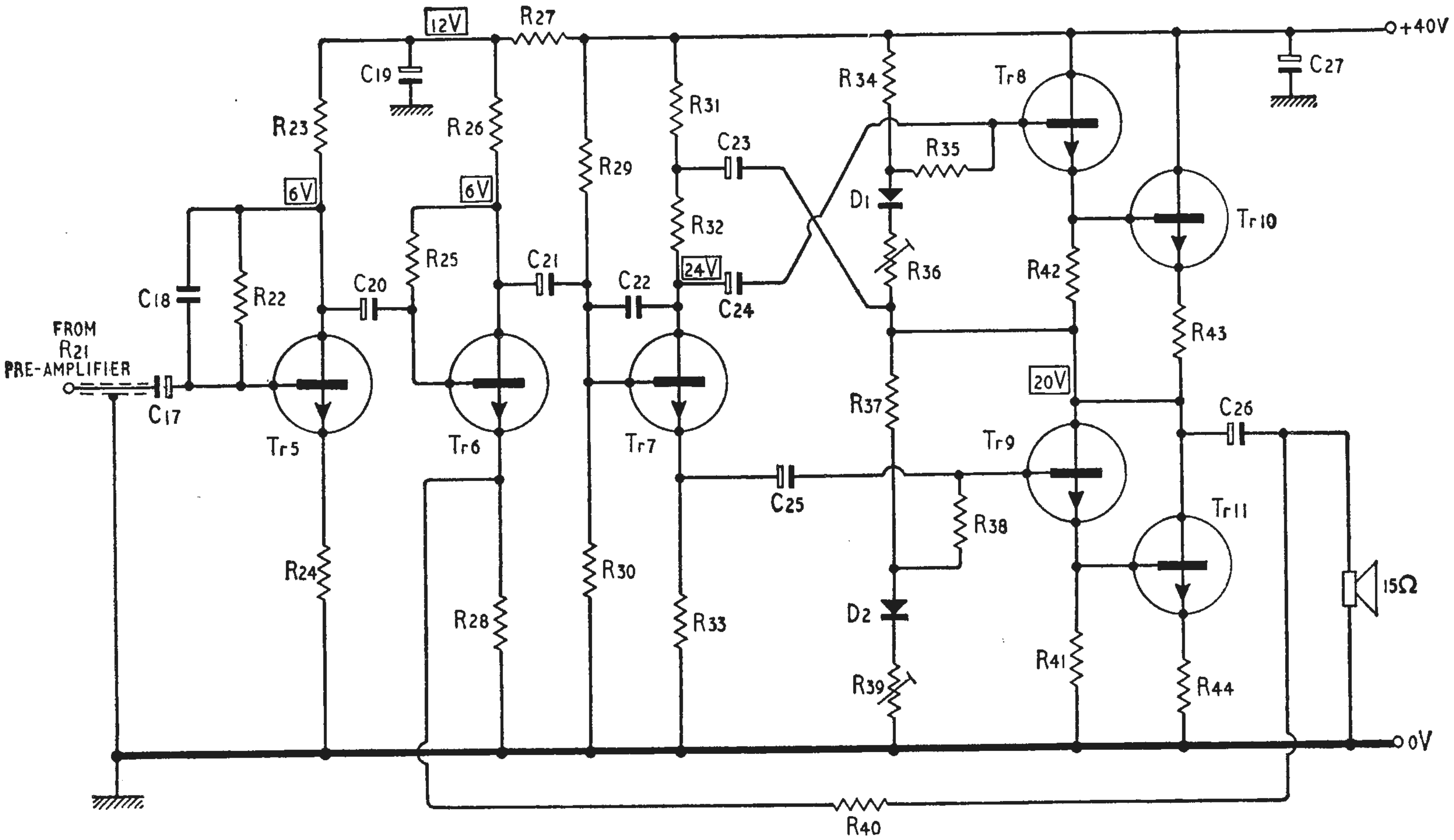


Fig. 3. 7-watt power amplifier. Tr10 and Tr11 are mounted on $2\times2\times\frac{1}{16}$ in copper or aluminium heat sinks insulated from the chassis. Alternatively, the chassis may serve as a heat sink, from which Tr10 and Tr11 are electrically insulated by 0·002in mica washers.

by feeding the output stage from the low output impedance of the emitter follower drivers.

Voltage feedback is taken from the loudspeaker to the emitter of Tr6. Tr5 and Tr6 are conventional common-emitter stages employing local feedback from collector to base and also emitter degeneration.

To accommodate output transistor spreads the resistors R_{36} and R_{39} must necessarily be preset types, and the amplifier will depend for correct operation on their settings. These perform the functions of (1) controlling the standing current for elimination of crossover distortion, and (2) allowing the maximum voltage swing across the loudspeaker load to be attained. When optimally adjusted their values may be determined and they can be replaced by fixed resistors, the value being about 82Ω for typical transistors.

While the use of an oscilloscope and signal generator would be an advantage, a simple d.c. check ensures that the two conditions are satisfied and can produce near optimum results. With an Avometer inserted in the 40 V rail (100 mA range) the preset controls should be increased in turn from minimum until the Avometer reads 70 mA. At the same time it is necessary to check that the d.c. collector voltage of Tr11 remains at approximately one half of the supply voltage, i.e., 20 ± 1V. The second check ensures that condition (2) is fulfilled and that the standby dissipation of the output transistors is the same.

Main Amplifier Specification

Supply voltage 40 V (stabilized).
Nominal input impedance 1 kΩ.
Nominal output impedance < 1Ω.
Nominal input sensitivity 20 mV r.m.s.
Power output 7 W (20 c/s to 20 kc/s) into a 15Ω resistive load.
Total harmonic distortion typically 0·25% at 1 kc/s.
Bandwidth (with C_{18} and C_{22} removed) 1 Mc/s at 1 W output.

RECORDING SYSTEM

(1) Recording Amplifier

The recording amplifier includes the necessary stages of amplification for low and high level inputs, equalization

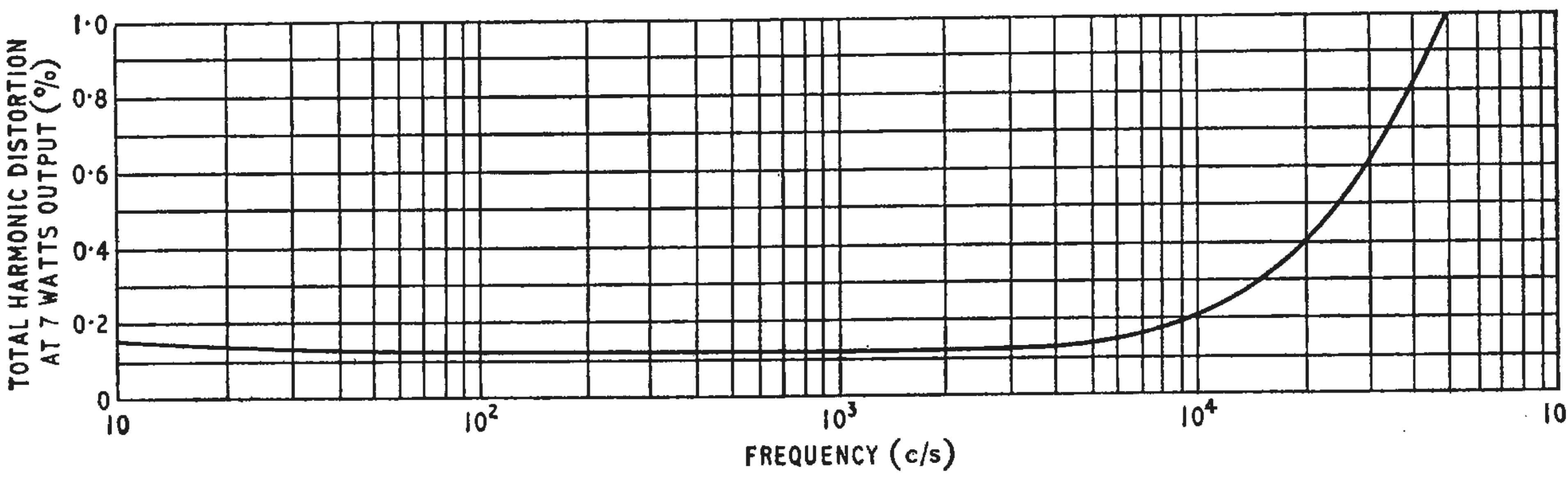


Fig. 4. Power amplifier harmonic distortion.

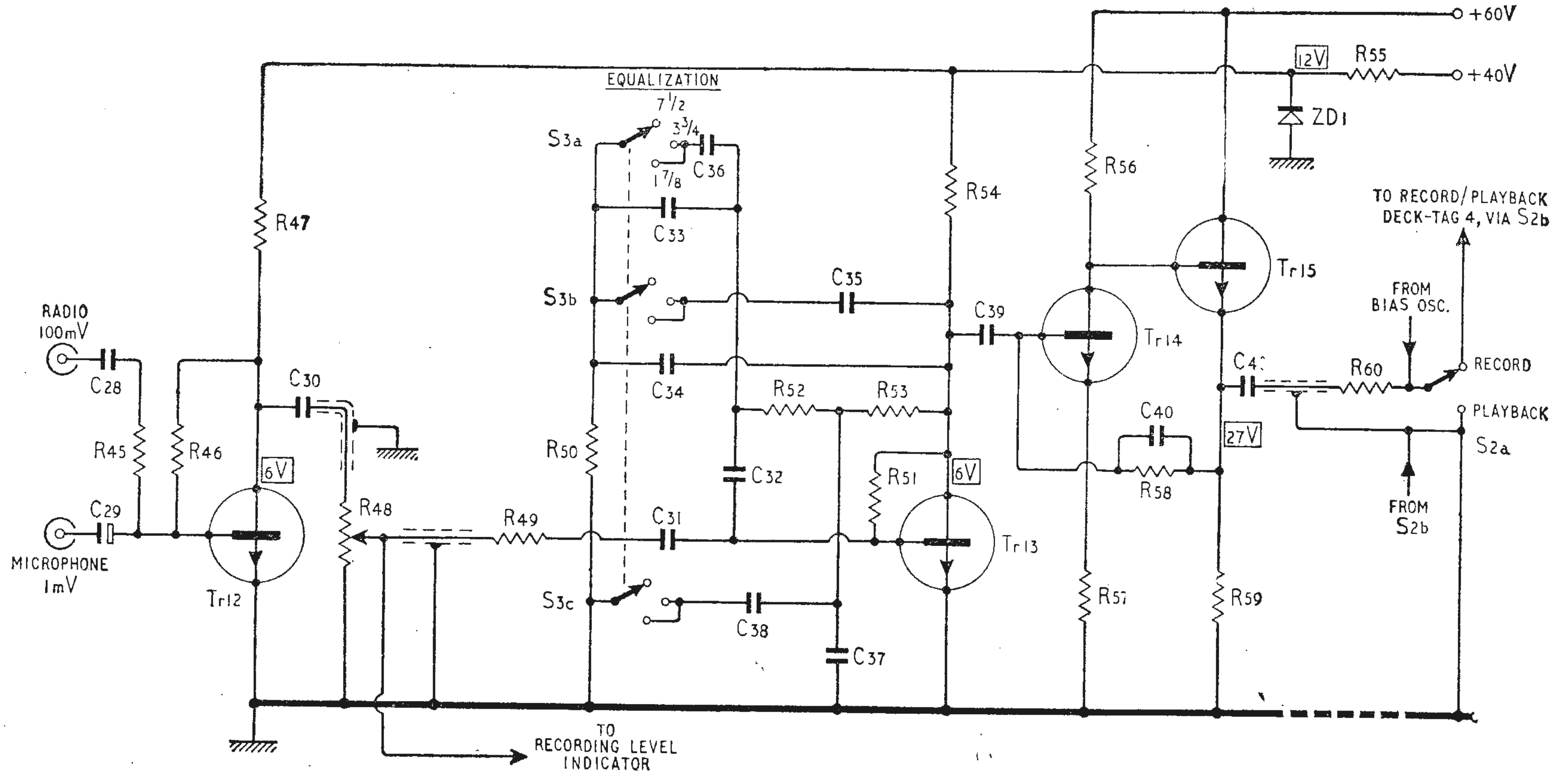


Fig. 5. Recording amplifier circuit.

and also an output stage to feed the recording head.

The output stage must be capable of feeding the recording head with a constant recording current at all audio frequencies and include some provision for isolating the bias voltage from the amplifier output otherwise severe clipping would result.

In conventional circuits a popular method is to use a step-up transformer in a single-ended output stage, enabling a large output swing to be attained. Inserting a high value series or swamp resistance at the amplifier output then ensures that the head is fed from a constant-current source. To reject the bias voltage a filter in the form of a tuned parallel LC circuit or parallel-T RC network is sometimes included before the record head. Whether the filter is necessary or not really depends on the amplifier output impedance since with a low output impedance the bias voltage could already be sufficiently attenuated through the swamp resistance.

In the adopted method, which avoids a transformer, the large output swing is obtained by running the output stage from a high supply voltage. Sufficient local negative feedback applied from the emitter of Tr15 to the base of Tr14 preserves a high degree of linearity in spite of the large dynamic excursions.

Since Tr15 is an emitter follower encompassed by a feedback loop, the amplifier output impedance will be very low and will decrease with increasing frequency because of the shunting effect of C_{10}. At the oscillator frequency (55 kc/s) it is approximately 50Ω. An additional bias rejection filter is therefore unnecessary since the bias voltage will automatically be attenuated by a factor of 3000:1, i.e. the ratio of the swamp resistance to the amplifier output impedance.

If the transformer is to be avoided then a capacitor (C_{11}) must be used to couple the output stage to the recording head. It is essential that this component is a non-electrolytic type, having negligible leakage and so prevent any d.c. magnetization of the recording head.

Equalization.—This is accomplished by a parallel-T

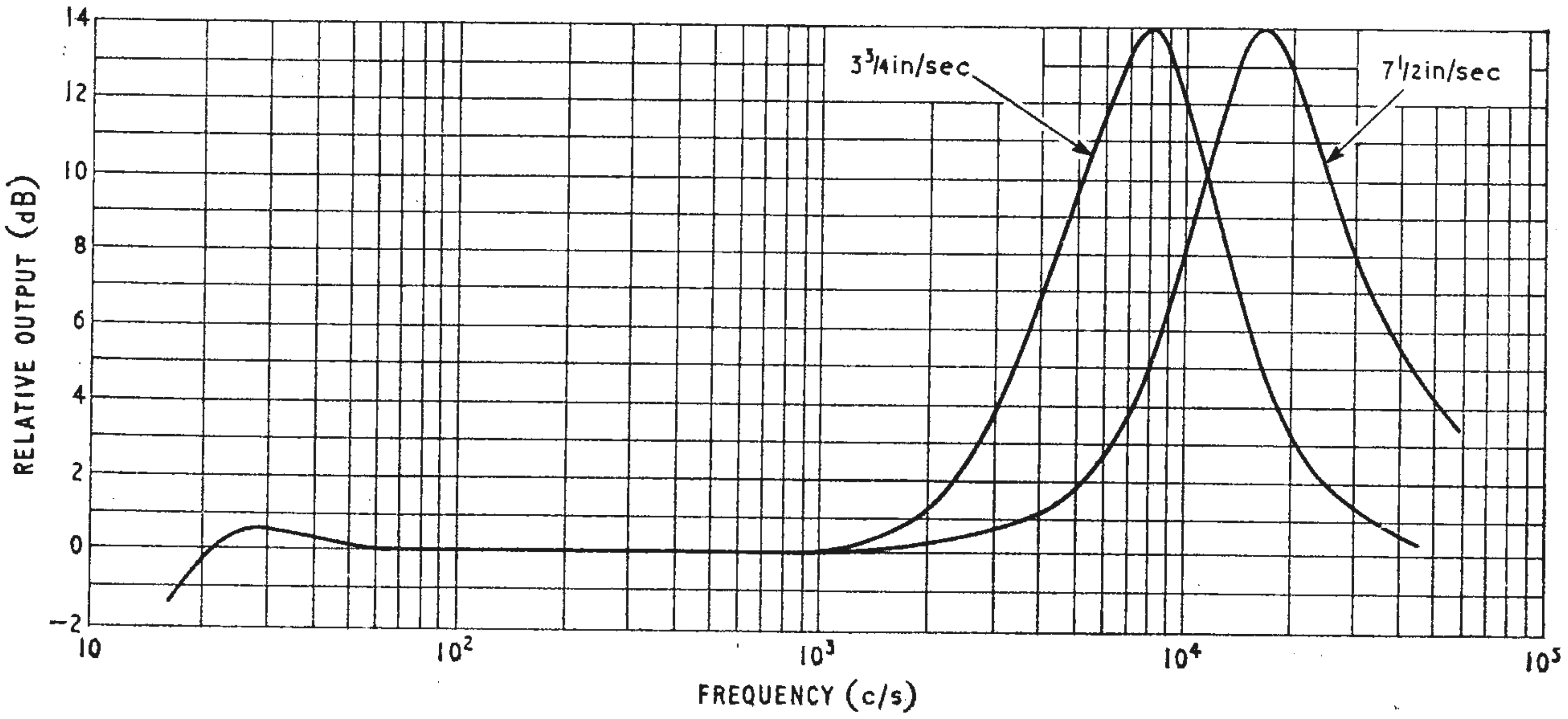


Fig. 6. Record amplifier amplitude-frequency response.

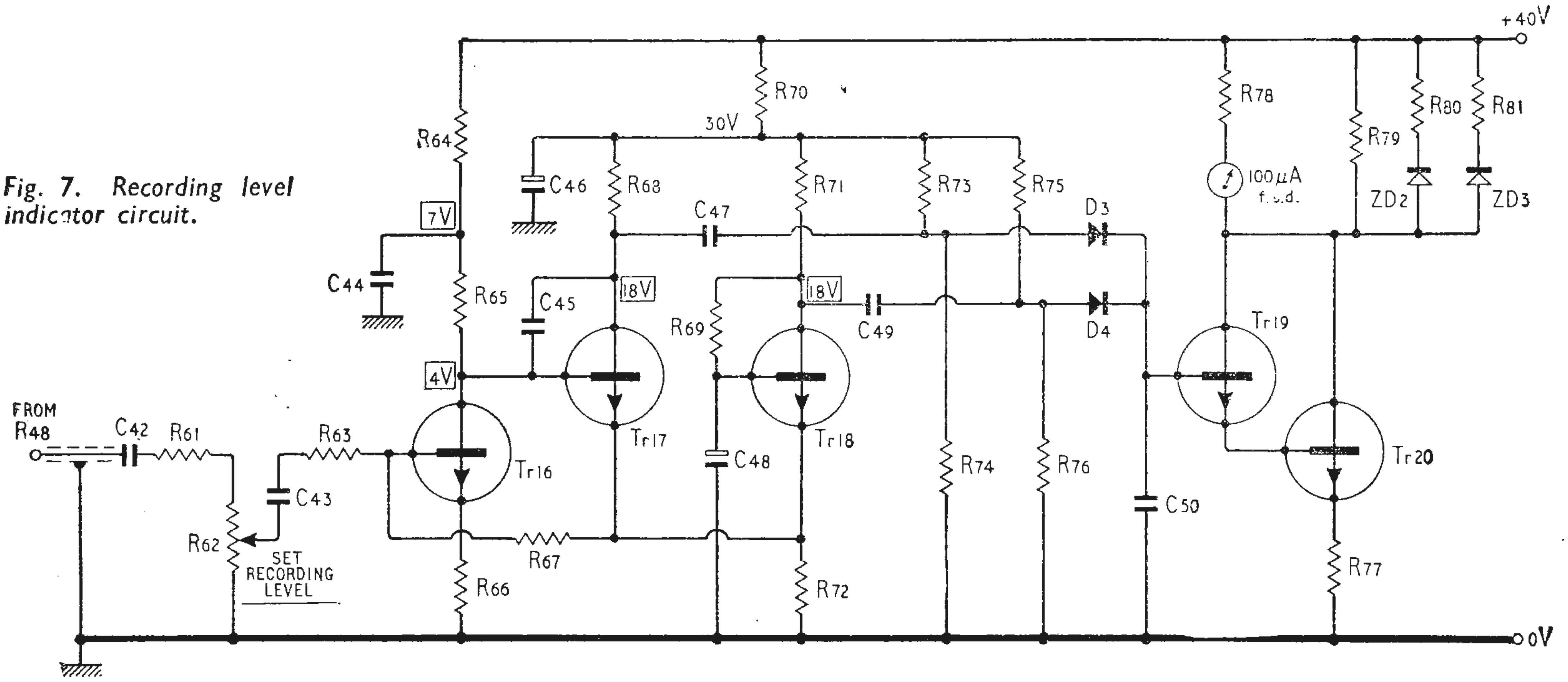


Fig. 7. Recording level indicator circuit.

RC network in a feedback path from collector to base of Tr13. It provides treble lift to compensate for head losses above 1 kc/s (see Fig. 6). Approximately 14dB of lift is required at 16 kc/s (relative to 1 kc/s) for a tape speed of 7½ in/sec while the same amount of lift is required at 8 kc/s for 3¾ in/sec. The frequency of the peaked response is accordingly altered by switching each arm capacitance of the parallel-T network.

Tr12 is run at a quiescent current of 1 mA, and has an input impedance of 1 kΩ. It is intended for use with a low-medium impedance dynamic or ribbon microphone. Input sensitivities are 1 mV r.m.s. for microphone and 100 mV for radio, corresponding signal-to-noise ratios being 70dB and 60dB respectively.

(ii) Recording Level Indicator

A recording level indicator should essentially be a peak registering type because music has a large peak-to-mean ratio. To sensibly accomplish this, the indicator should have a fast attack time and slow decay time, and preferably follow a logarithmic law. Fig. 7 shows such an indicator.

The signal at the base of Tr16 is amplified and fed directly into the base of Tr17, where Tr17 and Tr18 are a differential pair. The differential output is rectified by diodes D_3 and D_4 so that a change in d.c. level at the base of Tr19 produces a collector current variation in Tr20 which is directly proportional to the amplitude of the audio input.

The instrument attack time is determined by C_{50} and R_{71} and is approximately 20ms. Its decay time is determined by C_{50} and the input impedance of the compound emitter follower Tr19 and Tr20 and is approximately 1.5 seconds.

The reference diodes ZD_2 and ZD_3 in the collector of Tr5 form a non-linear network so that a logarithmic relationship is obtained between the meter current and the applied input signal. This relationship is such that for a meter scale of 10 divisions each division corresponds to an input differential of 6dB.

A slight forward bias is applied to diode D_3 and D_4 *via* resistive chains R_{72}, R_{73}, R_{74} and R_{75}, to prevent non-linearity being introduced by their forward characteristics. This will give rise to an initial no-signal reading on the meter of 1μA.

Peak recording level.—This is a level chosen so that the amount of distortion introduced due to the non-linearity of the tape B-H curve is about 2%. With the Collaro record/playback head type C1 at optimum h.f. bias current this condition corresponds to a recording current of 50μA r.m.s.

To monitor this current a 50Ω resistor is inserted in the earthed lead of the recording head. A 1 kc/s signal source is then injected into the radio input of the recording amplifier and the voltage across the resistor measured with a valve voltmeter or oscilloscope.

The potentiometer R_{62} may then be adjusted so that peak recording level may be set at any desired point on the meter scale. About two-thirds full scale deflection is usually most convenient.

(iii) Erase/Bias Oscillator

Fig. 8 shows a push-pull 55kc/s oscillator which provides erase and bias signals. Second harmonic distortion

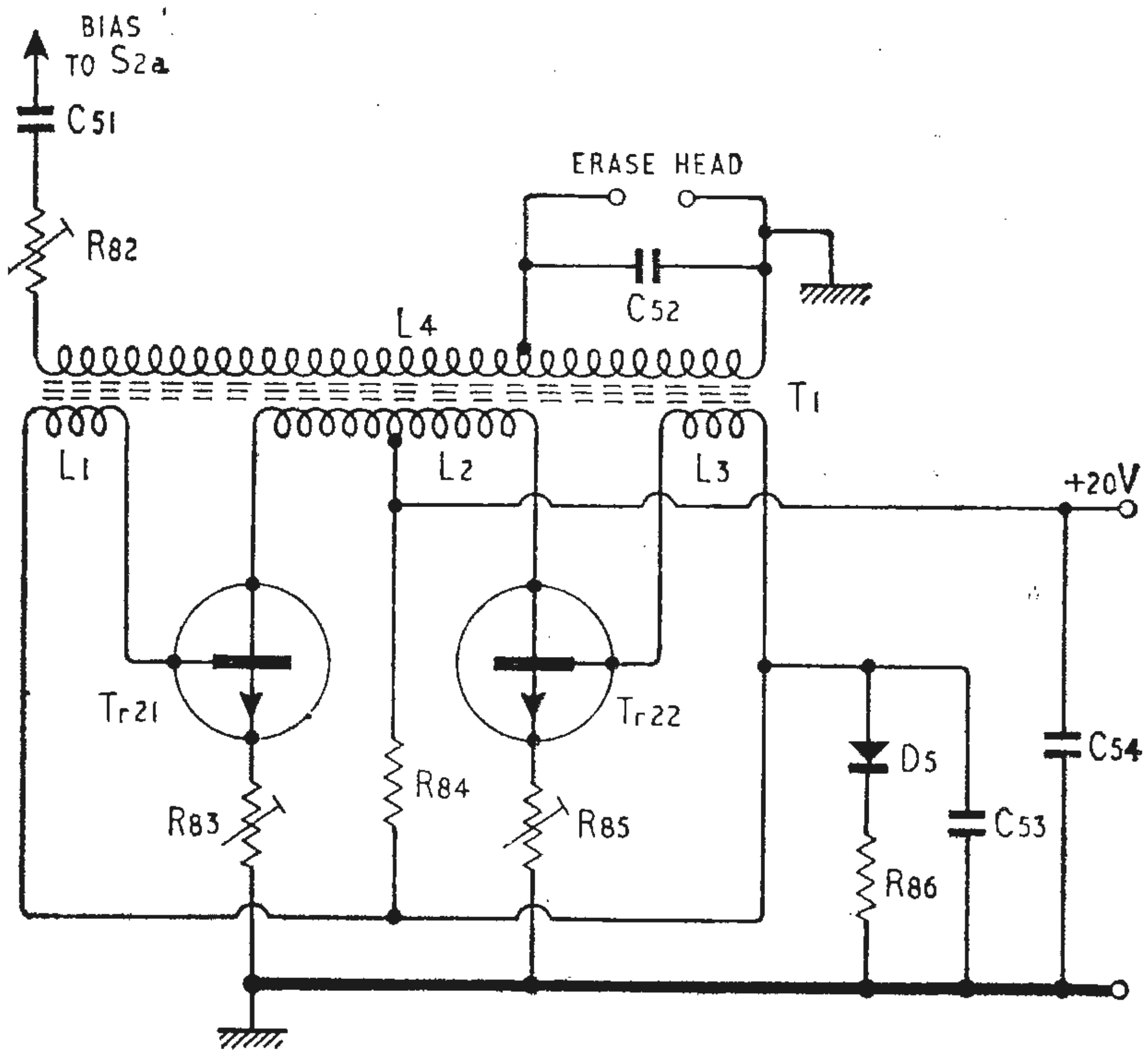


Fig. 8. Erase and bias oscillator designed for Collaro Studio tape deck.

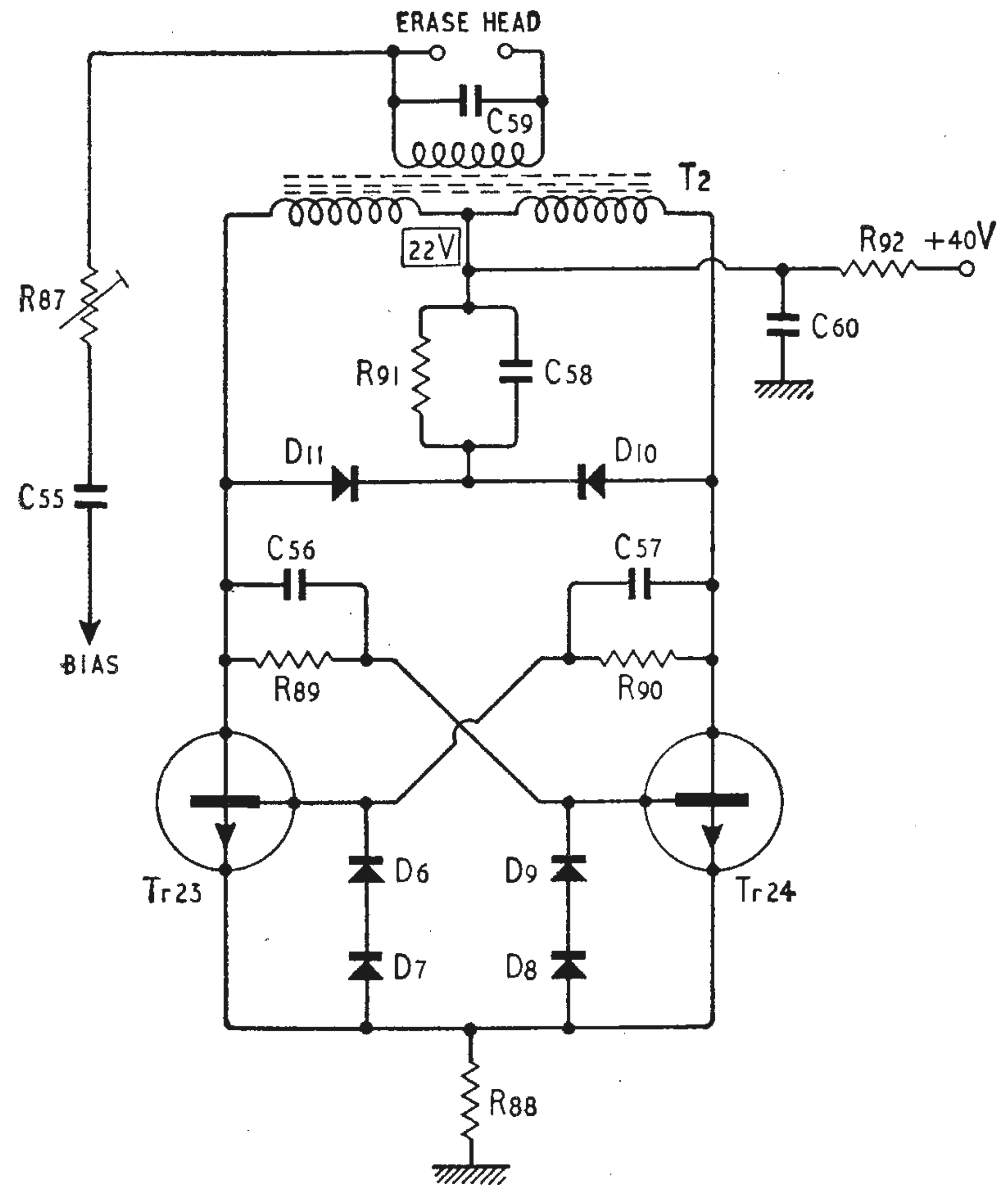


Fig. 9. Class D oscillator designed for use with Wearite deck, model 4B.

content is low (<1% of the rated output) due to the symmetrical drive arrangement which tends to cancel even harmonic distortion. This is particularly important since the presence of even harmonics will increase the noise level on the tape. The generated waveform should therefore be as pure as possible.

Initial warm-up effects are compensated by the network D_5, R_{86}, C_{53} which maintains high amplitude stability so that the h.f. bias level does not vary significantly. The frequency of oscillation is determined by the tuning capacitor C_{52} directly across the erase head. At this frequency the erase voltage is approximately 28 V r.m.s. and the bias voltage which is controlled by the preset resistor R_{82} is variable between 40 and 60 V r.m.s.

The preset resistors R_{83} and R_{85} exercise considerable influence over the generated waveform and should be set for the best waveform attainable, after which they may be replaced conveniently by fixed resistors. In the author's case the value of the resistors 18Ω. The dissipation in transistors Tr21 and Tr22 is such that heat sinks are unnecessary.

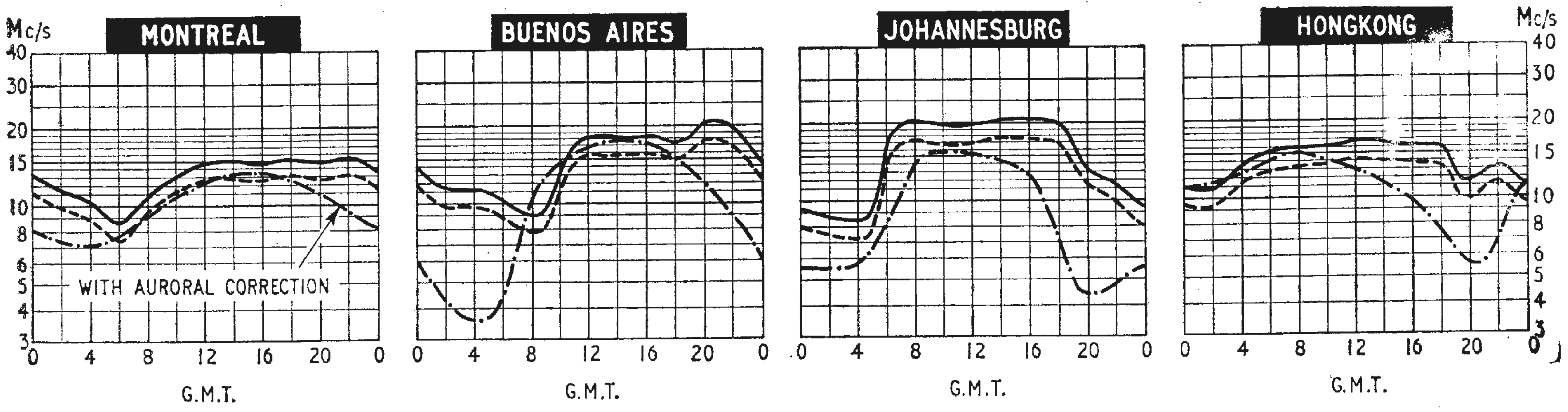
The decoupling capacitor C_{54} helps to produce a decaying ultrasonic voltage when switching off the supply which substantially demagnetizes the head.

At this stage it is worth mentioning a highly efficient class D oscillator which was designed for use with the Wearite tape deck model 4B. Very briefly the circuit (Fig. 9) behaves like an inverter with a tuned secondary winding, and relies on rapid switching action so that square waves appear at the transistor collectors. The harmonics are filtered out by the tuned circuit leaving a sine wave of fundamental frequency 56 kc/s. Approximately 30 V r.m.s. is developed across the erase head.

Square-wave operation ensures that transistor dissipation is reduced to a minimum, enabling small signal general-purpose types to be used.

To be concluded. Details of the power supply, constructional notes and a wiring diagram of the complete system will be published next month.

H. F. PREDICTIONS — JULY



The prediction curves show the median standard MUF, optimum traffic frequency and the lowest usable frequency (LUF) for reception in this country. Unlike the standard MUF, the LUF is closely dependent upon such factors as transmitter power, aerials, and the type of modulation. The LUF curves shown are those drawn by Cable and Wireless Ltd. for commercial telegraphy and assume the use of transmitter power of several kilowatts and aerials of the rhombic type.

Conditions this month should differ very little from those experienced in July 1963, as the ionospheric index is almost the same for the two months.

As is usual near to sunspot minimum it may well be found that frequencies considerably above the MUF can sometimes be received. This is particularly true during daytime in the summer months and for circuits to the Far East.

Integrated Electronic Circuits

A SHORT GUIDE FOR POTENTIAL USERS

By S. FORTE,* Ph.D., B.Sc., A.M.I.E.E.

INTEGRATED electronics is a radically new concept of electronic design and a revolution in the traditional methods of manufacture of future electronic equipment. This new technology permits the design and fabrication of electronic circuits in solid pieces of material the size of a pinhead. The electronic engineer of tomorrow will not manipulate selections of discrete resistors, capacitors, diodes and transistors to achieve a required function: rather he will have the much more fundamental task of manipulating the movement of electrons and holes in a microscopic piece of semiconductor material to achieve the same purpose. The ideal of a molecular block with no recognizable circuit elements is illustrated by an analogous device in everyday use—the quartz resonator, which exhibits the properties of a resonant circuit while having no identifiable inductance or capacitance. Although we are not yet at the stage when an electronic function can be defined purely in terms of molecular action without any reference to a circuit as such, enormous strides have been made in this direction. In semiconductor integrated circuits, for example, complex electronic circuits are formed on a single piece of semiconductor material 0.050 inch square, and although identifiable circuit components still exist they are in a completely new form.

To the newcomer to the integrated electronics art there always appear to be two highly competitive and quite distinct technologies, leading to two quite distinct products. This impression is strengthened by the endless controversy which exists between the supporters of the two techniques—thin film techniques on the one hand and semiconductor techniques on the other.

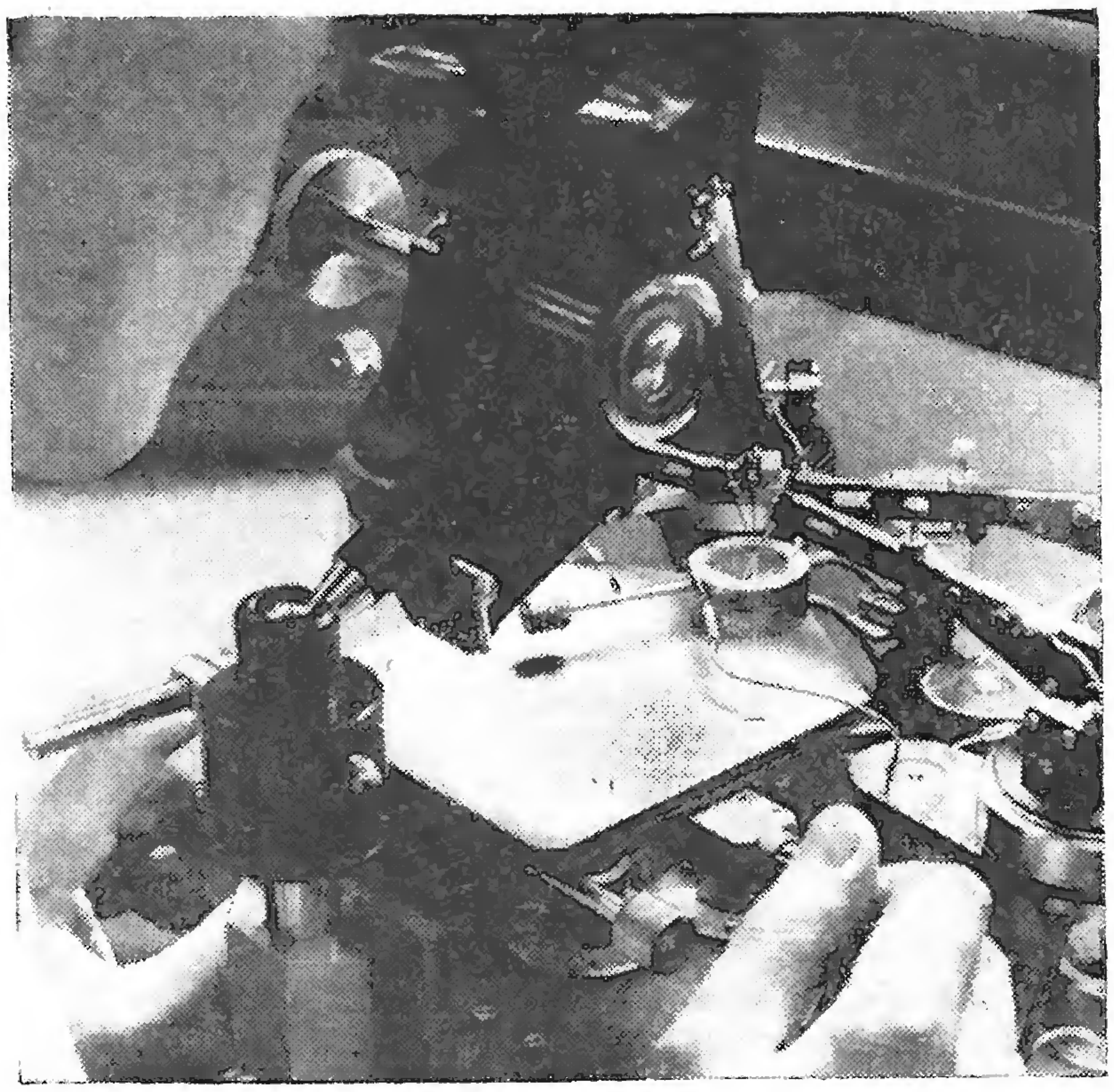
The controversy arises in the main from the background of the contending parties. In general, supporters of thin film circuits tend to be the traditional components manufacturers who, seeing the danger signals, are recognizing that future sales of conventional resistors and capacitors will inevitably take a downward plunge and have decided that their only solution lies in the philosophy "If you can't beat them, join them." These manufacturers have entered the field with strong traditional skills and discipline and with extensive manufacturing facilities which are best adapted to the thin film circuit art. Producing thin film resistors in a flat ceramic substrate, after all, differs but in geometry from the standard production of metal oxide film resistors of cylindrical shape.

The protagonists of the semiconductor technologies, in general, started life as manufacturers of diodes and transistors, so that it is only natural for them to extend their area of activity into circuits which are produced by essentially the same planar techniques.

The problem is further complicated by one major new factor. As the manufacturers of components (whether of passive or of active components which, traditionally, have been supplied to the manufacturers of electronic equipment) turn to producing what are no longer components but entire circuits—the acknowledged province of the equipment manufacturers—the traditional balance is upset. Equipment manufacturers find that supplies of "components" encroach more and more into their field of activity. Should they accept a *de facto* situation and buy in these complete circuits as just other components, they would lose control of the circuit design and would soon degenerate into no more than assemblers of other people's designs. This is rather an over-simplified and pessimistic picture, but clearly there is a considerable measure of truth in it. Witness the emergence both in Britain and the U.S.A. of extensive "in-house" integrated circuit facilities set up by the larger equipment manufacturers in order to retain control over the detailed design of their equipments—for which, after all, they must bear the ultimate responsibility to their customers.

The situation is quite obviously very delicate and fraught with danger. There will undoubtedly be, as a result, a long period of uncertainty before the electronics industry finds its New Look and settles down in its new guise.

What of the techniques themselves? The clear distinction made between thin film techniques and semiconductor techniques is quite false, since both are always required. In order to produce thin film circuits the



Preliminary electrical evaluation and elimination of faulty devices is performed on semiconductor integrated circuits while they are still in slice form.

---

*The Marconi Company Ltd.

manufacturers will always require semiconductor active devices for connection to the thin film networks. Equally the planar process which is the basis of the manufacture of semiconductor integrated circuits relies heavily on thin film techniques—a thin film of silicon dioxide is used for passivation in the manufacturing process and thin aluminium films provide the interconnections within the integrated circuit. There is thus no basic conflict between the techniques. The misunderstanding arises because of the difference between the end products being offered by the two protagonists, as we shall see below.

The normal thin film circuit (t.f.c.) of the type being offered commercially on the market comprises an inert substrate (usually of glass or ceramic; of prime dimensions of the order of centimetres), on to which are deposited, by evaporation, sputtering, plating, silk screening or any other similar process, thin layers of materials which perform the functions of resistors, capacitors or conductors, depending on the material used. These are deposited in a suitable pattern so as to form a complete network. Because these techniques do not permit the production of active components, conventional diodes and transistors must subsequently be attached to form a complete functional circuit. (Thin film transistors and diodes are under current investigation, but are not as yet a realistic proposition.) This obviously entails a multiplicity of connections and does not lead to a very high order of reliability. Thin film circuits, however, may be more useful where passive networks only are required —for attenuators, RC phase shifting networks, etc.

Extension of planar technology

The semiconductor integrated circuit (s.i.c.), as has been stated previously, is based on the planar transistor technology.

An extension of this technology utilizing the same processes of photo-lithography, etching, diffusion and epitaxy, permits the formation of resistors and capacitors as well as transistors and diodes, so that entire electronic circuits are achievable through the same sequence of operations. The details of the technology are well documented, and it is not the purpose of a brief review such as this to go into them in any depth. It is, however, worth while explaining how, by the use of refined, photo-lithographic techniques, very complex patterns can be etched with a high degree of accuracy into the silicon dioxide layer which forms a hard, glasslike protective coating over the silicon slice. These patterns, when suitably treated in a diffusion furnace, result in one of the electrodes of a transistor or a diode or perhaps in a resistor. Other patterns are etched and treated in subsequent operations to form a circuit. The circuit is completed by the evaporation of an overlay pattern of interconnecting conductors (usually aluminium) joining suitably exposed contact areas of the appropriate circuit elements.

Thus the thin film technology plays a vital part in the production of semiconductor integrated circuits. A further marriage of the two techniques takes place in the so-called hybrid circuit, where the active elements (diodes and transistors) are formed in the silicon slice by the normal planar process, but where the passive elements (resistors, capacitors and conductors) are deposited as thin films on to the thermally grown silicon dioxide protective coating. This offers the higher performance usually associated with thin film passive elements, as compared with their diffused counterparts, while retaining all the advantages of the s.i.c. in reliability, ruggedness and cost.

Almost inevitably integrated circuit manufacturing techniques result in an enormous compression in the size of electronic devices—hence the common use of the term "microelectronics"—but this is by no means the prime reason for the utilization of these techniques. There are, of course, applications where size and weight are all-important—such as in missile and space applications—but, in general the main concern is with reliability.

Reliability has always been an elusive objective in the design of electronic equipment, and as the complexity of electronic systems grows, this problem is seriously aggravated. It is quite normal to find that the reliability of an electronic system, consisting of several bays of equipment and incorporating hundreds of thousands of electronic components as well as hundreds of thousands of electrical connections, soldered, welded, crimped and wrapped, is extremely poor. Mean times between failures of some few hours (or even minutes) are quite commonplace. The implications of this in, for example, large defence systems, are readily apparent.

Reliability the spur

The new technology offers the possibility of hitherto undreamt-of reliabilities. This is the main spur to the enormous effort which is being expended everywhere on integrated electronics. Why should this be so? There are several obvious reasons, and some not quite so obvious.

(1) The integration of circuit elements to form a complex electronic function results in a major reduction of separate electrical connections—one of the acknowledged main sources of failure in electronic equipment.

(2) The use of integrated circuit techniques results in what is virtually a solid equipment of low mass; this will minimize the effects of shock.

(3) The use of pure materials throughout the manufacturing process, and subsequent restriction of contamination of the circuits by hermetic encapsulation, have a marked effect on reliability.

(4) Perhaps the least obvious but most important, the production of a complete circuit in integrated form, particularly a semiconductor integrated circuit, is reduced to a series of very closely controlled processes. We have eliminated the multiple control which exists in traditional manufacture, where one component comes under one manufacturer's control, another under a second manufacturer and so on; the assembly is another stage, the metalwork another, etc. In an integrated circuit the entire unit is fabricated under the one single control and the resulting effect on reliability cannot but be impressive.

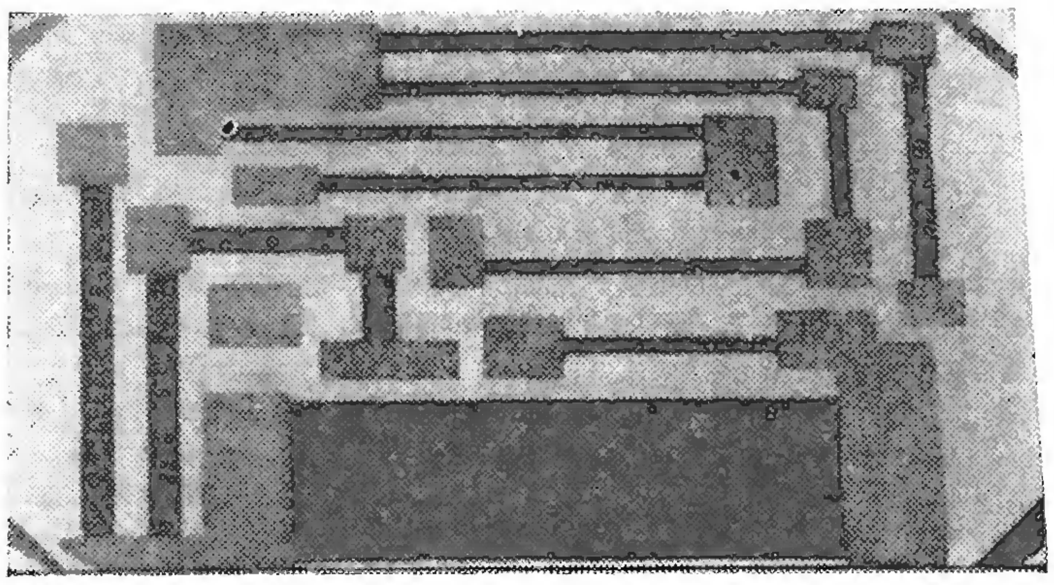
The reasons enumerated above to justify the allegations of greater reliability of integrated circuits have been confirmed by life tests. Reliability data accumulated in the short number of years during which integrated electronics have grown up has surpassed all expectations.

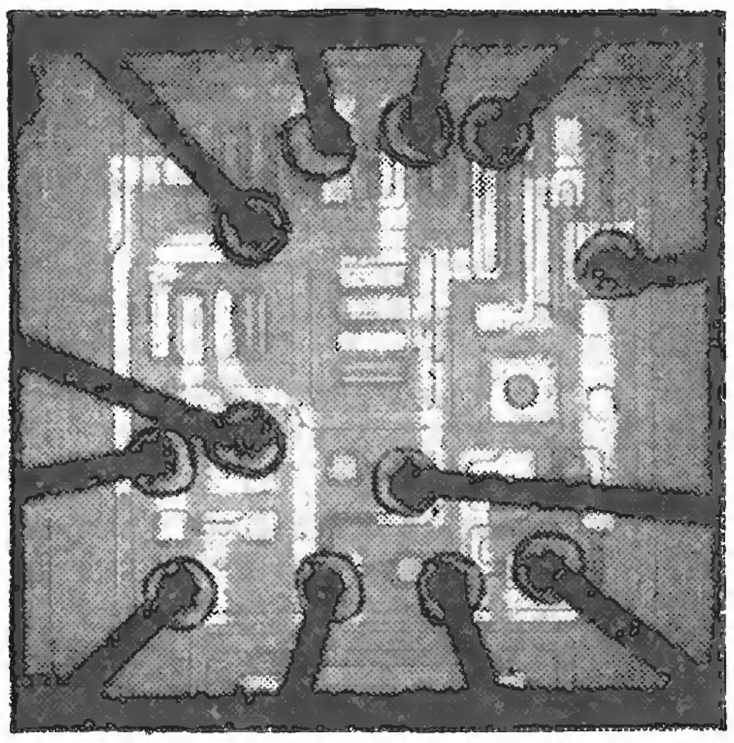
There are, it is true, many limitations in the application of integrated electronics. Inductors cannot easily be produced. Tolerances are not all that they could be and there are several restrictions on the values of resistance and capacitance that can be used. There will exist for a long time the necessity for the closest co-operation between equipment designer and integrated circuit designer in order to arrive at the best solution. New techniques and improvements are continually emerging, however, and there is no doubt that the restrictions will gradually be eased. As production yields rise, as a result of technological improvements, costs will keep falling, so that integrated circuits will find wide applications in every type of electronic equipment.

INTEGRATED CIRCUIT UNITS

THIN FILM CIRCUITS ▶

Contain only passive circuit elements and conductors, in the form of very thin films (0.0002 in or less) deposited on a flat insulating substrate. Active circuit elements cannot yet be integrated, but thin-film semiconductor devices are being developed for the purpose.



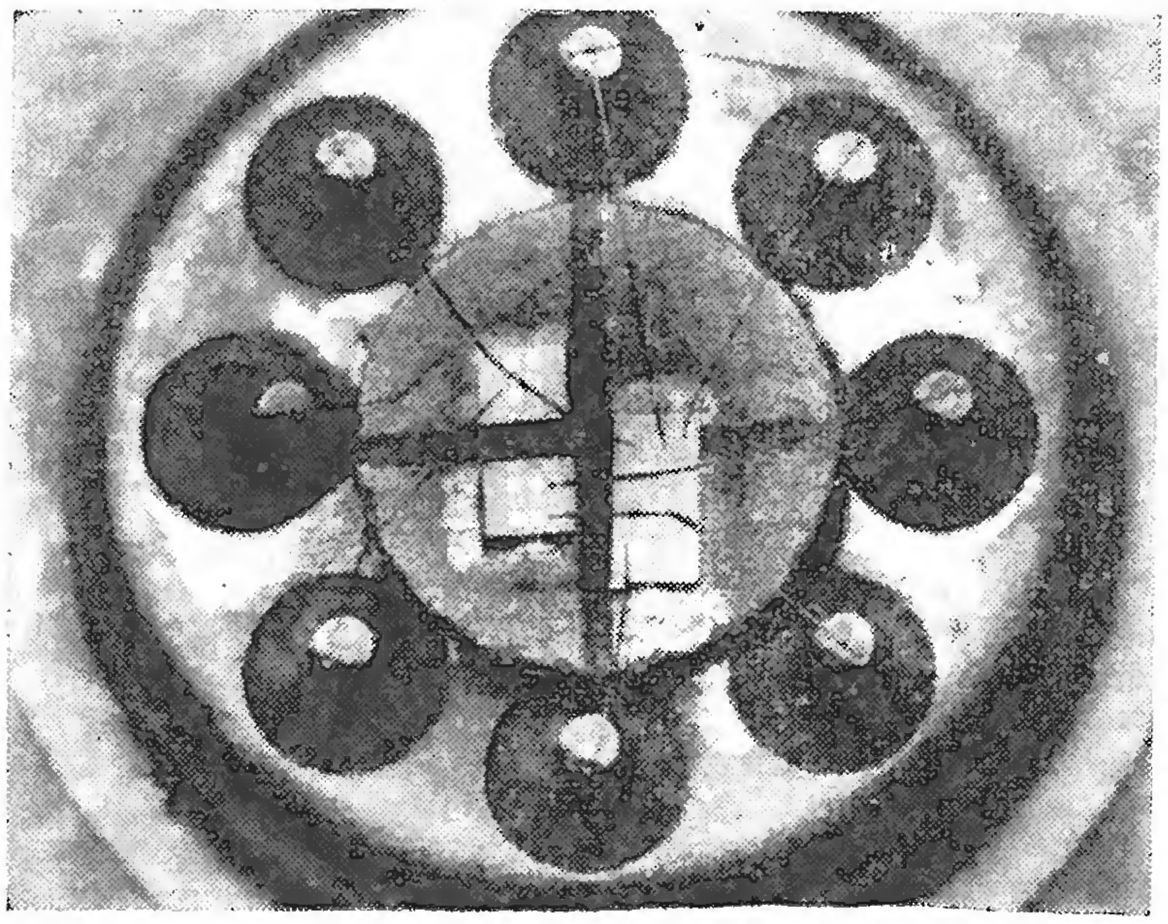


◀ SEMICONDUCTOR MONOLITHIC CIRCUITS

All circuit elements, passive and active, are formed in a single chip of semiconductor material (usually about 0.1in square) and are subsequently interconnected by a network of evaporated conductors.

MULTICHIP CIRCUITS ▶

Constructed from a number of separate semiconductor chips, which are mounted in a standard component package (e.g. a transistor can) and interconnected by bonded leads. On each chip is formed one or more active and/or passive circuit elements.



HYBRID INTEGRATED CIRCUITS

Active circuit elements are formed in a semiconductor chip, and this is covered by an oxide coating on which the passive elements are subsequently deposited by thin film techniques.

HYBRID SEMI-INTEGRATED CIRCUITS

Constructed as a thin film circuit, to which semiconductor integrated circuits and/or discrete active or passive circuit elements are connected. Packaged sub-systems are made up from groups of interconnected thin film and semiconductor integrated circuits.

LETTERS TO THE EDITOR

The Editor does not necessarily endorse opinions expressed by his correspondents

Metal Oxide Silicon Transistors

MY attention has recently been directed to an article by F. Butler entitled "Applications of Metal Oxide Silicon Transistors," in the February issue.

Whilst not wishing to detract from the article, which achieved its object of conveying the exciting prospects of a new device, I would like to point out that it was unduly optimistic on at least two points.

First, the statement "the 1/f component seems to be absent or at least abnormally low" is unfortunately incorrect. It was probably based on a consideration of the model of the MOST which describes it as an ohmic resistor of variable cross sectional area. As such the device would produce only thermal noise and would have a very low thermal drift. This model has now proved to be incorrect, or at least oversimplified and, in fact, measurements show that the MOST produces 1/f noise and that the level of this noise is greater than for conventional transistors. In addition the drift with temperature, expressed as voltage referred to the input, is several times greater than that for a silicon transistor. These facts have disappointed those circuit engineers who hoped to design low drift differential amplifiers of high input impedance based on these devices.

Secondly, the mutual conductance of the current MOST is very low being less than 2 mA/V even when the drain voltage is at its maximum permissible value at 30 V. The result is that the voltage gain of a conventional R-C amplifier is very low, being one or two times. It is misleading to quote the gain of a voltage amplifier in terms of its power gain which always results in a very pleasing looking answer when applied to high input impedance devices.

A useful voltage gain can be obtained using a high tension power supply and a high drain load and I have made amplifiers in this way with gains greater than 25.

Experimenters should bear in mind that the gate insulation of the MOST can easily be destroyed if the permissible potential difference between gate and source is exceeded; unearthed apparatus and tools, charged capacitors, and even charged human bodies coming into contact with the gate can easily result in destruction of the device. These are statements which I can verify from personal experience.

M. R. HARKNETT,
Dept. of Electronics,
Southampton. University of Southampton.

The author replies:—

There now seems no doubt that the noise characteristics of insulated-gate field-effect transistors cannot be predicted accurately from consideration of a simple model. In earlier correspondence (*W.W.*, April 1965, p. 193), I have already commented on the point now made by Mr. Harknett and I have nothing further to add. It is a mistake to reject outright a new device on the grounds that its performance is deficient in a single respect when in other respects its characteristics are unique. If low noise is a dominant requirement it would be sensible to use junction-type f.e.ts instead of the insulated-gate transistor. For example, spot noise figures of 1 dB and 5 dB are quoted for Texas Instruments transistors 2N2497-2N2500 with generator resistances of 1 MΩ and 10 MΩ respectively. These devices have an input impedance in excess of 5 MΩ at 1 kc/s, far less than for the MOST but large enough for many applications in which low noise is of importance. The range of applications which I described were selected to exploit the good features of currently available devices without incurring serious penalties because of their defects. As regards the mutual conductance of these transistors, I agree that figures between 1 and 2 mA/V are normal and that, consequently, the voltage gain is rather low, particularly when the device is associated with conventional transistors operating from low voltage supplies. In the application notes issued by some manufacturers drain loads up to 0.1 MΩ are suggested but in my view this is not particularly good practice. In the first place, the amplifier must work into a second stage of abnormally high impedance. Secondly, the high gain of the f.e.t. will result in excessive Miller feedback and poor high-frequency response, especially if the generator impedance is very high. For this reason I recommended the circuits of Figs. 4 and 5 in my original paper, preferring to regard the f.e.t. as an impedance converter rather than a voltage amplifier. I look on voltage gain as an inexpensive commodity and would not hesitate to use two stages to achieve with ease some end which might have been reached in one stage with difficulty.

As regards the precautions which must be taken in storing, handling, installing and using insulated-gate transistors, I endorse everything that Mr. Harknett says. The high input resistance of a MOS transistor depends on the perfection of a thin insulating layer of silicon dioxide. If this breaks down, the transistor may degenerate into one more like the junction type or it may fail catastrophically. The most likely causes of breakdown are:—

(a) Sliding the device up and down in a plastic container, thus generating electrostatic charges.
(b) Brushing the leads against insulating fabrics (nylon, wool), when the humidity is low.
(c) Faulty soldering techniques (electrical leakage, potential differences between the soldering bit and the chassis under assembly).
(d) Transients on the gate electrode input terminal.

Where possible, all the electrode leads should be electrically connected by a thin wire or foil wrap until the device is soldered into place, the lashing then being removed. The best soldering iron to use is one heated by gas. A low voltage electric iron can easily collect static charges and is not absolutely safe. All this suggests that f.e.ts are fragile devices but once in circuit they perform reliably except as regards input voltage transients, I know of no method of safeguarding against these. Special care is obviously required if the f.e.t. forms the input stage of a radio receiver. Atmospheric electricity, line voltage transients, car ignition interference, and pulses generated by controlled rectifiers are all potential hazards.

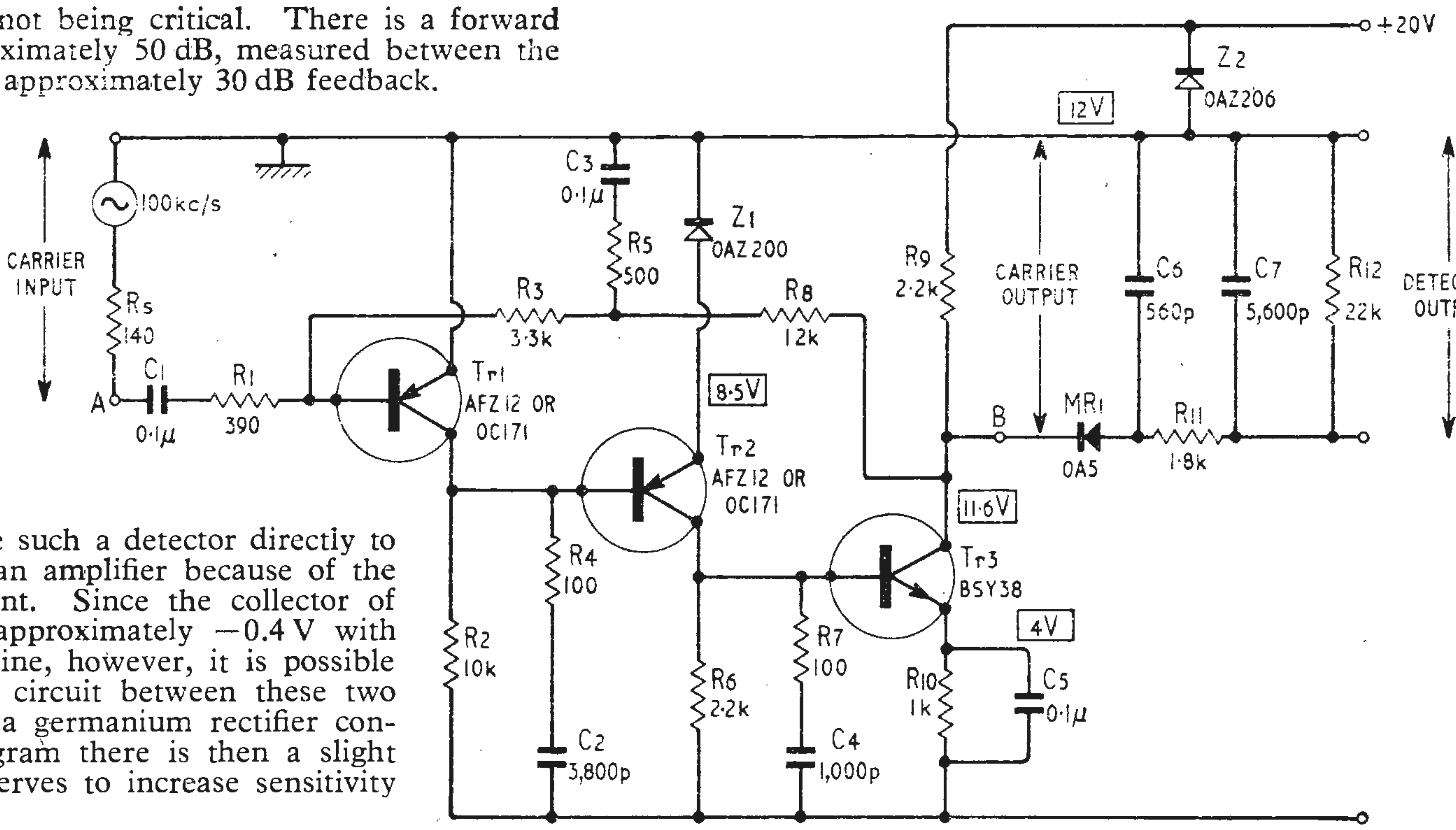
F. BUTLER

Wideband Amplifier

WITH reference to the article by F. Butler in the March *W.W.*, perhaps readers may be interested in the accompanying directly connected three transistor amplifier with overall negative feedback. This amplifier has a shunt feedback circuit giving low input and output impedances. Such an amplifier ideally requires a high impedance source to avoid shunting the feedback path, and to prevent reactive components in the generator impedance from causing unwanted phase change. However, the input circuit shown consisting of a total source resistance of 400 to 500 ohms and a 0.1 μF feed capacitor has been found to be adequate.

The Zener diode Z1 determines the potential at Tr1 collector and hence the collector current. The collector potential of Tr3 will be determined closely by the potential of Tr1 base, allowing for a small range of voltage drop in the resistors R_3 and R_8 in the feedback path, due to Tr1 base current. Hence the voltage drop in the collector load of Tr3 is defined, together with Tr3 collector current. The voltage drop across the emitter load of Tr3 and the collector current of Tr2 are thus also determined.

The step-circuit corrector networks across Tr1 and Tr2 collector loads were found to increase the stability of the amplifier, the values not being critical. There is a forward voltage gain of approximately 50 dB, measured between the points A and B, with approximately 30 dB feedback.



An important advantage of the circuit is the low output impedance, at both a.c. and d.c., which is very suitable for feeding a series diode detector, since the rectified current does not then cause potential changes in the source. Usually it is difficult to couple such a detector directly to the resistive load of an amplifier because of the d.c. component present. Since the collector of Tr3 is operating at approximately −0.4 V with respect to the earth line, however, it is possible to connect the diode circuit between these two points. When using a germanium rectifier connected as in the diagram there is then a slight forward bias which serves to increase sensitivity a little.

The circuit values shown produce a maximum loop gain at approximately 20 kc/s but the feedback and gain figures quoted were measured at 100 kc/s. The overall amplitude-frequency response characteristic at 5 kc/s and 3.8 Mc/s has fallen by 3 dB compared with the level at 100 kc/s.

Wembley, Brent. G. J. POPE

Pulse Width Modulated Audio Amplifiers

I SHOULD like to propose a simple circuit for overcoming the difficulty raised by M. D. Salmain in the June issue, concerning the design of class D amplifier output stages. The difficulty arises when an inductive load, with a high impedance at the pulse repetition frequency, is used. In these circumstances, during part of the pulse cycle the load is sending back to the amplifier energy stored in it inductively, and the problem is to ensure that this energy is returned to the power supply rather than to the output transistors. One way in which the latter possibility can arise is illustrated in Fig. 1, which shows the complementary-transistor output stage commonly used. The arrows indicate the directions of the currents, and it should be noted that the collector-base junction of Tr1 is conducting in the forward direction and supplying a base current to make Tr2 conduct in spite of the opposing input current. Since Tr2 has approximately the full supply voltage across it the dissipation problems mentioned by Mr. Salmain occur.

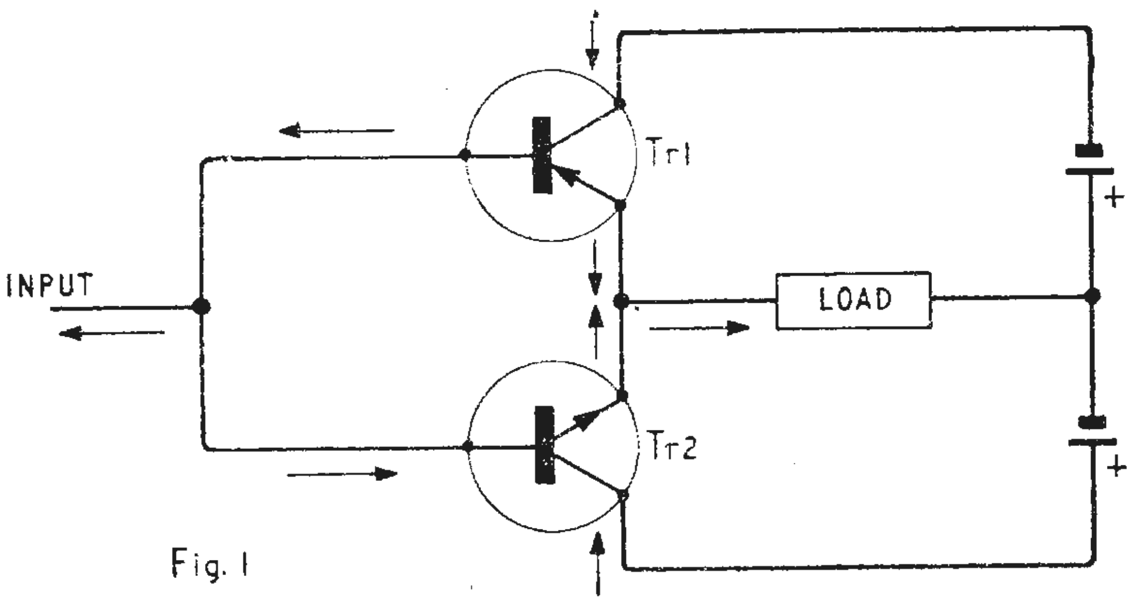


Fig. 1

With the circuit of Fig. 1, Tr2 can be cut off only if sufficient drive current is available to bottom Tr1 when it is conducting in reverse. Since the drift field type of transistor will probably be used in order to obtain a short switching time, the reverse current gains of the output transistors will not be very high, so that a large drive current will be needed to bottom Tr1. This in turn will introduce dissipation problems in the driver stage. My proposed circuit, which is shown in Fig. 2, requires only sufficient current to bottom the transistors when they are conducting in the *forward* direction to reduce the dissipation in the output stage to the minimum possible. The principle of operation is as follows. Diodes D1, D2 are used as in K. C. Johnson's circuit in *Wireless World* of March 1963 to provide an alternative path for the reverse current. The new feature of the circuit is the bias network formed by R and C, which is arranged to produce a bias voltage greater than the forward voltage drop across the diodes, and hence provide a reverse bias to cut off the transistor which has the full supply voltage across it. For the circuit to operate correctly it should be driven from a source of comparatively high impedance, and in this respect K. C. Johnson's circuit is to be preferred to that of Turnbull and Townsend in the April issue, where the drive is taken directly from an emitter follower.

The subject of distortion in open loop class D amplifiers, mentioned by C. M. Sinclair in the June issue, is an interesting one, and I should like to make some further comments on it. Both the circuits discussed above have the feature that although the output voltage for a given input current is reasonably independent of the current drawn by the load if this current flows in one direction only, if the load current changes sign during the period between two successive switching operations then the output voltage changes by some tenths of a volt. This is because reversing the direction of the load current causes the circuit to operate in a different mode, and the change in output voltage depends on the voltage drops across the transistors or diodes concerned. There is not space here to go into the details, but it will be found that the effect on the audio input voltage/output voltage characteristics of the complete amplifier is to produce a type of distortion similar to the crossover distortion characteristic of class B amplifiers. In the present case, the crossover region is the region for which the output current is bidirectional owing to the audio current being less than the amplitude of the high frequency components of the current

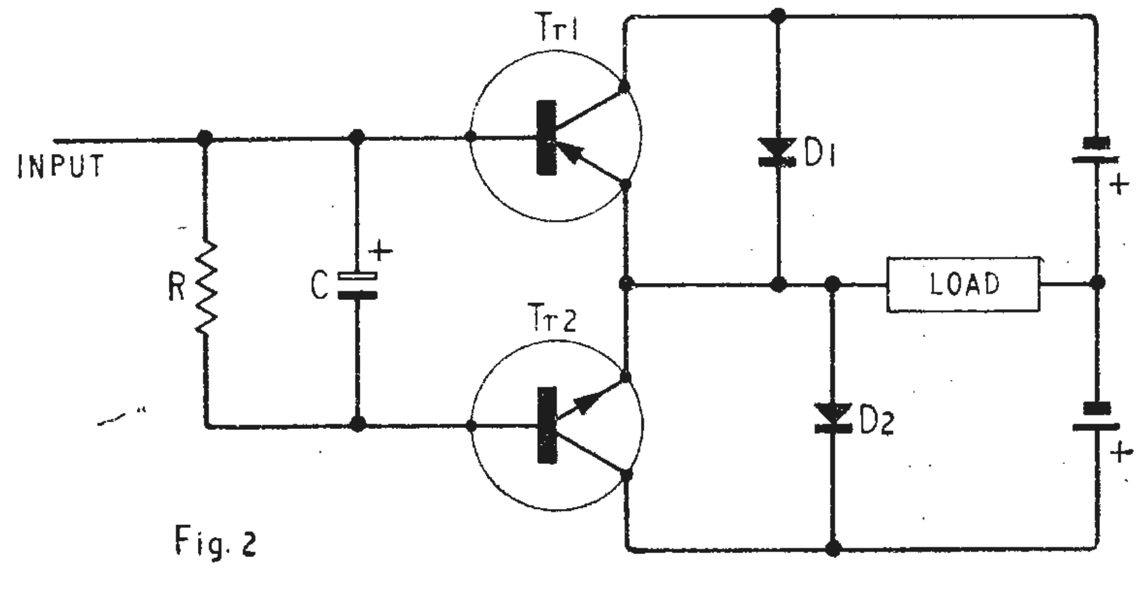
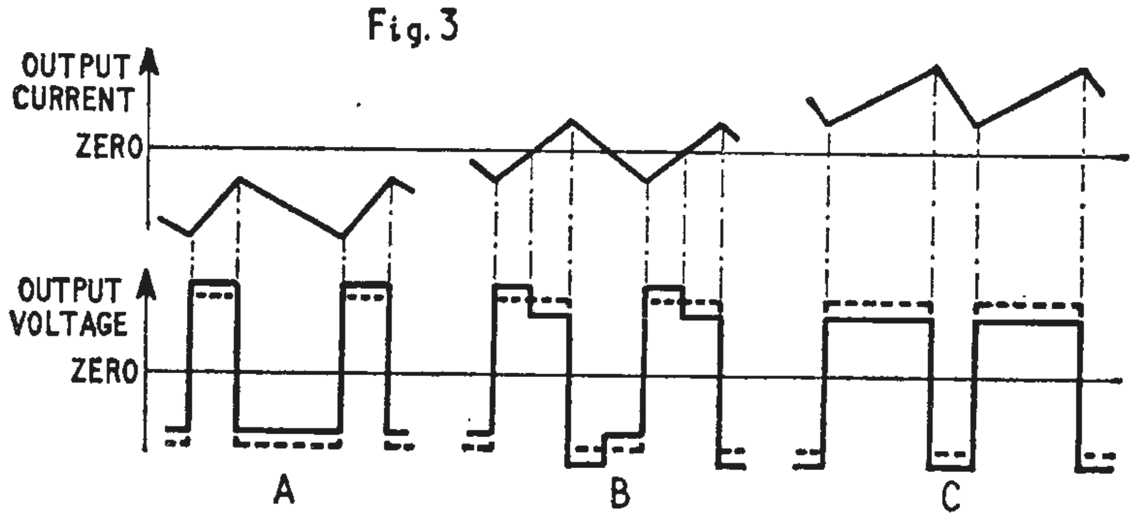


Fig. 2

Fig. 3



through the load. The amount of distortion is of the same order as that of the corresponding class B amplifier having the same quiescent current, and it would appear to render the open-loop system unsuitable for applications which require the lowest distortion figures, whereas with the closed-loop system the distortion can be made as low as is desired by increasing the feedback.

Now the current through the load consists of a sawtooth waveform at the pulse repetition frequency superimposed on the audio current. It may therefore be either bi-directional or uni-directional, depending on the value of the audio current. Since a uni-directional output current may be in either sense, there are altogether three possibilities, as illustrated in Fig. 3, which shows typical waveforms for the output current and output voltage in the three cases. For simplicity, it has been assumed that the output voltage remains constant provided that the directions of the input and output currents do not change, so that the output voltage is restricted to one of four different values. The broken lines indicate the voltage waveforms for an ideal output stage, whose output voltage is independent of the output current. In this case the audio input voltage/output voltage characteristic of the complete amplifier has the linear form indicated by the broken line in Fig. 4 (provided that the pulse width varies linearly with the input voltage). Now what is the effect of replacing the broken waveforms in Fig. 3 by the continuous ones? It will be seen that the only difference between the two waveforms in cases A and C is that one waveform is shifted relative to the other by a constant voltage. A similar shift occurs in the audio output voltage, since this is essentially just the average value of the voltage taken over one pulse cycle. In case B the shift in audio voltage is intermediate between the shifts in A and C. The resulting amplifier characteristic is shown by the continuous line in Fig. 4. If more realistic waveforms are used in place of those shown in Fig. 3, the effect is to round off slightly the sharp corners in Fig. 4.

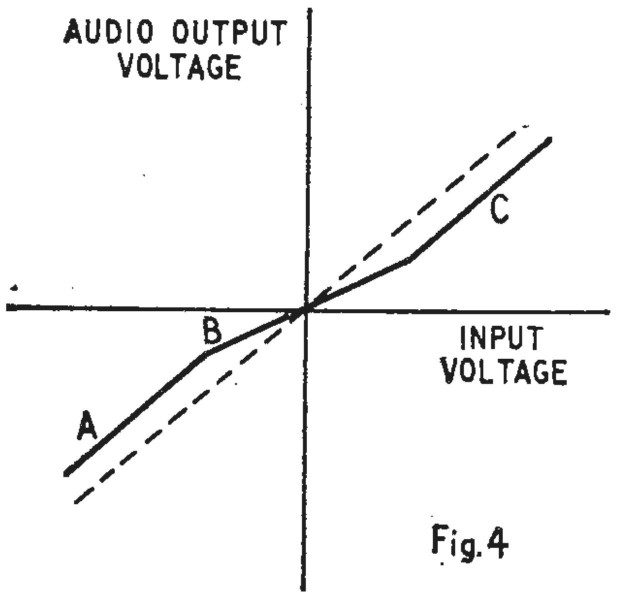


Fig.4

The conclusion to be drawn from Fig. 4 is that open loop class D amplifiers are subject to a form of cross-over distortion, similar to that occurring in class B amplifiers. The distortion resulting is of the same order as that of the corresponding class B output stage having the same quiescent current consumption, and would appear to render the open loop system unsuitable for applications requiring low distortion figures, whereas in the closed loop system the distortion is considerably reduced by the feedback present.

B. D. JOSEPHSON,
Cambridge. Royal Society Mond Laboratory.

SINCE February 1963 when D. R. Birt first published his design for a modulated pulse a.f. amplifier in *Wireless World* there has been a steadily growing interest in switching-type power amplifiers using the principle of time-ratio control of the mark-space duration of a rectangular waveform. This article, which apparently inspired the production of a 10 W and, later, a 20 W audio amplifier by Sinclair Radionics, Ltd., was followed by a letter in the March 1963 issue of *W.W.* in which K. C. Johnson outlined his own ideas for such a system. In the U.S.A., Prof. A. G. Bose of M.I.T. came up with another idea. A brief account of the principle appeared under the title "Two-state Modulation Simplifies Audio Circuits" in *Electronics* for 23rd August, 1963. Finally, we have the system described by Turnbull and Townsend.

Quite clearly there are dozens of ways in which the basic idea can be employed in practice to produce an audio amplifier of extremely high efficiency or high output power. The same idea of time-ratio control can be used in regulated power supplies. A thought-provoking note on Energy Conversion appeared in *Electronic Design* of 21st June, 1962, p.4. Though concerned mainly with d.c.-a.c. conversion, the scheme discussed seems to be adaptable for use in a low-frequency power amplifier.

There is room for argument about the relative merits of fixed or variable switching frequencies and about the concepts of negative feedback in this context but there is no doubt that the basic objectives of high efficiency and low distortion can be realised in all the competing systems. Unfortunately, most designers are reticent when describing the characteristics of the load into which the amplifier must work. A closer look at the requirements seems to be called for, and for this purpose we can assume that the amplifier characteristics are ideal. Quite clearly a pure resistance load is inadmissible. Even with no audio input to the amplifier, a square wave voltage of the switching frequency would be applied to the load, exactly as for a square wave inverter, causing a large energy dissipation. Most authors seem to assume that when a loudspeaker load is used, the coil inductance will be sufficient to cause a rise of impedance, at the switching frequency, to a value which will minimize energy loss. It seems unwise to rely on this effect without a precise knowledge of the speaker characteristics. Moreover, people tend to use multiple speakers, with cross-over networks, equalizers and so forth which might affect the amplifier performance.

It may be argued that in such cases one should make use of a low-pass filter to reject the switching frequency and other undesired high-frequency components of the amplifier output. The design of such a filter on an image-parameter basis is impossible and one must invoke modern network-theory concepts. This is because of the unequal terminating impedances and the reactive loudspeaker system. A little more information about this aspect of switching-type amplifier performance would be welcome.

Next, there is the problem of radiation. This so far has been rather glossed over but it seems that the higher the switching frequency and the more perfect the switching waveform, the more troublesome this will be. There is no need to labour the point, but it should not be ignored. Bias oscillators in tape recorders, quench oscillators in super-regenerative receivers and the various oscillators in superheterodynes have all set their own problems and this one promises to be still more objectionable.

Several correspondents have commented on the lack of low-priced switching transistors suitable for use in two-state modulators, particularly when high power output is required. A possible but not very elegant solution might be to divide the audio range into two bands, say 20-1,500 c/s and 1.5-20 kc/s. The lower band contains most of the energy in speech and music and could be handled by inexpensive high-power switching transistors or even by controlled rectifiers or gate turn-off switches when extremely high output power is called for. The upper band could be dealt with by low-power high-speed switching transistors. Separate loudspeakers could be fed from each channel. There are, of course, objections to this scheme on acoustic grounds and the extra cost might be justifiable only for outputs in the range 100 W-10 kW or so. One (possibly academic) advantage of a multi-channel, multi-speaker system is that Doppler frequency-shifts of high-frequency tones radiated from a single cone (which is simultaneously executing high-amplitude low-frequency motion), would be reduced or in part eliminated.

The object of this letter is in no sense to discredit the switching-mode amplifier. It will have served its purpose if it elicits some more information on the problems of coupling single or multiple speakers to the amplifier output, while maintaining high efficiency and level frequency response.

Cheltenham. F. BUTLER

Experience with Integrated Circuits

Reports from the London components conference and R.E.C.M.F. exhibition reveal rapid progress—but a few snags as well

BRITISH electronic manufacturers are approaching integrated circuits with typical British caution. At present they are not entirely happy about price and some aspects of performance. But there has been widespread investment in plant for making integrated circuits—by both equipment and component manufacturers—from which it seems clear that the new technology is here to stay. These were the main impressions which emerged from a joint I.E.E./I.E.R.E./I.E.E.E. conference on electronic components and material held in London in May—a conference which, whether the organizers intended it or not, was dominated by integrated electronics. The President of the I.E.E., O. W. Humphreys, expressed the prevailing mood in an opening address in which he spoke of "the promise—or the threat" of integrated circuits, and the consequent new relationship between equipment and component manufacturers, and remarked that there was a lot of room for mistakes and wrong decisions. He seemed to imply that management was still in a state of uncertainty about the commercial implications of the new technology.

Although one of the main arguments for integrated circuits is that they cost less to produce than equivalent conventional circuits, it appears that potential users are at present being deterred by the prices charged by manufacturers. One speaker at the conference thought that this was because users were not comparing costs on a proper economic basis—they were not taking into account all the overheads associated with conventional equipment production. Another speaker asked when integrated circuits would be cheap enough for use in domestic television sets. A thin-film circuit manufacturer replied that he would soon be able to supply circuits at prices equivalent to 2d or 3d per conventional component. A double NOR gate, he said, would cost 5 to 7 shillings.

The small size of integrated circuits (an unavoidable consequence of the method and economics of manufacture) is the cause of further trouble in their utilization—notably in the making of connections. It is ironic that in the majority of applications means have to be found for "getting back some of the size which had to be lost," as one speaker put it, to allow interconnections to be made without excessive difficulty. C. P. Sandbank (S.T.L.), presenting a paper on interconnection techniques, pointed out that an integrated circuit might have the same number of terminals as a radio valve but, because of its much greater functional complexity, was not simply connected to its immediate neighbours but to perhaps a dozen similar circuits spread throughout the equipment. One solution he offered was a matrix interconnection board allowing the circuit units to be spread out in two dimensions (Fig. 1). The X and Y conductors were 0.05 in wide strips carried on 0.097 in wide insulating tapes of glass fibre, the tapes being interwoven so that access to both X and Y conductors could be obtained from one side of the mounting frame. Patterns of interconnections could be formed by removing the conductor material at required points and joining X and Y conductors by soldering on tinned discs at crossing points. Such a matrix could also be produced by thin film manufacturing techniques, using masks to lay down the required pattern of joints and breaks.

Apart from the user's difficulties with external connections there are those of the circuit manufacturer in bringing out connections from the various circuit electrodes and junction points to the terminals of the package. Typically this is done by thermo-compression bonding of extremely thin gold or aluminium wires to the electrodes and terminal posts. One user, A. T. Lawton (E.M.I.), was obviously worried by the hazards to circuit reliability presented by these internal connections and other mechanical features of construction. He had been breaking open the packages of integrated circuit units produced by various manufacturers and examining the circuits (mostly silicon) for flaws under optical magnification. Some of the results were presented as colour slides. One example Lawton criticized was a bond made to an electrode on top of a previous bond that had come apart—he contended that the whole unit should have been rejected. Another was a flaw in the silicon base material running through a deposited conductor: this, Lawton pointed out, could cause high resistance in the conductor and, consequently, a hot spot in the device. An example of "black plague" in an integrated circuit was shown. This was a chemical compound which could form in bonds comprising a silicon substrate, a deposited aluminium conductor and a gold connecting wire. It caused the conducting path to become a high resistance and so virtually cease to conduct.

Lawton also criticized the use of only one bond between the internal wire and the terminal post, since the wire had to be broken at this point in order to start the next bond. Two or more bonds were desirable. Lands provided on the substrate for bonding should be as

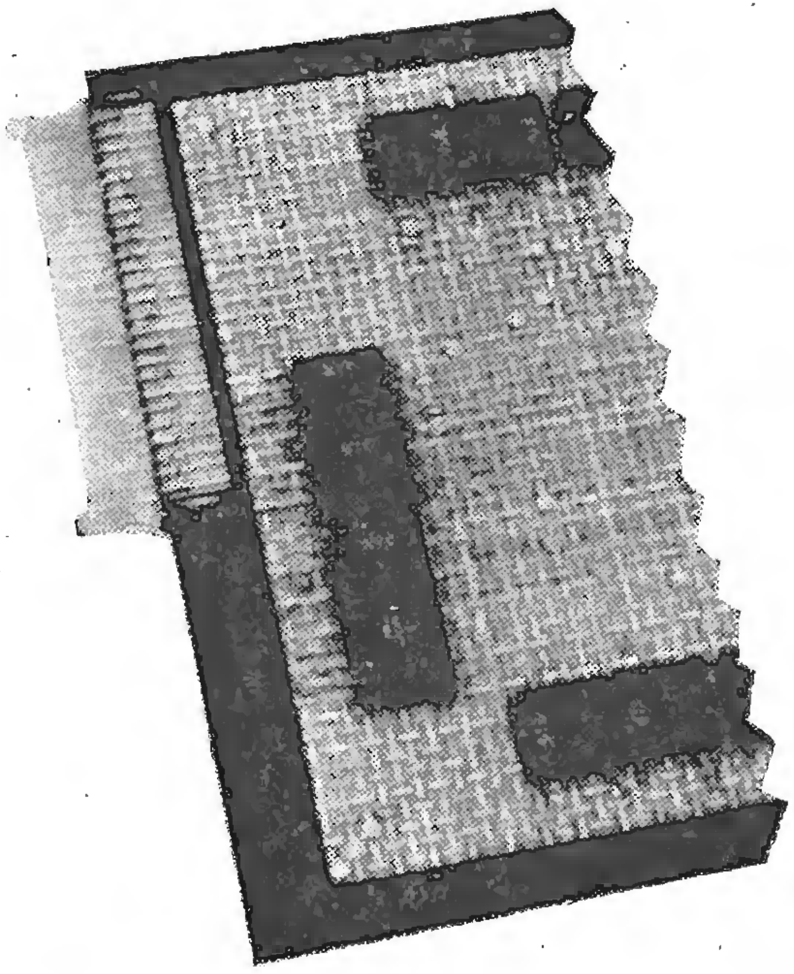


Fig. 1. S.T.L. woven tape matrix (0·1in pitch) fitted with thin film circuit elements.

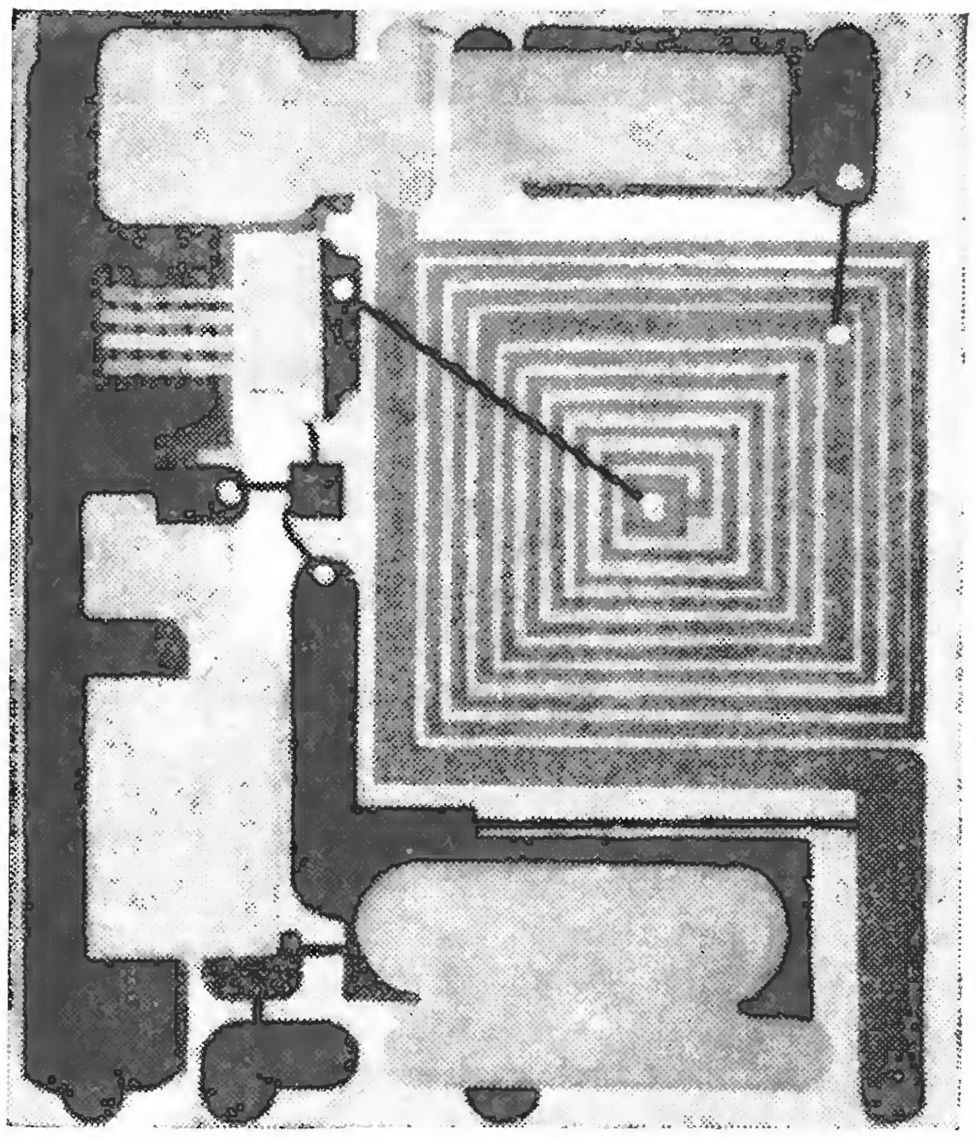


Fig. 2. R.R.E. integrated circuit tuned r.f. amplifier incorporating plated square-coil inductor.

large as possible, and "ball" or "nail" bonds were preferable to "wedge" bonds. He had discovered that certain manufacturers had been changing package outlines, lead identifications and semiconductor manufacturing processes of what were ostensibly identical units without making these changes known on the data sheets. Although the changes were, in fact, improvements, the practice could lead to performance troubles and necessitate expensive modifications in the final electronic equipment.

As a result of his investigations, Lawton advised users to consider claims of integrated circuit reliability with some caution, and recommended his own practice of obtaining samples and opening the packages to check on engineering standards before embarking on full-scale use in equipment. He also thought that manufacturers should devote more study to the physics of failure in the devices.

The advent of integrated circuits has tended to stimulate current work on active networks because they enable inductances to be simulated by transistor-RC combinations quite simply and cheaply. This approach is based on the general experience that inductors cannot easily be made by integrated circuit manufacturing techniques—the main problems being that the conductivity of the film is too low to permit a reasonable Q in the inductor and the conductor line definition is not good enough to allow a flat coil of sufficient inductance to be formed in an area of a few square millimetres. H. G. Manfield (R.R.E.), who is well known as a pioneer in integrated circuitry, described a technique by which these problems could be overcome and which had resulted in inductors with good Q factors of 50 to 80. An integrated-circuit tuned r.f. amplifier incorporating such an inductor had been constructed (see Fig. 2) for operation in the 10-100 Mc/s region.

The principle of the technique was to reduce the high resistance of the thin film conductor, caused by skin effect at r.f. and the chemical and mechanical structure of the film. At 50 Mc/s, for example, the skin penetration depth would be about 10μm in conventional conductors—somewhat greater than the total thickness of the usual thin film conductor economically obtainable by vacuum deposition. Manfield's technique was first to deposit a normal thin-film flat coil (about 2-3μm thick) and then increase its thickness to about 0·0007 in by electroplating. As a result of the plating not only was the coil resistance reduced but the edges of the conductor were more clearly defined and "hedged"—thereby improving the line definition and further increasing the Q (because a large proportion of the current was carried at the edge of the coil).

The coils were made square, rather than circular, mainly because the original pattern to be photolithographically reproduced was formed by an R.R.E. technique of winding plastics strip round pegs in a pegboard. At the same time, a square coil provided about 12% more inductance than a circular coil of the same number of turns. Manfield claimed that the accuracy of reproduction of inductor values by this method was better than 1%—an improvement on that obtainable with conventional wound coils. The process was very suitable for producing integrated i.f. amplifiers, and inductors could be made cheap enough for use in domestic television receivers.

Techniques for manufacturing thin-film resistors for integrated circuits were discussed by G. France (Welwyn), who was particularly concerned with the problems of obtaining good stability and repeatability of resistance value. For example, in order to achieve good long-term stability it was necessary to use a film material with the lowest possible sheet resistance. Thus, if large resistor values were required within small areas, it was necessary to have very narrow track widths; but there was a lower practical limit to the width of the track imposed by the finite edge definition of the pattern reproduction process. Fig. 3 shows the relationship between resistor tolerance and line width in two types of resistor.

C. B. Oliver (G.E.C.) showed how the thickness and specific resistivity of tantalum film could be very easily measured for process control in integrated-circuit manufacture without the use of special measuring instruments. In tantalum circuits the resistors were adjusted to required values by anodization, the anodizing circuit being automatically cut off when a monitor resistor reached a target value. By Oliver's method, the specific resistivity and initial thickness of the film could be calculated from the initial and final resistances and the anodizing voltage.

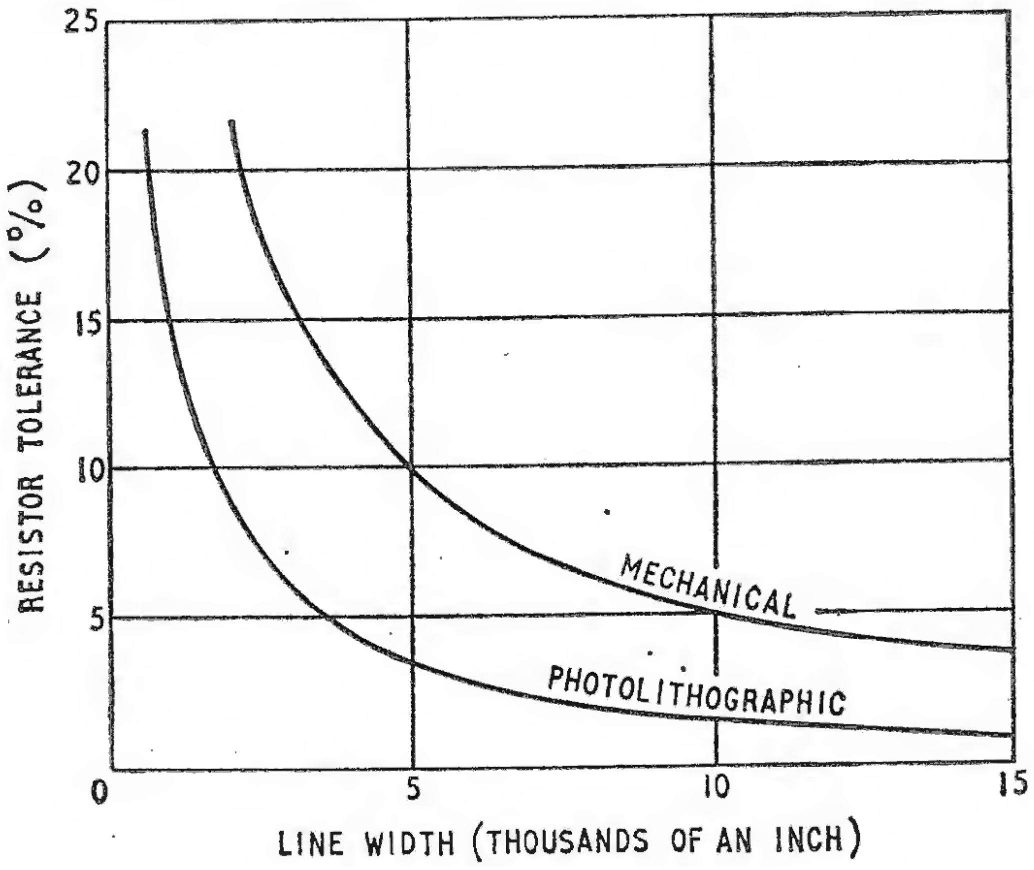


Fig. 3. Relationship between resistor tolerance and line width in Welwyn resistors produced by mechanical and photolithographical techniques.

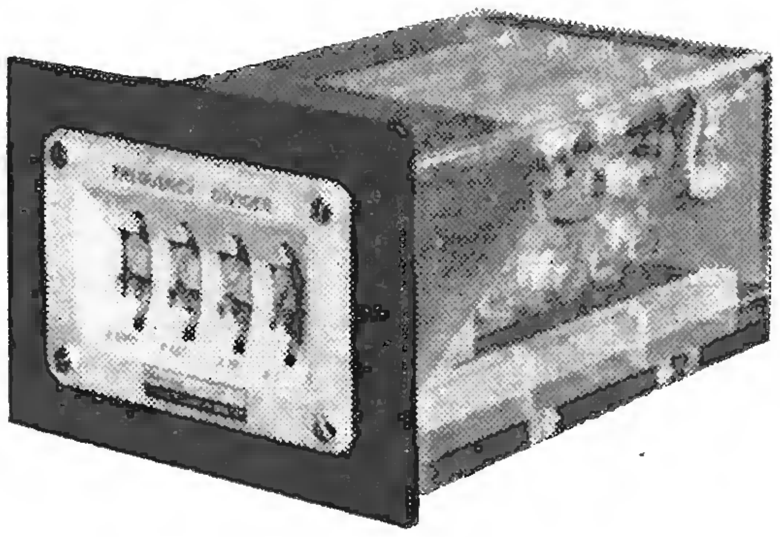


Fig. 4. Marconi integrated circuit variable frequency divi-

G. W. Hill (S.I.R.A.) described the experimental production of polymer insulating films by deposition in a vacuum chamber, using electron bombardment and a silicone pump fluid as the raw material. Films of 250Å to 20,000Å thickness had been obtained by this method.

An improved bond structure enabling aluminium wires to be bonded successfully to heavily oxidized aluminium films was described by D. Baker (G.P.O.) and R. E. Warren (S.T.C.). The end of the wire lead was formed into the shape of an eyelet. Breaking strength of the bond was only slightly smaller than the breaking strength of the wire.

The conference offered very little on the application of integrated circuits, but there was one contribution, by O. Jakits (S.T.C.), to the controversy on the relative merits of monolithic and multichip semiconductor circuits. Experimental monolithic and multichip NAND gates had been compared in switching performance, using identical external circuits. It was concluded that multichip circuits were faster and more flexible. But the discrepancy in speed was not as great as might have been expected because design optimization between various components could be achieved more readily in monolithic circuits. New manufacturing techniques for monolithic circuits, however, gave hope for increased flexibility, and this, together with good reliability, would make the monolithic variety increasingly attractive.

At the R.E.C.M.F. exhibition the application side was more strongly represented. An interesting example was Marconi's latest integrated circuit device—a frequency divider with a division ratio variable between 1 and 1,000. The device (Fig. 4) comprises three divider stages in cascade, the first two dividing by 10 and the final divider being variable between 1 and 10 and set by the hundreds digit selector. An output from the final divider (i.e., after 100, 200, etc., counts) causes two auxiliary trigger stages (associated with the two ÷10 stages) to count, the counts being determined by the tens and units digit selectors. Consider the divider set to divide by 864: the final stage is set to ÷8 and the two trigger stages set to count 6 and 4, these being started when 800 pulses have been counted. When the first stage has counted 4 it is "discharged" by the trigger and recommences to count up to 10. An output is consequently obtained for 14 input pulses. Subsequent outputs are obtained for 10 input pulses. The output pulses are counted by the second stage, which is discharged after the first six pulses, thus counting 16, and then counts 10's. The eight pulses required by the final stage to give an output are thus made up from $7\times10+1\times16=86$ pulses into the second stage, these 86 pulses being made up from $1\times14+85\times10=864$ input pulses.

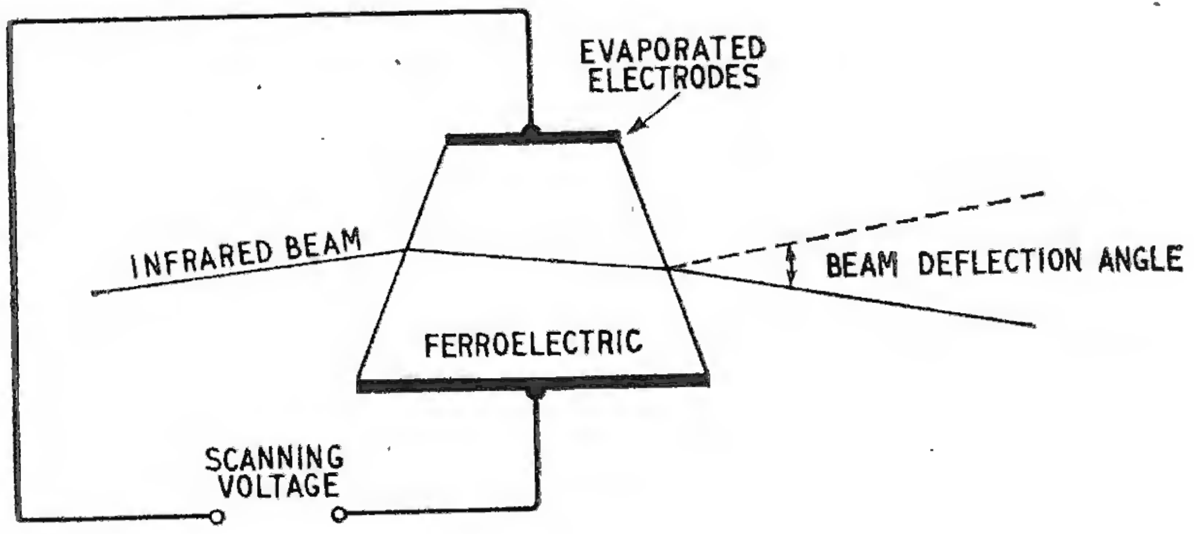
The basic frequency dividing circuit uses the now familiar diode-pump pulse counter with a transistor to improve linearity (see *Wireless World,* March, 1958, p. 108, and August, 1964, p. 404), and feeds into a trigger circuit. Direct coupling in cascaded stages is facilitated by use of complementary frequency dividing modules. The modules (mounted in TO-5 cans) can be made to count any fixed number of pulses, by altering the capacitor ratios in the pump circuit, or to count a variable number of pulses, by altering the aiming potential of the trigger circuit. The two auxiliary trigger circuits, referred to earlier, also use frequency dividing modules (variable) which are normally made inoperative by a clamping circuit module. This module is also used for triggering, or discharging, the two ÷10 circuits, and as a limiting or inverting amplifier. The auxiliary trigger counter circuit is started by an output from the final dividing stage setting a bistable which releases the clamp. The bistable is reset by the output from the auxiliary dividers. The complete divider is thus built around four modules and a quantity of conventional components. Maximum operating frequency is 10 Mc/s.

Such integrated circuit equipment is hybrid, in that conventional components are also used—at some expense to reliability. But if the number of modules required to perform the majority of circuit functions can be kept small enough, this could lead to a sufficiently large demand to realize an economic advantage in the use of semiconductor integrated circuits.

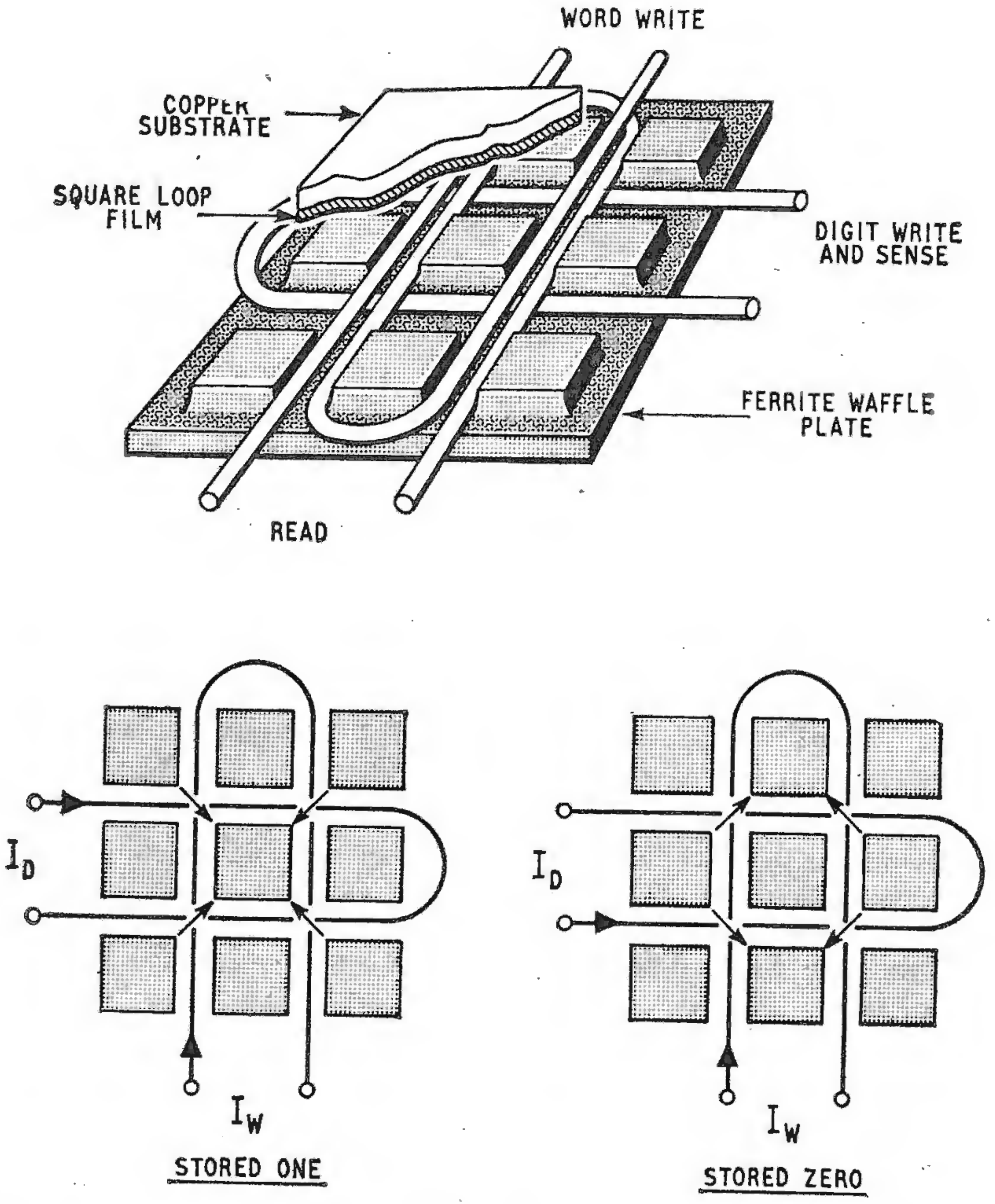
Further items from the Conference and Show

Scanning an infra-red beam by means of a ferroelectric device was suggested as a possibility by E. Fatuzzo of RCA Laboratories, Zürich. A prism made of a ferroelectric material such as barium titanate would have an electric field applied to it by two electrodes, as shown, and the infra-red beam would be passed through it. The dielectric constant of the material at infra-red would depend on the electric field, and so the absorption coefficient and the refractive index would be field-dependent. Variation of the applied field would therefore alter the angle of deflection of the beam. Orthogonal scanning could be achieved by two such prisms arranged at right angles. A disadvantage would be that the intensity of the beam would be modulated as well, and Fatuzzo thought the field-dependence effect might be employed more successfully as a variable absorber. He said it should be possible to modulate infra-red radiation at rates ranging from zero to microwave frequencies. Conceivably laser beams could be modulated.

Proposed method for scanning an infra-red beam, using a ferroelectric prism.



Cheap and fast storage of digital information is the object of development work at Standard Telecommunication Laboratories on a "waffle iron" storage technique originally devised by J. L. Smith and A. H. Bobeck of Bell Telephone



Waffle-iron thin-film store showing (above) principle of construction and (below) method of holding information by diagonal magnetization components in film.

Laboratory, U.S.A. A low-reluctance ferrite plate is used to provide flux closure paths for a thin film magnetic storage medium (see diagram). Grooves cut in the ferrite house read and write conductors, and information is stored by diagonal magnetization components in the film over the intersections of the grooves, as shown by the arrows. The low reluctance flux closure paths mean that drive requirements are reduced, and because the ferrite "waffle iron" structure defines the storage states an isotropic film may be used—avoiding the manufacturing difficulties associated with anisotropy in other types of thin film stores. The wires can be laid in one operation. An experimental store with a capacity of 2,048 words of 64 bits each has been built on this principle and was described by R. M. Glaister (S.T.L.). The read/write cycle time is 600nsec. A storage density of 1100 bits/in^2 is possible. It is hoped to develop a version in which each bit is stored by only two magnetic cells instead of four and in which the read/write cycle time is 400nsec.

Digital instruments.—Digital Measurements and Solartron both showed a.c./d.c. digital voltmeters. Digital Measurements showed the DM2003, a general purpose voltmeter incorporating a simplified version of the DM2140 a.c./d.c. converter. The Solartron a.c./d.c. voltmeter (LM1420A) is built around the d.c. integrating type, LM1420. Also using this last-mentioned voltmeter was the resistance test set (LM1621). This can be employed as a resistance deviation meter, the nominal value being set on the decade switches and the LM1420 used to present the percentage deviation (with a sensitivity of 0.01% per digit). Alternatively the test set can be used to measure absolute resistance, in which case a LM1410 voltmeter acts as the null-indicator for the Wheatstone bridge and the resistance value is read off from five decade switches selecting the standard resistance.

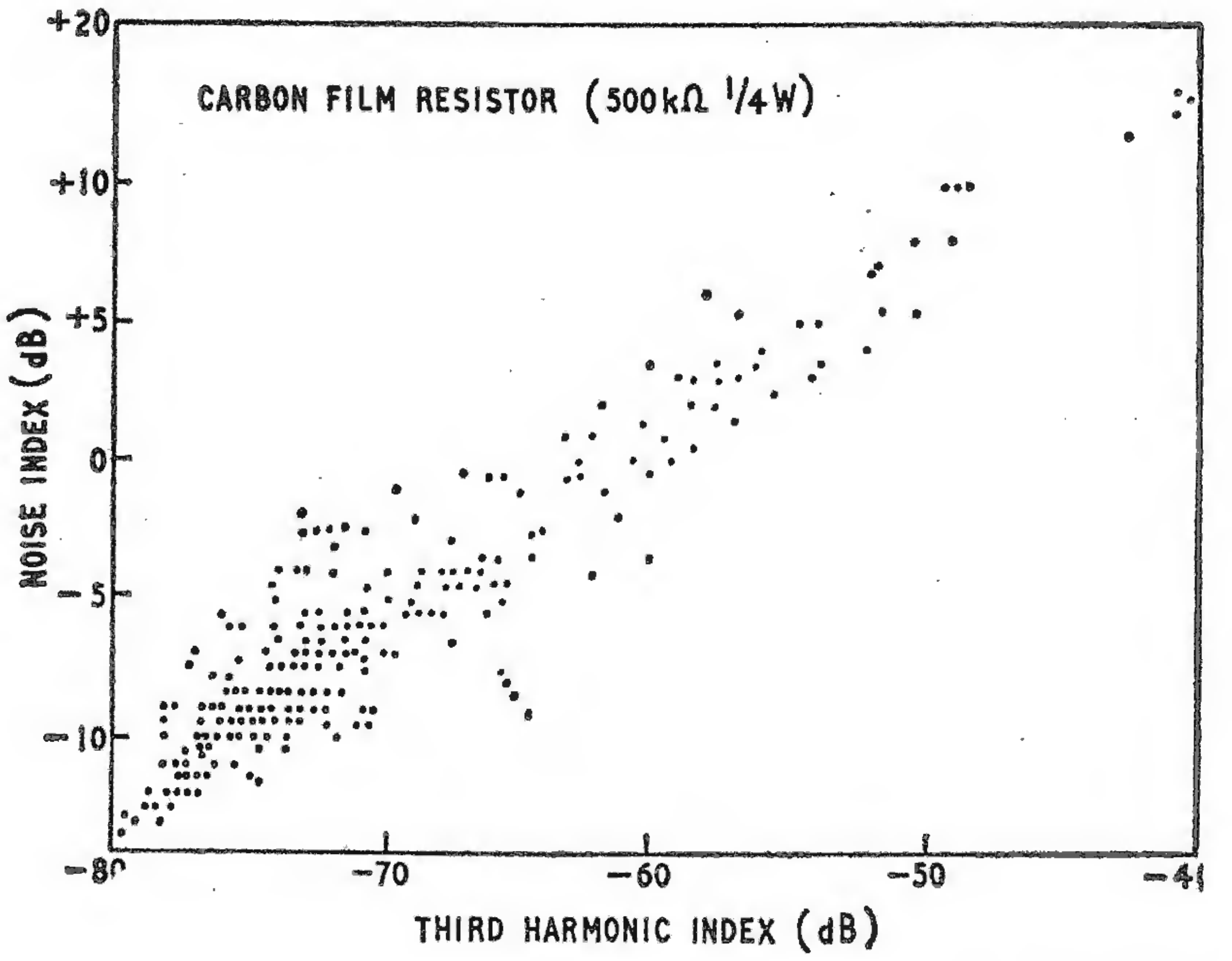
A new resistor tolerance indicator is available from Muirhead, measuring deviations from ± 0.001% to ± 10%. A capacitance adaptor for digital frequency meters was shown by Digital Techniques. The adaptor delivers a timing pulse, the width of which is directly proportional to the capacitance being measured. Another digital instrument of interest was a frequency counter shown by Microwave & Electronic Systems and manufactured by Eldorado (U.S.A.). This can measure frequency from 10 c/s to 6.4 Gc/s in three ranges without use of a transfer oscillator or heterodyning. The accuracy is ± 1 digit in seven and the average oscillator stability is 5×10^{-8} per 24 hours. Many of the digital instruments displayed now incorporate polaroid filters to reduce reflected light.

Glass delay lines, using zero temperature-coefficient glass, were described by Mr. Greenhalgh of Corning Glass Works, U.S.A., whose U.K. agents are Electrosil. An acoustic wave is launched into a block of glass by a piezo-electric transducer bonded to it, and travels along a path formed by multiple internal reflections before being picked up by a second transducer some microseconds later. Time delay independent of temperature is their main feature. For digital information storage, lines with delays ranging from 1.4 μsec to 350 μsec are available, allowing, for example, storage capacities from 14 bits to 3,500 bits at a digit rate of 10 Mc/s. Attenuation figures range from 30 to 80 dB. Typical input impedance figures are $C_{in} = 100$ pF with $R_{in} = 4{,}000\ \Omega$; and $C_{in} = 650$ pF with $R_{in} = 1{,}000\ \Omega$.

Measuring resistor non-linearity.—An improved method of measuring the non-linearity of fixed resistors, based on the third harmonic generated when a pure sinewave is applied to the resistors, was discussed at the conference by P. L. Kirby (Welwyn). It overcomes the disadvantages of the currently used "voltage coefficient" parameter, which suffers from a dependence on heating effect and on the level of the applied voltage. Called "third harmonic index" the new parameter is given by

$$\text{t.h.i.} = 20 \log_{10} \frac{\text{third harmonic r.m.s. volts} \times 10^{-6}}{(\text{applied fundamental volts})^3}$$

An interesting degree of correlation has been found between t.h.i. and noise index in a large group of carbon film resistors (see graph) and this may prove valuable in eliminating potential resistor failures, as there is a known empirical relationship between high levels of current noise and subsequent lack of stability in normal operation. A resistance linearity meter for measuring the percentage of third harmonic of a 10 kc/s signal passed through a resistor is made by Radiometer of Denmark and available from Livingston Laboratories.



Correlation between third harmonic index and noise index in a large group of carbon film resistors (Welwyn). Correlation coefficient is 0.9.

WORLD OF WIRELESS

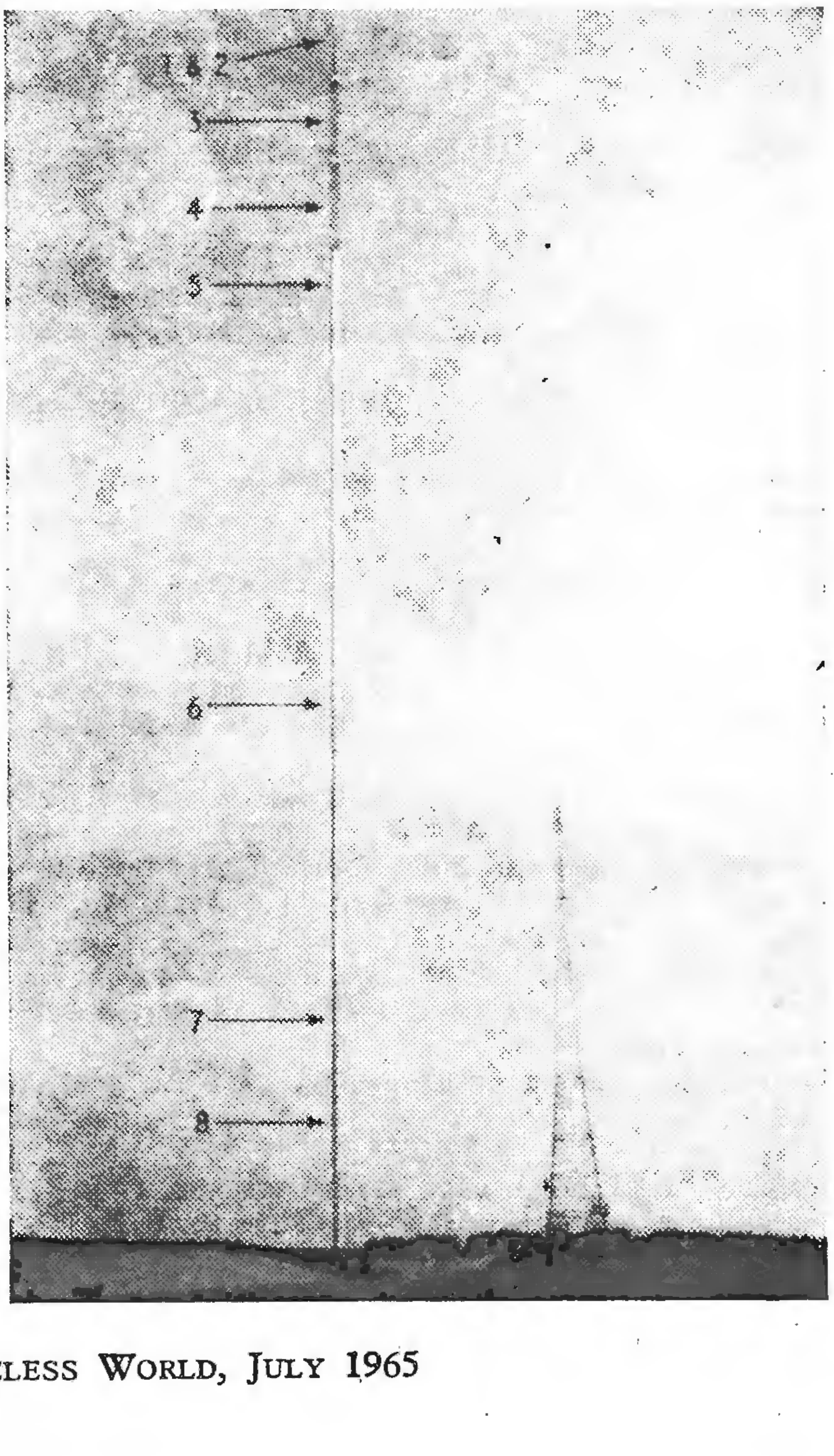
Receiver Imports and Exports

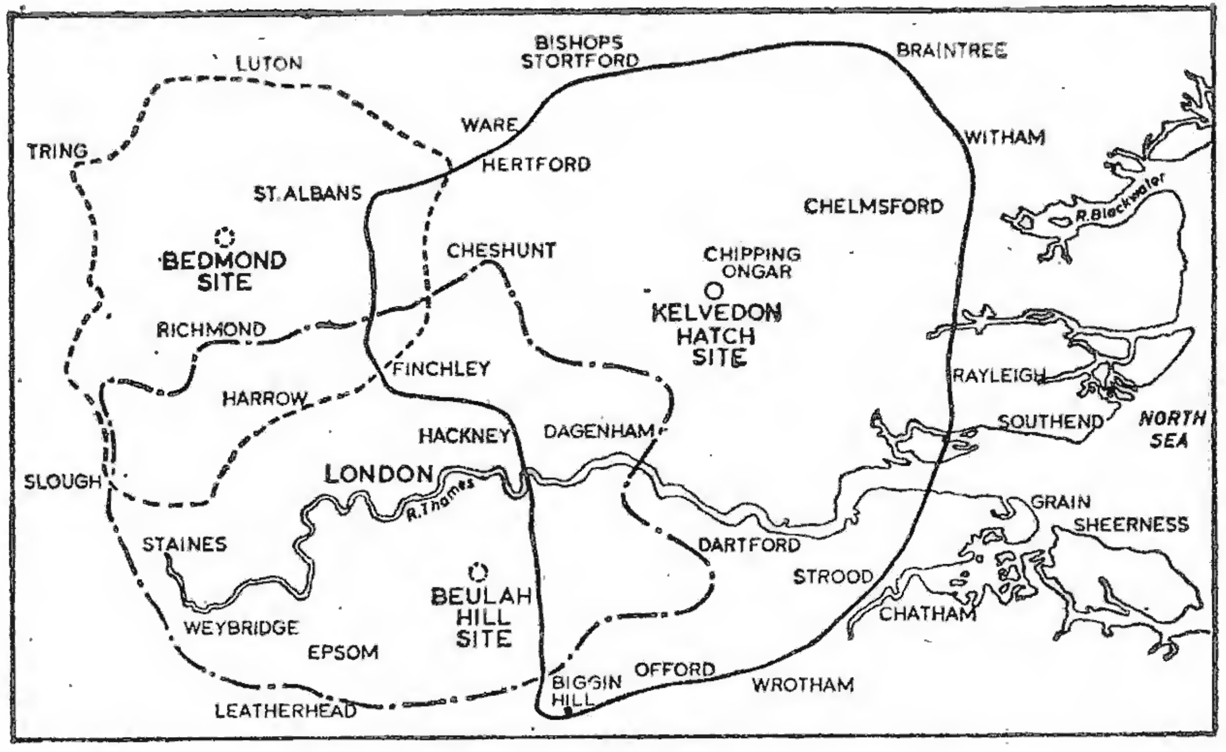
LAST year British radio receiver exports totalled only 62,327, according to statistics compiled by the British Radio Equipment Manufacturers' Association. This figure is less than half the number for each of the two previous years (122,792 in 1963 and 121,638 in 1962) and the income £565,000 as against over £1M in 1963 and in 1962.

Radio receiver imports, however, rose from 1,624,100 in 1963 to 1,891,500 in 1964, which represents an £820,800 increase to £5,232,400. Most of the imported receivers were of the transistor type and came from Hong Kong (1,447,400 in 1964).

The average price varies considerably from country to country, with, in 1964, Hong Kong being the lowest at £1 17s 4d (the previous year's price was £1 19s 3d) to Denmark at the other end of the scale at £12 7s 9d. Overall average price for imported transistor receivers was £2 13s 11d.

To quote from this year's B.R.E.M.A. report "It would be difficult to over-emphasise the serious nature of the threat presented by low-cost competition which the industry is now facing. The damage already done to the industry is severe but the situation will become progressively more serious as Hong Kong manufacturers expand their range of products in the radio field and as Japanese competition develops after the removal, with effect from 1st January 1966, of the quotas prescribed in the Anglo-Japanese Trade Treaty."





A car radio-telephone service *will be operating in the London area within the next few months. The three fixed stations for the scheme have been equipped by Pye Telecommunications and are ready to go into operation. One is located in South London at Crystal Palace, another near Kings Langley, Herts., and one near Brentwood, Essex. The overall service area is shown on the map. The licence for the car installation, which must be Post Office approved, costs £30 per annum. Charges will be 1s 3d for three minutes in the service area, plus 5d for every extra minute. For long distance calls the normal manually connected trunk call charge, plus a 1s "radio fee", will be made.*

Radio Show Cancelled

"BECAUSE of the decision of many of the largest companies in the British radio industry not to take part," the organizers of The '65 Show, as it was to be called, have been compelled to cancel the show planned for late August. Industrial and Trade Fairs Ltd., who took over the organization from Radio Industry Exhibitions Ltd., state that in the circumstances it would not be possible to hold a radio and television show which would fulfil its object of presenting the industry in all its aspects both to radio and television dealers at home and overseas and to the general public. The B.B.C. had promised full support and was planning to broadcast from the show throughout each day.

It is understood discussions are taking place concerning the form which an International Show might take in 1966.

Technical Writing

AS a result of experience gained since the introduction of the City & Guilds examination in Technical Authorship in 1960 the Institute has prepared a new one-year part-time course in Technical Writing. The first examination for the certificate will be held next year. Possession of this certificate will be a pre-requisite for sitting the revised Technical Authorship examination which will be offered in 1968. The new scheme for this examination envisages a two-year part-time course of study leading to the award of the certificate in Technical Authorship, which is intended as the normal qualification for technical authors in electrical, electronic or mechanical engineering.

I.T.A.-B.B.C. Aerial Masts.— *The final stage in the construction of a 1,265 ft cylindrical television mast at Emley Moor, near Huddersfield, Yorks, has now been reached. This mast, which is the tallest structure in Europe, is one of three being built by B.I.C.C. and E.M.I. to a new design for the I.T.A. and will be shared with the B.B.C. The other masts are located at Winter Hill, Lancs. (1,015 ft) and Belmont, Lincs. (1,265 ft). The mast consists of a 9 ft diameter steel tube (with a lift inside to give access to the aerials) for the first 900 ft. At the top of this is a 365 ft lattice structure to carry the television aerials, which will be enshrouded by a fibreglass tube. Starting from the top, the aerial sighting is: 1 and 2. Two u.h.f. aerials each capable of carrying two services; 3. Band III aerial for the I.T.A. (to replace the aerial on the existing tower); 4. Band III aerial for future development; 5. Band II aerial capable of carrying three f.m. sound services; 6. Outside broadcast dishes for the B.B.C.; 7. Dishes for the G.P.O.; and 8. Outside broadcast dishes for the I.T.A. The present mast is in the background.*

Radio and Space Research.—The name of The Radio Research Station, set up by the D.S.I.R. and now an establishment of the Science Research Council, has been changed to the Radio and Space Research Station. The main work of the station is carried out at Ditton Park, near Slough, Bucks, but in addition there is at Winkfield, Berks, a minitrack installation for tracking and receiving telemetry from satellites, and next year the radio telescope under construction at Chilbolton, Hants, is expected to come into operation. The Station is also responsible for small stations at Port Stanley in the Falkland Islands, at Singapore and at Lerwick, Shetland Islands.

I.E.E. Membership Structure.—It is proposed by the I.E.E. to change its membership structure. If the proposals are approved by the members and by the Privy Council, existing members will become fellows; associate members will be members; and a new class of associated members combining present graduates and associates will be formed. In addition a new class of non-corporate membership will be introduced for those who, while interested in some of the activities of the Institution (as for example doctors interested in medical electronics) do not qualify for any other class of membership. They will be known as associates. The total membership of the Institution increased during 1964/5 by just over 2,000 bringing the total to 54,150.

Appleton Lecture.—To commemorate the life and work of Sir Edward Appleton who, as recorded in our last issue, died on April 21st, the I.E.E. is to inaugurate an annual Appleton Lecture. Sir Edward was awarded the Institution's Faraday Medal in 1946 for "the conspicuous services rendered by him in the advancement of electrical science, particularly in the field of radio propagation." The date of the first lecture will be announced later.

PAL Transmissions by B.B.C.—On May 24th the B.B.C. started a new series of experimental colour transmissions from Crystal Palace (channel 33) using the PAL system. They are radiated during the BBC-2 trade tests from Monday to Friday from 1200-1300 and 1500-1600.

Soviet colour television tests have recently been conducted from Moscow via the satellite Molniya 1 to a receiving centre some 1,500 km away and back to Moscow via a land radio-relay link—a total distance of 80,000 km. There were comparative tests between N.T.S.C., Secam and also a Soviet modification of the French system.

A conference on "**Inelastic scattering of electrons by solids**" is to be held at the Cavendish Laboratory, Cambridge, on July 9th and 10th. It is being organized by the Electron Microscopy and Analysis Group of the Institute of Physics and Physical Society.

The millionth Avometer in the range introduced in 1923 was presented by Avo Ltd. to a Swedish company who donated it to the Royal Swedish Air Force. A further ten presentation models were given to the company's representatives in seven other countries and to three distributors in the U.K. who were in several cases handing them on to education establishments.

THIS MONTH'S COVER

The montage is composed from real and symbolic integrated circuits and links with the articles on integrated circuit technology on pages 331 and 337. The photograph shows a Texas Instruments operational amplifier with differential inputs and a Class B output capable of giving 10 V peak-to-peak with a 600 Ω load.

Component Standardization.—The Radio & Electronic Component Manufacturers' Federation is financially sponsoring four members of the delegation being sent by the British National Committee to the Tokyo meetings of the International Electrotechnical Commission in October. The "component" delegates will be D. S. Girling, of S.T.C., who will be covering fixed capacitors; A. G. Manson (Plessey), covering reliability and fixed and variable resistors; P. G. Williams (Mullard) integrated circuits; and R. T. Lovelock (Belling & Lee) environmental testing. The Federation is also jointly sponsoring with B.R.E.M.A. and E.E.A. Dr. D. G. Reynolds (Rank Organisation) who will be concerned with capacitors and resistors.

U.H.F. Television Aerials.—Concern has been expressed by the R.E.C.M.F. that some aerials which are being sold for u.h.f. reception do not comply with the accepted standard which ensures that aerials cover all four channels allocated to a particular area. The bandwidth required is 88 Mc/s with a minimum total deviation of 3 dB and a minimum deviation of 1 dB across any one channel. Some aerials being sold in the Birmingham area are marked for channels 40-50 but peak at 40 (the channel at present in use) with negligible performance on channel 50.

The London U.H.F. Television Conference, originally planned for September to coincide with the Radio Show, has now been postponed until November 22nd and 23rd. Sponsored by the I.E.R.E., I.E.E., Television Society and the U.K. section of I.E.E.E., it will be held at the I.E.E., Savoy Place, London, W.C.2. Further information and registration forms can be obtained from the Joint Conference Secretariat, I.E.R.E., 9 Bedford Square, London, W.C.1.

BIRTHDAY HONOURS

RECIPIENTS of honours on the occasion of the Queen's Birthday included:—

K.B.

Sir Ronald German, C.M.G., director general, Post Office.

K.B.E.

Walter Cawood, C.B., C.B.E., B.Sc., Ph.D., chief scientist, Ministry of Aviation.

C.H.

P. M. S. Blackett, F.R.S., professor of physics at Imperial College until appointment as deputy chairman of the Government Advisory Council on Technology.

C.B.

G. G. Macfarlane, Dr.Ing., B.Sc., A.M.I.E.E., director, Royal Radar Establishment.
J. A. Ratcliffe, C.B.E., F.R.S., director, Radio and Space Research Station, Slough.

C.B.E.

F. C. Wright, director, Standard Telephones & Cables Ltd.

O.B.E.

Lt. Col. A. W. Reading, M.C., T.D., A.M.I.E.E., of R.E.M.E.
T. H. Bridgewater, M.I.E.E., chief engineer, television, B.B.C.
T. C. Macnamara, A.M.I.E.E., technical counsellor, Associated Television Ltd.
D. Scott, Assoc.I.E.E., engineer-in-chief, Cable & Wireless.

M.B.E.

B. Ash, executive engineer, Post Office Laboratories.
Master Air Electronics Operator T. McHugh, D.F.C., A.F.M,. Royal Air Force.
F. E. Page, senior radio officer, s.s. *Loch Garth.*
S. F. Sharpe, senior executive officer, Government Communications H.Q.
W. Woolfenden, engineer-in-charge, I.T.A. station, St. Hilary, Glam.

I.S.O.

L. L. Hall, A.M.I.E.R.E., asst. staff engineer, G.P.O.
W. Darwin, chief executive officer, Government Communications H.Q.

B.E.M.

L. C. Ware, production supervisor, Mullard Radio Valve Co.

PERSONALITIES

E. L. E. Pawley, O.B.E., M.Sc.(Eng.), M.I.E.E., head of the B.B.C.'s Engineering Services Group since 1950, has been appointed Chief Engineer, External Relations. He will be responsible for contacts with the G.P.O. on engineering planning, and will continue his work in the international field with the European Broadcasting Union and the International Radio Consultative Committee. He has been chairman of the Technical Committee of the E.B.U. since 1952. Mr. Pawley, who took his degrees at the City and Guilds Engineering College, joined the B.B.C. in 1931 after five years in the European Engineering Department of the International Standard Electric Corporation and with the Bell Telephone Company, Antwerp.


E. L. E. Pawley

J. E. F. Voss, B.Sc., A.M.I.E.E., has been appointed to the post of Chief Engineer, Administration, in the B.B.C. and will be responsible for the work of the engineering information department, engineering secretariat, and engineering staff administration. After graduating at Northampton Engineering College, Mr. Voss became an education officer in the R.A.F. and rose to the rank of wing commander during his wartime service on radar duties. Mr. Voss joined the B.B.C. in 1949 as a lecturer in the engineering training department. In 1962 he was appointed Superintendent Engineer, Television (London Studios) and since June 1963, he has been Superintendent Engineer, Television Studios and Outside Broadcasts.


J. E. F. Voss

Donald Scott, Assoc.I.E.E., engineer-in-chief of Cable & Wireless Ltd. since 1963, is to retire at the end of September. He has been with the organization since 1919 and served overseas for many years before being appointed asst. e.-in-c. in 1955. He is 61. Mr. Scott will be succeeded by **A. S. Pudner,** M.B.E., M.I.E.E., M.I.E.R.E., aged 48, who joined C. & W. in 1934. The major part of his service has been abroad. He was appointed an assistant e.-in-c. in 1961 and since September 1963 has been deputy e.-in-c. The new deputy e.-in-c. is **R. W. Cannon,** A.M.I.E.E., who is 41 and has been asst. e.-in-c. since 1962. He joined the company in 1941. **John Powell,** M.Sc., A.Inst.P., A.M.I.E.E., M.I.E.R.E., is to become an asst. e.-in-c. He was a radio officer in the Merchant Navy for four years prior to joining C. & W. in 1946. He specialized in telegraph switching and automatic correction and in 1957 went to the Post Office Research Station returning to C. & W. four years later as assistant manager of the development centre. He was project engineer for the SEACOM cable link from Jesselton to Hong Kong. Mr. Powell, who is 41, obtained a B.Sc. degree in maths and physics from London University in 1955 and four years later was awarded his masterate for work in the field of electrical discharges in gasses.


A. S. Pudner

Prof. M. R. Gavin, M.A., D.Sc., F.Inst.P., M.I.E.E., is to be principal of Chelsea College of Science and Technology in September and vice-chancellor when the college becomes a university of technology. Prof. Gavin, who received his doctorate from Glasgow University for work on valves for decimetric waves, was for eleven years at the Research Laboratories of the G.E.C., Wembley, before entering the academic world. His first appointment was as vice-principal of the College of Technology, Birmingham, and head of the department of physics and mathematics. Since 1955 he has been at the University College of North Wales, Bangor, where he has been professor of electronic engineering and head of the department of electronic engineering set up in 1958.

B. J. Vieri, B.Sc., aged 24 of Reading, has won the Television Society's John Logie Baird Travelling Scholarship for 1965. He is at present carrying out research into television bandwidth compression under Professor Colin Cherry at Imperial College. Mr. Vieri obtained his degree in engineering at Birmingham University and subsequently joined Imperial College where he has just completed his studies for his Ph.D. The Baird Scholarship is awarded annually by Baird Television Ltd.

C. Robert Jefferies, who at the end of May retired from the position of sales director of London Electrical Manufacturing Company after 20 years' service, is to become honorary secretary of the International Radio Control Model Yacht Racing Union. Mr. Jefferies began his career in the radio industry with Lissen Ltd. in 1922. From 1927 to 1933 he was with Celestion and he then spent some time with McMichael.

F. Poperwell, technical director of Reslosound Ltd., has also been appointed to the board of Derritron Radio Ltd. as technical director. Both companies are in the Derritron Group. Before joining the Group in 1961 Mr. Poperwell was with G.E.C. for 35 years, and was technical supervisor of the sound equipment division.

M. A. Burchall, A.M.I.E.R.E., who has been with Advance Electronics for the past year, was recently appointed chief engineer of the Volstat Division at Hainault, Essex. From 1957 to 1961 Mr. Burchall was with Leo Computers and for the following three years with Elliotts where he was responsible for the design of the power supply system for the 503 computer.

John D. Clare, M.Sc., A.M.I.E.E., managing director of Standard Telecommunication Laboratories for the last 2½ years, has been appointed technical director of ITT Europe Inc. Mr. Clare joined S.T.L. from the Ministry of Aviation, where he was director of research, guided missiles. He will be based in Brussels at the European area management headquarters of International Telephone and Telegraph Corporation, where he will be responsible for the co-ordination of research, development and engineering in the Corporation's establishments in fourteen European countries. Succeeding Mr. Clare as managing director of S.T.L. is **Stanley B. Marsh,** B.Sc., A.M.I.E.E. Mr. Marsh, who is a graduate of London University, comes to S.T.L. from the Ministry of Aviation, where he was head of airborne radar development at the Royal Radar Establishment, Malvern. From 1940 to 1949 he was with the Post Office Research Establishment at Dollis Hill.


J. D. Clare


S. B. Marsh

L. F. Mathews, M.Brit.I.R.E., for several years ATV's assistant controller of communications and outside broadcasts and now Midlands' controller, has received the Radar and Electronic Association's plaque "for services to the Association." Mr. Mathews was with the B.B.C. prior to joining Associated Television in 1955.

Peter D. Hall, B.Sc., M.I.E.E., has been appointed an executive director of International Computers and Tabulators Ltd. Mr. Hall, who is 45, joined the Air Ministry after graduating at London University in 1940, and worked on the early development of radar and radar counter-measures. At the end of the war he was for five years at the Atomic Energy Research Establishment. He joined Ferranti in 1951 as a senior development engineer, and became manager of the Electronics Department four years later and manager of the Computer Department in 1958.

D. A. Bell, M.A., B.Sc., Ph.D., M.I.E.E., F.Inst.P., is to be the first incumbent of the newly established chair of electronic engineering in the University of Hull. He will take up the appointment in October. Dr. Bell, who in 1933 graduated B.A. in physics at Magdalen College, Oxford, where he took his B.Sc. the following year, was in industry (Cossor and British Telecommunications Research) for several years until 1949. He was then appointed to the staff of the University of Birmingham, where he received his Ph.D. From 1961 to 1964 he was director of the British research laboratory of AMF at Reading and is at present visiting professor of telecommunications at McGill University.

OUR AUTHORS

S. Forte, Ph.D., B.Sc., A.M.I.E.E., who contributes the article on integrated electronic circuits, is a graduate of Leeds University where he also carried out three years' post-graduate research in the field of network synthesis. He joined Marconi's research staff in 1955 and in 1959 took charge of a section investigating parametric amplifiers, varactor multipliers and general microwave solid-state techniques. For the past few years he has been responsible for the company's Microelectronics Applications Laboratory.

D. L. Grundy, Grad.I.E.E., and **J. Collins,** joint authors of the article describing a silicon transistor tape recorder in this issue, are both in the Applications Laboratory of Ferranti at Chadderton, Lancs. Mr. Grundy, who is 26, joined Ferranti's in 1955 where he initially worked on the suppression of voltage transients in silicon rectifiers. More recently he has been concerned with the use of semiconductors in high-power pulse generators, modulators, r.f. amplifiers and oscillators. Mr. Collins, also 26, has been with Ferranti since 1957 and went into the Application Lab. in 1961. He has worked on the development of stabilized power supplies and audio amplifiers and is now working on low noise microminiature amplifiers.

B. L. Hart, B.Sc.(Hons.), A.M.I.E.R.E., contributor of the article on a ramp generator in this issue, graduated in physics at Queen Mary College, London University, in 1951. He then spent two years in the Royal Corps of Signals before taking a year's post-graduate course at Edinburgh University where he obtained a diploma in electronics and radio. From 1954 until 1961 he was in industry, and is now a lecturer at West Ham College of Technology, London, E.15.

NEWS FROM INDUSTRY

G.E.C. wants more of the Computer Market.—The General Electric Company is stepping up its activities in the computer market especially in computers and systems for industrial applications and also for research and development applications. International Systems Control Ltd., with whom G.E.C. has for some time been associated in the computer field, has recently become a wholly owned G.E.C. subsidiary. G.E.C. is also spreading its interests through agreements with Compagnie Europeene d'Automatisme Electronique, of France, and the Scientific Data Systems Corporation, of America, for the joint development, manufacture and marketing of computers. Under the new set-up International Systems Control will manufacture and market under the name "I.S.C. Series 90" the S.D.S. range of compatible general purpose digital computers for scientific and engineering computing, simulation, and industrial control applications. The smallest computer in the range makes extensive use of monolithic integrated circuit techniques. Basic systems will be available at prices between £12,000 and £200,000.

New S.T.C. Communications Plant.—The Postmaster General opened a new factory of Standard Telephones & Cables at Basildon, Essex, on June 18th. Costing some £2.25M and covering nearly 24 acres, the new plant, built to accommodate the Transmission Systems Group, has a floor area of 447,000 sq ft. The greater part of the largest division in the Group, land line systems, has already moved from the company's North Woolwich, London, plant into the new factory, which at present employs about 2,600 people. Shortly to move to Basildon, are the microwave development laboratories and systems engineering departments from St. Mary Cray, Kent (for which 33,000 sq ft is reserved) and the microwave production units from North Woolwich. The address of the new plant is Chester Hall Lane, Basildon (Tel.: Basildon 3040; Telex 99101).

Whitehall Television Network.— *A large closed-circuit television system has been installed in the Ministry of Defence building in Whitehall to speed up the transmission of information within the Ministry. It has been designed to accommodate up to 32 camera channels feeding up to 100 screens in as many as 70 different locations. Both mobile and static cameras are used in the system. All the functions are remotely controlled from a single control room (shown above), which employs a solid state switching matrix. The duty controller (on the extreme left) can monitor any of the sound or vision connections made by the four operators, who each have push-button control consoles. In front of these consoles, is a rack with 32 pre-view monitors. These are in sections of four and controlled from a panel beneath. Eight-inch monitors and oscilloscopes are also provided in the control racks to allow engineers to check picture quality before transmission. Cameras can be focused from the control room. The network was designed and installed to Ministry requirements by Peto Scott Electrical Instruments Ltd., of Weybridge, Surrey.*

M.A.T.E. Feasibility Study.—The Ministry of Aviation has awarded a contract to Marconi Instruments Ltd. to undertake an intensive six-month feasibility study on the Multi-system Automatic Test Equipment project. This study will look into the problems of providing rapid automatic testing of electronic and electro-mechanical military equipment, together with facilities for fault location and the calibration of individual units. The investigation is to be carried out in conjunction with Honeywell Controls Ltd., the Marconi Company and the Wayne Kerr Company.

U.K. Television Transmitters for the U.S.A.—Marconi television cameras and transmitters are to be used in a new u.h.f. television station to be built by Television Chicago. This, Marconi tell us, is the first time British television transmitters have been sold in the United States. The order calls for two 25 kW u.h.f. transmitters and associated drive units (similar to equipment ordered for BBC-2) and six Mark V transistorized 4½-in image orthicon cameras.

Desk-sized Computer for Government Radar Research.—The Royal Radar Establishment, Malvern, has placed an order for a Marconi MYRIAD computer for use on advanced radar research projects. This is Marconi's first order for this new desk-sized computer which uses silicon microelectronic circuitry to provide greater reliability than has been possible with previous machines. Although designed primarily for air traffic control and defence applications, the high capacity and flexibility of the MYRIAD makes it suitable for use in many other fields. This real-time, on-line computer, which is to be delivered next March, is to have a storage capacity for 16,384 words of information. The basic price of the MYRIAD computer, which includes a standard 8,192 word store, a high speed interrupt facility and a "highway" input/output system, is in the region of £45,000. The "highway" system makes it possible to connect over 100 separate peripheral devices to the computer.

Colour Television Patent.—The Zenith Radio Corporation has been issued a patent on a basic colour television development originated in the company's research laboratories nearly 15 years ago. The original application, which covers an active matrix for providing three colour control signals from two colour transmissions and is widely used by receiver manufacturers, was first filed in 1951. The delay in issuing the patent was through extensive litigation with the Radio Corporation of America, who contested it.

Pre-packaged Semiconductors for Retail Market.—The International Rectifier Company, of Oxted, Surrey, have introduced a comprehensive range of packaged semiconductors through appointed I.R. retail centres. All the components offered are pre-packed and most include operating data. The range so far includes solar cells, transistors, rectifier diodes, zener diodes, silicon-controlled-rectifiers, selenium photo-cells and experimenter kits.

Loudspeaker connectors to the German DIN Specification 41529 should be adopted by U.K. manufacturers as standard for extension loudspeaker outlets according to the British Radio Equipment Manufacturers' Association in a statement to its members.

The Universal Capacitor Company, acquired by the London Electrical Manufacturing Company two years ago, has recently changed its name to LEMCAP Ltd.

SGS-Fairchild Ltd., of Ruislip, are to build a second factory for the manufacture of integrated circuits and consumer-type semiconductor devices.

Elliott-Automation Radar Systems Ltd. has been formed within the Elliott-Automation Group to co-ordinate its principal activities in radar. Commander H. Pasley-Tyler has been appointed chairman and E. A. N. Whitehead chief scientist.

Redifon Ltd. have supplied a £55,000 h.f. communications system to the government of Malaysia. The three stations are equipped with Redifon G426B 1.5 kW transmitters and R403 receivers.

Marconi "Autospec" error correcting equipment, to improve the quality of teleprinter channels, has been incorporated in an American-built radio communications network now operating in South Korea.

Radyne Ltd., of Wokingham, are to manufacture, under licence, Westinghouse ultrasonic cleaning equipment.

Hall-effect semiconductor devices are being made at A.E.I's Lincoln factory. The range includes two types of probe and two types of multiplier.

Price reductions of up to 40% are announced for some of the semiconductor devices being made by A.E.I.

Imhofs (Retail) Ltd., of 112-116 New Oxford Street, London, W.C.1, have been appointed the main Eddystone retail distributors for the London area.

Advance Electronics Ltd. and Van der Heem Electronics N.V., the Dutch company which makes test gear and communications equipment, have signed reciprocal manufacturing and marketing agreements.

Omron Ltd., of 313 Edgware Road, London, W.2 (Tel.: PADdington 2370), has been formed to market electronic and electro-mechanical timers, proximity switches and micro-switches. The technical manager is F. J. Pettit.

An industrial products group has been established within the Stevenage Works of the Guided Weapons Division of the British Aircraft Corporation.

The Electronic Machine Group are transferring their headquarters from Bromley, Kent, to Willow Lane, Mitcham, Surrey (Tel.: MITcham 7080; Telex 261250). Electronic Machine Control, a subsidiary, will also operate from this address, which is the headquarters and works of Vacwell Engineering, another subsidiary.

Sealectro Ltd. have moved from Surrey to Walton Road, Farlington, Portsmouth, Hants. (Tel.: Cosham 70323; Telex 86142).

Electronics at the Paris Air Show

DEVELOPMENTS IN NAVIGATION AND RADIO SYSTEMS SEEN AT LE BOURGET

On the day the Paris Air Show opened it was announced that British European Airways had just become the first airline in the world to land a passenger-carrying aircraft in normal service with the aid of an automatic flare-out system. The aircraft was a Trident jet, flying from Le Bourget to London, and the Smiths flight control equipment, working in the "autoflare" mode, had automatically controlled the aircraft in pitch and airspeed—the pilot still steering it in azimuth—during the final levelling-up, or flare-out phase, before touch-down. This event underlined most effectively what the static exhibition of the Air Show was saying in a variety of small ways—that more and more of the pilot's functions are being taken over by automatic systems. It is an inevitable trend, made necessary by higher speeds of flying, stringent safety requirements, economic pressures of airline operation and, in the military field, by the technical demands of the East-West arms race.

Radio and radar techniques are playing a big part as sensing devices in these automatic systems (autoflare, for example, is very dependent on the radio altimeter), while the information processing functions in the systems are performed by other electronic devices—notably analogue and digital computers. For navigation purposes, radio techniques are, of course, well established as means for providing ground references. Unfortunately they have not been as well developed and utilized as they might be, mainly because of slowness in reaching international agreement on ground stations and difficulties in providing maintenance for them. There has consequently been a strong impetus to develop navigational aids which are self-contained in the aircraft.

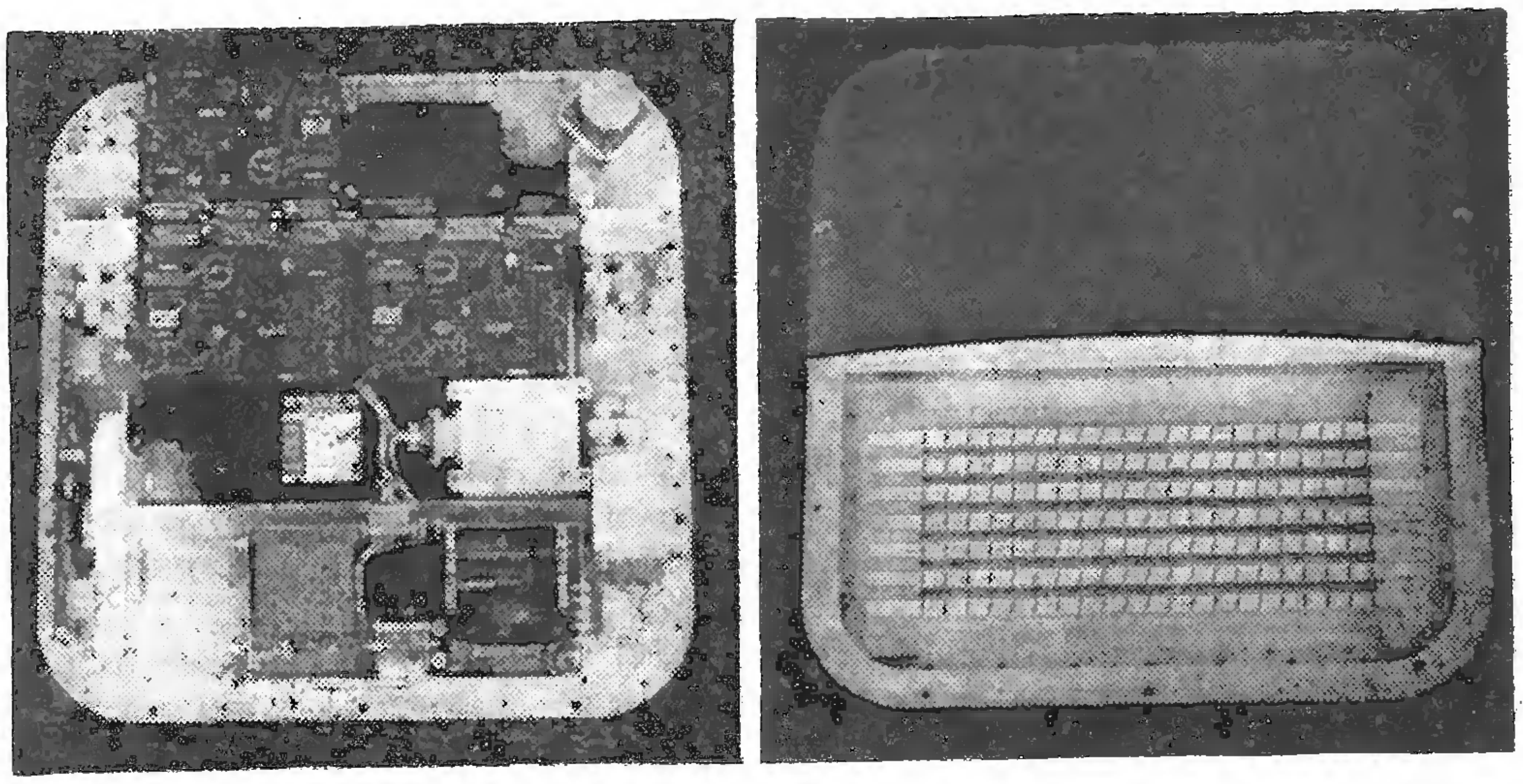
C.S.F. radar display unit and fire control gun sight in the Mirage IIIC aircraft.

Inertial navigation is one of the most strongly favoured self-contained aids at present and is of particular interest because it has been selected for the Concord supersonic airliner. In this system a fixed position reference is carried in the aircraft in the form of a gyroscope platform, and the aircraft's position, required course, estimated time of arrival and other data are calculated by an electronic computer from input measurements of aircraft acceleration in different axes relative to the fixed platform. The Concord system was shown partly by Ferranti, who are supplying a miniature inertial platform with three orthogonally mounted gyros and associated measuring accelerometers, and partly by the French company SAGEM, who are providing the electronic computer. This computer is a digital machine—necessary to obtain the required accuracy—but by the use of integrated circuit techniques it has been kept down to a weight of about 25lb and a size that would fit easily into a suitcase.

Airborne digital computers of similar size were shown by SAAB (for navigation and other operations in the Viggen military aircraft) and by Elliott (for fuel management and systems checking as well as navigation), who also displayed their latest inertial platform, the E-5, with gas-bearing gyroscopes.

Another type of self-contained navigational aid represented at the Show was Doppler radar. This enables aircraft speed to be obtained from continuous measurement of Doppler shift in radio waves transmitted from the aircraft and reflected back to it from the ground. It is also possible to derive distance travelled (by integration of velocity) and drift angle from the required track. Marconi, whose AD560 Doppler Navigation Sensor will be used in the Concord, were showing a new version, the AD570 which is notable for a very light-weight and compact aerial. This new model operates at 13.3 Gc/s and uses solid-state circuits except for the klystron transmitter output valve. The aerial comprises a linear array of slotted waveguides producing four beams, and the position of the array is servo controlled so that all the beams experience the same Doppler shift (measured by mixing the returned signal with a sample of the transmitted signal). In this way the array is aligned with the velocity vector of the aircraft (Doppler shift being greatest along the direction of motion) and drift angle is obtained by comparing the longitudinal axis of the aerial with that of the aircraft. The 1-watt r.f. output of the transmitter is time shared between the four beams by semiconductor switching. Accuracy of speed measurement is claimed to be better than 0.3% and of drift measurement better than 0.25°.

Also a new design was a somewhat simpler Doppler radar shown by Decca. This is intended for use in vertical take-off and short take-off aircraft, and because of the pressing need for saving weight in these aircraft the designers have traded accuracy for lightness, sim-



Doppler radar unit including electronics (left) and slotted waveguide aerials (right) developed by Decca for VTOL and STOL aircraft.

plicity and ease of installation by using a fixed aerial without stabilisation. The weight of the self-contained electronics and aerial unit (see photo) is, in fact, 30 lb. Again the operating frequency is 13.3 Gc/s, but the electronics are completely solid-state and the r.f. output from the varactor multipliers is equally divided by a passive network between three beams. One model, intended for helicopters, has an r.f. output of 100 mW and will indicate velocity along heading, across heading and vertical velocity with accuracies not worse than ±1%. A second model, with higher r.f. output power, will indicate the ground speed, accurate to within 3.5 knots (at 100 knots), and the drift, accurate to within ±0.5° of the true value.

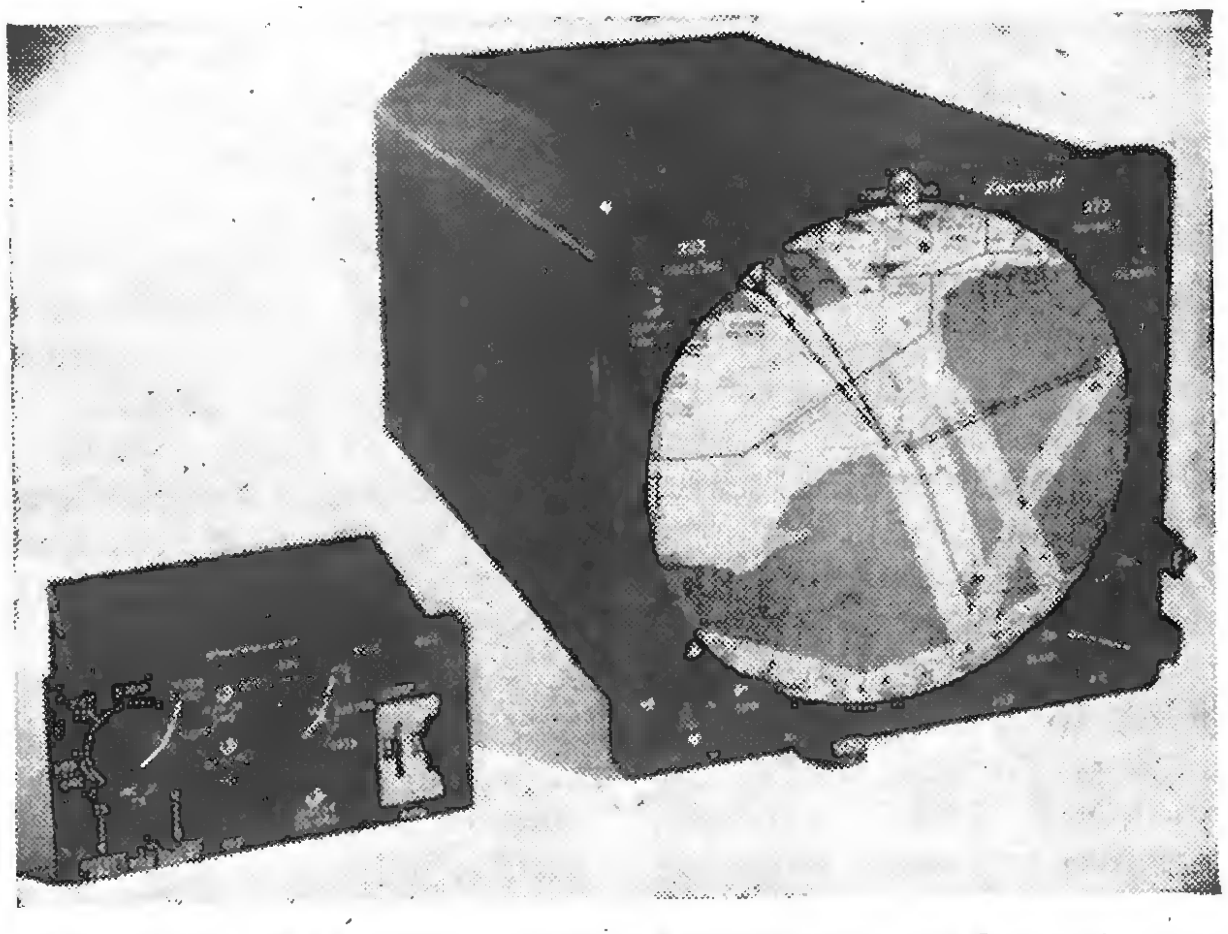
The radio altimeter is, of course, well established as a self-contained navigational aid and several advanced designs were on show. One example, designed for low altitude work, was the Honeywell radar altimeter, which uses the familiar pulse echo method of distance measurement to determine the aircraft's height. Operating at 4.3 Gc/s with a p.r.f. of 10-kc/s, the instrument is claimed to have high accuracy (typically ±1 ft at room temperature or ±5 ft over a temperature range of −65°F to 160°F) because it uses the leading edge of the returned pulse, rather than the vaguely defined middle, for time interval measurement. This is achieved by a closed-loop system which positions a gate pulse at the beginning of the radar return, and the voltage which performs the positioning is used as a measurement of time interval and hence altitude. Possible errors due to Doppler effect are avoided by the use of random-phase r.f. radiation.

Another self-contained radar device for height finding was the General Dynamics terrain following radar. This is a small equipment (33 in long, 8 in diameter and weighing 60 lb) with a fixed aerial dish, designed to assist military aircraft to fly high-speed low-level missions in any weather by guiding them over obstacles in their flight path. The K-band radar detects obstacles a selected distance ahead of the aircraft and the resulting range information is fed to an analogue computer which correlates it with height information from an altimeter and data on the aircraft's flight characteristics. The resulting output from the analogue computer then operates a simple indicator in which a pointer moves relative to a fixed horizontal reference mark, thereby telling the pilot whether to climb or descend. Alternatively the computer output can be used to control the aircraft's autopilot.

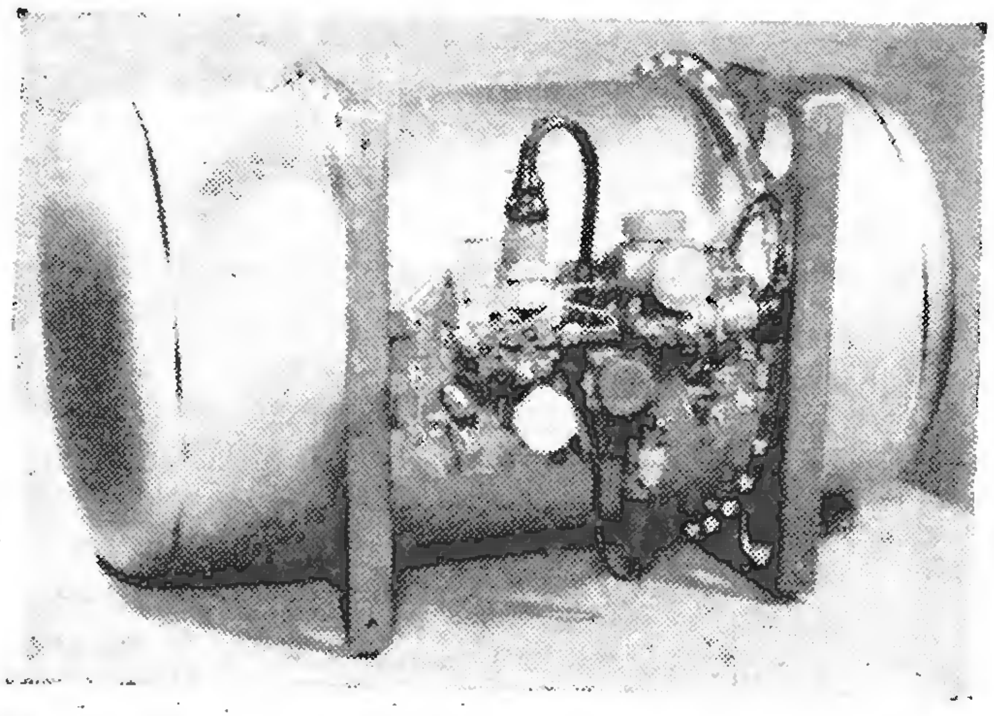
While airborne computers are certainly valuable in transforming inconvenient navigational data into more directly meaningful variables, they do not help a pilot's sensory system to take in large quantities of rapidly changing data presented to it simultaneously by a variety of indicators. One device which has helped considerably with this problem is the head-up display—an electro-optical unit by which the pilot sees luminous symbols on a transparent screen placed directly in his normal line of sight to the outside world. The images projected on to the screen (a half-silvered mirror) are collimated to infinity so that the pilot does not have to refocus his eyes in order to see them. The symbols include diagrams which are arranged to coincide with features of the outside world (e.g. a horizon line, a runway depicted in perspective) and instrument-type indicators.

Several versions were on show. Most of them, such as units by Computing Devices of Canada, Sperry and Elliott, used cathode-ray tubes to generate the images. The French company, C.S.F., however, argued that c.r.t. images suffer from lack of brightness in strong sunlight and showed as an alternative a purely optical system, designed for the Caravelle, in which the images were projected on to the screen from actual instruments as in an epidiascope. Indications of height, speed, horizon, deviation from ILS guidance and direction of flight were displayed, differentiated by different colours, and the brightness of the images could be varied according to the external light level.

A head-up display was also the means of visual presentation in an all-weather landing aid shown by Bendix. Called Microvision, it uses small microwave beacon transmitters stationed along both sides of the runway, and during the landing approach the pilot sees on the head-up display two converging lines of light spots corresponding to these beacons, marking the outline of the runway in perspective in much the same manner as landing lights. The beacons operate in the X band, transmitting 1-μsec pulses with a p.r.f. of 400 per sec, and in the aircraft the signals are picked up by small, fixed, wide-angle microwave aerials installed in the aircraft's nose. A direction-finding receiver then determines the angular position of the beacons with respect to the aircraft axes, and the co-ordinated information is presented on a c.r.t. in the head-up display. The system has a range of 10 miles.



Moving map display using 35mm film-strip shown by Ferranti.



General Electric 1-kW fuel cell battery as used in the Gemini two-man spacecraft.

Visual assistance of another kind is provided by the moving map display, of which several versions were shown. In this display a moving map of the route over which the aircraft is flying is presented by back projection of film-strip on a ground glass screen. The film strip is continuously positioned by the output of a navigational computer, and the projected image moves across the screen relative to fixed marks on the screen indicating the present position and heading of the aircraft—the effect being a continuous pictorial display of the aircraft's position relative to geographical features, airways, beacons and other navigational details on the route. Such a system is proposed for the Concord, and both Ferranti and Computing Devices of Canada were showing versions suitable for supersonic transports. If the film movement is controlled by a self-contained navigational aid and the pilot suspects that a position error has accumulated, the display can be manually re-adjusted by reference to the external navigational aid such as VOR/DME.

Ground-based systems for air traffic control and airfield surveillance included both primary and secondary radar equipments. Soon to be installed at Orly Airport, Paris, for ground controlled approach is a new transistorized X-band primary radar by Cie. Thomson Houston. It has a peak power of 200 kW and a range of 60 km on an aircraft like the Caravelle. Accuracy is claimed to be 30 metres in range and 0.1° in angle. C.F.T.H. are also involved in the Anglo-French secondary radar project SECAR, developed jointly by themselves and Marconi, which was demonstrated at the Show. The particular feature of the equipment is the Marconi aerial design, in which the control and interrogation pulses are radiated by separate aerial configurations to give different radiation patterns. A high speed switching system allows the patterns to be changed rapidly during the short interval between pulses and this permits the use of a single transmitter for both pulses instead of the usual two transmitters. Sidelobe suppression—necessary to ensure that the aircraft transponders are only activated by the main interrogation beam—is enhanced by the use of a high-speed phase shifter to produce special radiation patterns. Cossor, who have had secondary radar equipments working at London and Orly airports for some years, showed their latest air-traffic control transponder, the SSR 1600, which has now been fitted by many airlines.

For air traffic control radar, great assistance can be given to the controller by superimposing on the p.p.i. display "video maps" of the area, showing airways, reporting points, runway centre-lines, topographical features and other such data. In the Solartron video map system the map information is read from a glass plate negative by a flying-spot scanner synchronized with the radar scanner, the resulting video signal being mixed with the radar video signal presented on the p.p.i. display. An important requirement is that the resolution of the map scanner must be as good as that of the radar and this demands a scanning spot size as small as 0.001 inch. Solartron demonstrated their latest model in which the whole of the equipment has been compressed into a single-bay cabinet instead of the two-bay cabinet required for previous models.

Among the wide range of radio communications equipment on show were a number of new portable transmitter/receivers which had been made remarkably small and light by the use of integrated circuits. Typical of these was a Collins Radio Company of Canada u.h.f. transceiver which provides a.m. communication on any one of 3,500 channels in the frequency range 225-400 Mc/s. Transmitter r.f. output power is 2 watts and the receiver sensitivity is 3 μV. The equipment, including a self-stored whip aerial and a battery, is contained in a case measuring only 4 in by 6 in by 2 in. Sperry displayed an airborne integrated-circuit Loran receiver which was claimed to occupy less than one-third of the volume of any existing unit. Other new airborne sets, but using more conventional transistor circuitry, were an h.f. single-sideband transmitter/receiver with 400 W output power, shown by Compagnie Industrielle des Telecommunications, and a v.h.f. transmitter/receiver for use in business aircraft and gliders, shown by C.S.F., which weighs 2 lb, provides 12 channels and has a transmitter output power of 2 watts.

Equipment for spacecraft

Space-flight was well represented, both by individual contributions of manufacturers to the various satellite and research rocket programmes and by a special Space pavilion in which the work of the French Centre National d'Etudes Spatiales was displayed. For the general public the *pièce de resistance* was undoubtedly a full-size model of the Russian "Vostok" space vehicle in which Yuri Gagarin became the first man to travel in space. Radio systems in Vostock included a 20 Mc/s transmitter used for telemetering and as a position-finding beacon, and a two-way telephony link (9 Mc/s, 20 Mc/s and 143 Mc/s) for contact with ground stations at distances of 1,500 to 2,000 km. In addition there were radio systems for remote control of the orbit and of the flight of the capsule, a medium- and short-wave receiver, and a tape recorder, which could be automatically started by a verbal command from the astronaut and made to playback rapidly by a command transmitted from the ground. Television cameras were installed for viewing the astronaut when the craft was travelling over the U.S.S.R. A 10-day supply of electrical power was provided.

For the recent American two-man space flight in the Gemini vehicle, electrical power was provided by oxygen-hydrogen fuel-cells batteries, and the by-product of the reaction—water—was used by the astronauts. General Electric (U.S.A.) showed examples of these batteries which are now being made as standard production items. These ion-exchange cells convert the energy of the chemical reaction of hydrogen and oxygen into electrical energy, and are notable for producing more electrical power per unit weight of fuel than any other devices except nuclear plants. Two batteries of the type shown in the photograph were used in Gemini. Measuring 25 in long by 12½ in in diameter and weighing 68 lb, the cylinder contains 96 solid-electrolyte fuel cells, grouped into three modules, and can produce 1 kw at 25 V. The total fuel consumption is 0.9lb/kWh.

MONTREUX TELEVISION SYMPOSIUM

IMPROVEMENTS CONTINUE IN COLOUR AND MONOCHROME TRANSMISSION EQUIPMENT

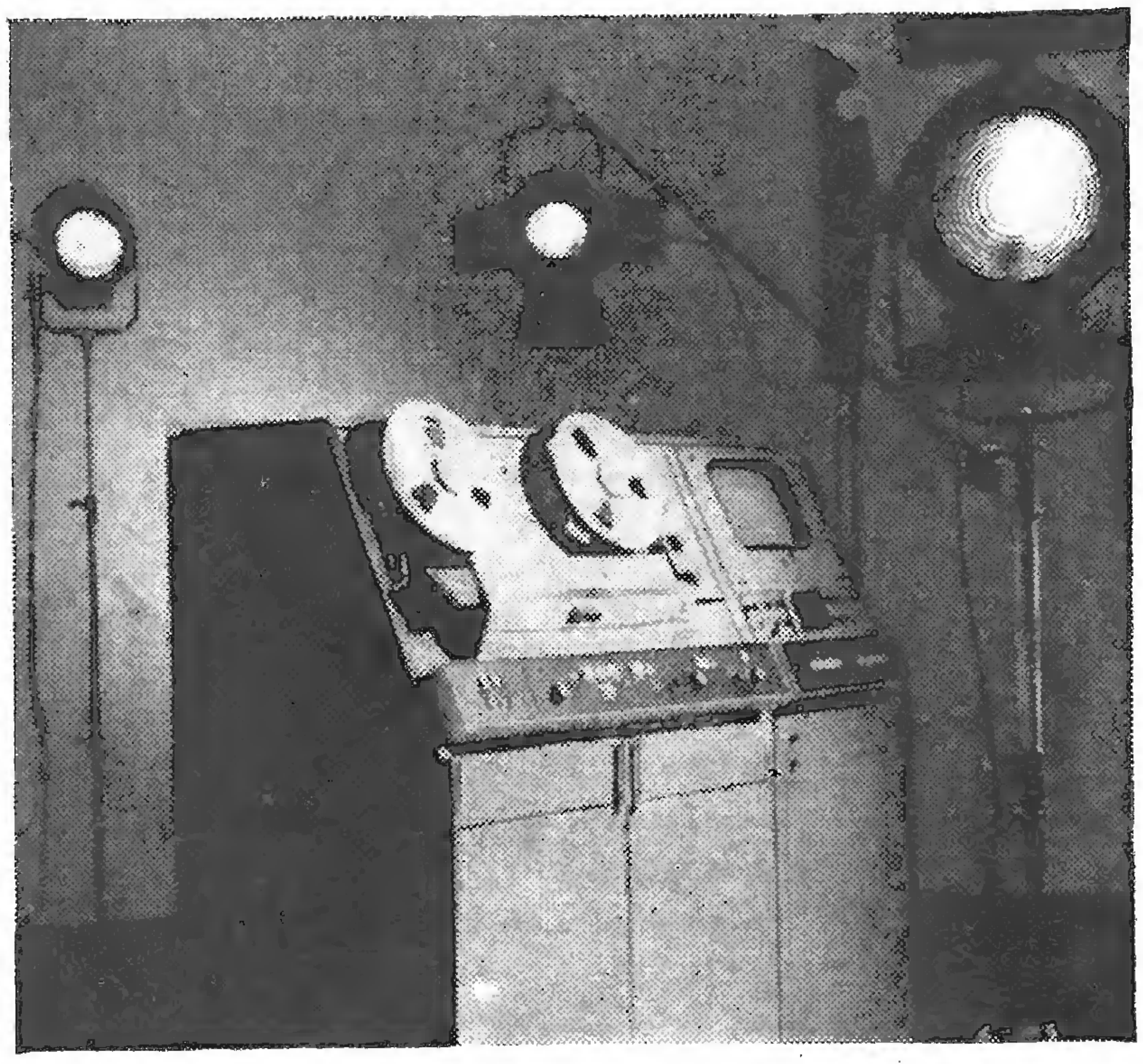
COMING as it did in the wake of the famous Vienna C.C.I.R. conference, the 4th International Television Symposium and Equipment Exhibition at Montreux inevitably reflected the strong current interest in colour television problems. After a masterly survey of colour signal transmission systems by Professor R. Theile (Institut für Rundfunktechnik, Munich), the case for N.T.S.C. was reiterated by Dr. G. H. Brown of the Radio Corporation of America. Commenting on the Vienna meeting, he remarked wrily that Europe semed to have devised very successfully a method by which no decision on a common standard could possibly be made. He compared the debacle at Vienna with the unfortunate situation in the U.S.A. in 1950 when the F.C.C. chose a non-compatible field sequential system of colour television—"but we were saved by incompatibility and had three years to rectify the mistake; I hope you also will have such good luck."

Much interest has been aroused by the Telycolour Ltd. system of colour television—claimed to allow conversion of existing black-and-white receivers at a cost of less than half that of the original set—and a short progress report on the scheme was presented by Henry Benaroya, managing director of the company which has its headquarters in Jersey, C.I. The essence of the scheme is that an optical mosaic made up of tiny lenses and colour filters (corresponding to the phospor dot pattern of a shadow-mask tube) is mounted in front of the screen of a special single-beam monochrome c.r.t., and during the period of each picture point the tube spot illuminates three filter elements (red, green, blue) in turn. During this sequence the beam is modulated according to the transmitted colour information, so that the integrated picture point seen by the viewer has the required brightness, hue and saturation. Benaroya showed a picture of a Pye camera adapted for the system and stated that a display tube was being developed by Rank Electronic Tubes in the U.K. and should be ready for demonstration within a few months. One of the critical features of the system is that, in order to achieve accurate illumination in space and time of the tiny mosaic filter elements by the tube spot, exceptional linearity of scanning is required. Doubts on whether this could in fact be achieved in a practical system were expressed by a number of delegates. Dr. Brown said that R.C.A. had worked on a system of this kind many years ago but they had not been skilful enough to solve the linearity problem. He remarked that they had given it up and decided to devote their energies to manufacturing the shadow-mask tube, since this seemed slightly less difficult.

Projection colour systems

The 75-year-old French veteran television inventor Georges Valensi has also been occupied with the problem of accurate registration, but in this case with registration of projected colour television images on large screens. Normally large-screen colour pictures are produced by separate red, green and blue projectors, the images from which have to be optically registered on the screen. Since all three projectors contribute fine-detail picture information the optical setting-up can be extremely difficult. Valensi's idea, put forward in a paper, is to overcome this registration problem by exploiting the limitations of the eye in perceiving fine detail in colour. (This effect is also used, of course, to make possible narrow-bandwidth chrominance signals in transmission systems.) Only two projectors are required—one to project basically the luminance information of the image in full detail and one to superimpose on it the colour information. Since all the fine detail is provided by the luminance image, any slight misregistration of the colour image, which contains only relatively coarse-detail colour information, does not cause fuzziness in the picture. The colour projector provides only hue information, at a high constant level of saturation, while the luminance projector provides both luminance and saturation information—the light output being modulated by a signal proportional to the ratio of luminance to saturation. Valensi suggested several schemes by which the principle could be put into practice, one using two Eidophor type projectors, another in which the saturated colour projector utilized ferroelectric light modulators and another in which the colour projector was formed by a light-modulating electrostatic storage tube and a trichrome optical filter. It will be interesting to see if anyone makes use of these ingenious ideas as more applications are found for large-screen colour television.

Projection of compatible colour television pictures is the latest facility offered by the Eidophor company, and a brief description of their simultaneous triple projector was given by J. C. Mol. The greatest advantage of this technique over projectors using colour cathode-ray tubes in Schmidt optical systems is the high light output that can be obtained. It will be recalled that in the Eidophor system, light from a powerful gas discharge lamp is modulated by means of a mirror carrying an oil film, the surface of which is deformed by a scanning electron beam modulated by the video signal. The first adaptation of this principle to large-screen colour display took the form of a single projector with a colour filter wheel working on the frame sequential system. This, of course, was not compatible with colour broadcasting standards. The latest equipment, however, is compatible, in that it has three integrated projector units, for red, green and blue, operating simultaneously. The triple mirror and electron gun system is



Ampex VR-2000 video tape recorder provides a 6 Mc/s vision bandwidth with automatic timebase and colour saturation control.

enclosed in a common vacuum chamber. Maximum light output is achieved by use of two light paths from the gas discharge lamp. The three primary colour video signals are individually corrected for black-level, contrast and gradation. The input can be either separate RGB video signals or a composite N.T.S.C. colour signal.

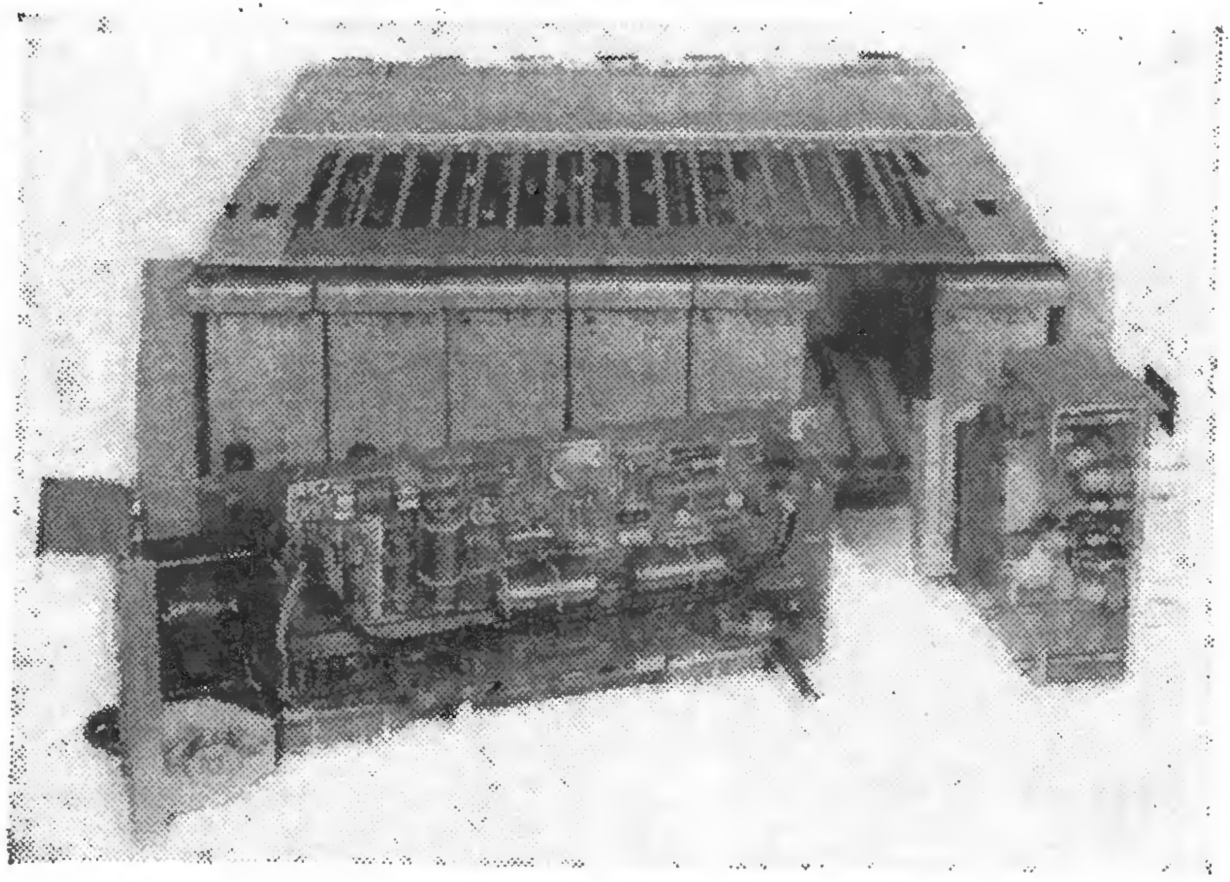
A trend in colour camera development mentioned by several speakers was the introduction of new compact and sensitive photo-conductive pick-up tubes in place of image orthicons. The tubes named were the Plumbicon (developed by Philips), which has a lead oxide target, and the Selenicon (developed by R.C.A.), which has a selenium target. Dr. Brown said that R.C.A. were using Selenicons in the chrominance channel of their four-tube camera, the luminance channel having an image orthicon. Resolution obtainable was equal to that of the best monochrome equipment. The three-tube camera could, under optimum light conditions, produce pictures equal in quality to those from a four-tube camera, but the four-tube camera would operate successfully over a wider range of light conditions.

Simplification of the optical arrangements for RGB analysis in vidicon colour cameras were described by Miroslav Beno of the Radio and Television Research Institute, Prague. In place of the conventional dichroic mirror system he had used a compact arrangement of two dichroic mirrors with their planes intersecting to form a cross. Astigmatism was corrected by a single cylindrical lens cemented to this colour-dividing cross. Another version of the same principle was a solid prism comprising six parts, and this had been used in a four-tube camera. Beno stated that resolution in the direct optical channel (green) exceeded 100 lines/mm, but was reduced to 50 lines/mm in the other two channels, in which the image was reflected.

During the colour systems controversy preceding the Vienna conference, there was a good deal of discussion about the performance of video tape recorders on colour. Protagonists of the N.T.S.C. system were at pains to point out that although the earlier recorders were inadequate for the European 625-line N.T.S.C. standard, with a 4.43 Mc/s colour subcarrier, the latest equipment was well able to cope with the stringent requirements of wider bandwidth and smaller timing, differential gain and differential phase errors.

Demonstrations of colour recording on such equipments were given by R.C.A. and Ampex. The R.C.A. machine was the established TR-4, modified to allow the so-called "high band" performance by the insertion of appropriate modules providing a bandwidth of 6 Mc/s and automatic timing control. It was stated that a completely new model, the TR-22HL, would soon be introduced in which high-band/low-band operation would be provided as a standard feature.

The Ampex VR-2000 recorder also offers high-band performance. This again means a video bandwidth of 6 Mc/s, with automatic control of the timebase and of colour saturation. The timebase regulator is a closed-loop control system in which the phase of the recorded colour burst is compared with the phase of the incoming colour burst, any error being used to advance or delay (by means of a variable delay line) the composite signal so that the error is eliminated. Differential phase error is claimed to be less than 5°. Since the carrier frequency and deviation in the frequency modulation recording system had to be increased for the 625-line N.T.S.C. signal (the deviation being now 7 to 9 Mc/s), the response of the recording head had to be improved. The head amplifiers (using nuvistors) have therefore been made integral with the head to reduce lead length and stray capacitance, and rotary transformers have been used for signal transfer, in place of slip rings, to reduce noise and cross-talk. Signal/noise ratio is claimed to be 43dB.



Modular transistor pulse distribution amplifier, type B4002, shown by Marconi at Montreux.

Solid-state circuitry

Apart from colour television, the other main technical trend reflected by the symposium was that of continued transistorization—which now has added interest because it points unmistakably in the direction of integrated circuitry. Marconi's, for example, exhibiting for the first time at Montreux, showed their new solid-state 4½-inch image orthicon the Mark V. One of the circuit design problems in this camera arose from the need to provide a solid-state line scan generator that would deliver a current of 2.7A p-p into the pick-up tube scanning coils. As a result of having to operate the output transistor in the fully saturated condition during its switching function a delay of about 6 μsec on the timebase was caused by hole storage when the transistor was switched off. This, together with delay in the camera cable, had to be compensated by closed-loop control of the scan generator timing. Marconi's also showed transistor pulse distribution amplifiers.

Another interesting transistorized equipment, seen in Europe for the first time, was a transportable video recorder made by the Sony Corporation of Japan. Measuring 25in high by 18 in by 17 in and weighing 145 lb, it has two heads recording on 2-inch tape on the principle of one field per scan. One head records a composite video signal while the other records a field sync signal, the combination of the two making up one complete field. This arrangement is adopted to simplify head alignment and reduce picture distortion. A 7-inch reel of tape will give a recording time of 1 hour.

The fact that solid-state circuitry can now be used right up to microwave frequencies was illustrated by compact portable microwave television relay equipment shown by Microwave Associates. One miniature transmitter weighing 12 lb, for example, allows communication in the 2,000 Mc/s band over a distance of 12 miles with a 2-ft dish aerial, and will operate for over an hour on its nickel cadmium battery. Another transmitter, weighing 15 lb and measuring 5 in × 10in × 7in, delivers 1 watt of r.f. output in the frequency range 1,990-2,110 Mc/s. The 500 Mc/s silicon transistor oscillator is electronically tuned to any of 7 channels, and the output, frequency modulated by the video signal, is first amplified by silicon transistor stages to a power of about 3 watts then frequency doubled twice by silicon varactor diodes and filtered to produce a 2,000 Mc/s output. The audio signal is conveyed by a 7.5 Mc/s sub-carrier imposed on the video signal. Varactor diodes are also used in the associated superhet receiver to multiply a crystal-controlled frequency of 125 Mc/s by 18 to obtain the required 2,000 Mc/s local oscillator frequency.

Efforts to introduce integrated circuits into television equipment were touched on by Dr. Brown of R.C.A. He gave as an example a thin film scanning generator designed for use with experimental flat image panels now being considered as alternatives to electron-beam pick-up and display tubes. This generator has 200 stages, operating in a fashion similar to that of a shift register, with strip output conductors spaced 0.0021 in apart. Two of these generators, deposited as thin film circuits (including thin film transistors) on the same substrate as the image panel, are used for orthogonal scanning of a panel with 200 X-conductors and 200 Y-conductors.

MANUFACTURERS' PRODUCTS

NEW ELECTRONIC EQUIPMENT AND ACCESSORIES

Transistorized Scope and Graticule Projector

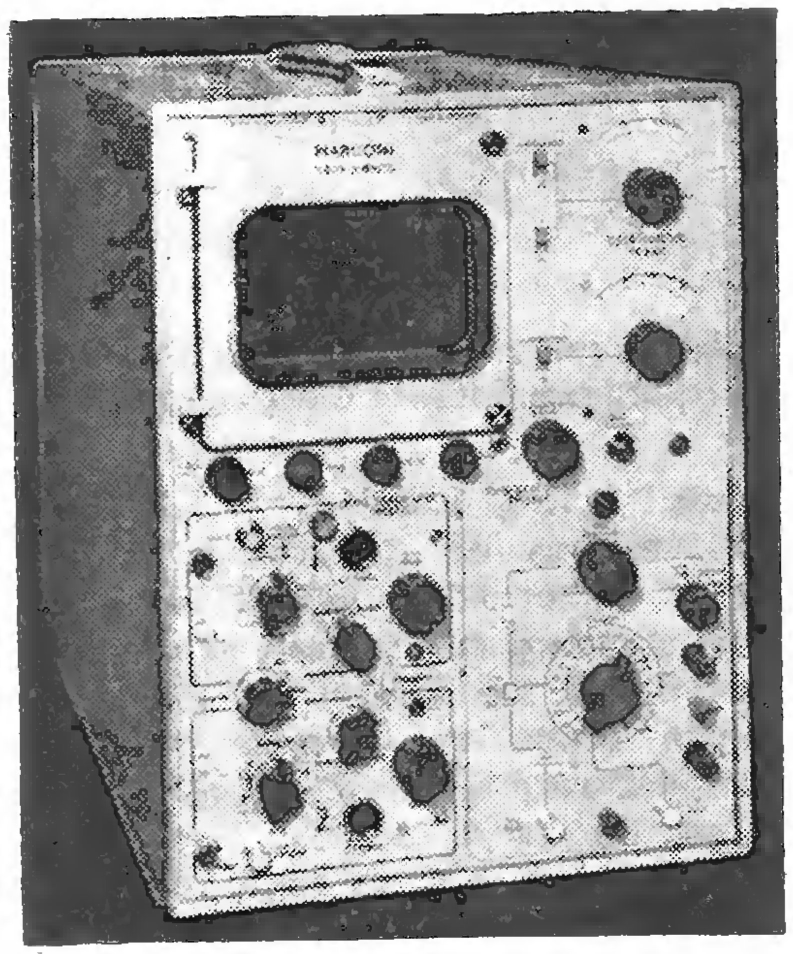
TRANSISTORS are used extensively in the new Type TF2201 oscilloscope announced by Marconi Instruments Ltd., of St. Albans, Herts. Cathode followers are retained in the input stages (E88CC) and allow a maximum input voltage of ±500 V.

Two Y units are currently available, the single-trace TM6970 and dual-trace TM6971, and one X (time base) unit, TM6967. Other plug-in units are in an advanced stage of development. Both Y units have a bandwidth of 30 Mc/s, a sensitivity of 50 mV/cm, and a rise time of 12 nsec, with an overshoot of <5%. Voltage (and time) measurements can be made with either the shift system, with an accuracy of ±2% for the 10 cm shift, or the graticule system, with an accuracy of ±3% of the standardized deflection (5 cm). The dual-trace unit will display the signals A, B, A+B, A and B on alternate sweeps, or A and B chopped at 500 kc/s. The input impedance of both units is 1 MΩ with about 30 pF shunt capacitance. A delay of 180 nsec is introduced by a delay line which permits measurement of the leading edge of a triggering waveform.

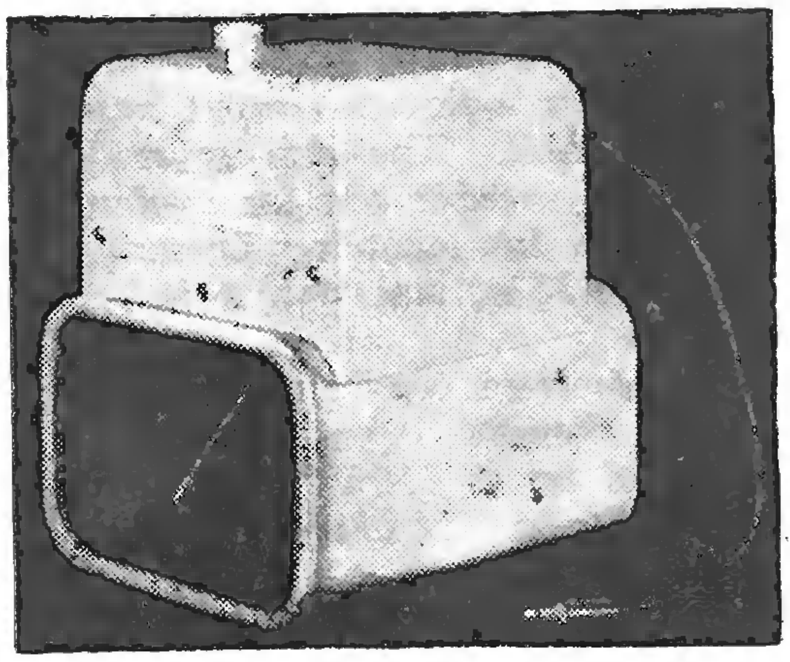
The X amplifier has a bandwidth extending from zero to 5 Mc/s with a sensitivity of 160 mV/cm. Time measurements can be made from 50 nsec/cm to 500 msec/cm but a sweep speed as fast as 10 nsec/cm is available. Sweep and gate output signals are made available at an impedance of 100Ω. Two probes are provided, one with a switchable 10:1 attenuator. The TF 2201 (and the modified earlier types) incorporates a bezel with a rectangular viewing area and BNC connectors.

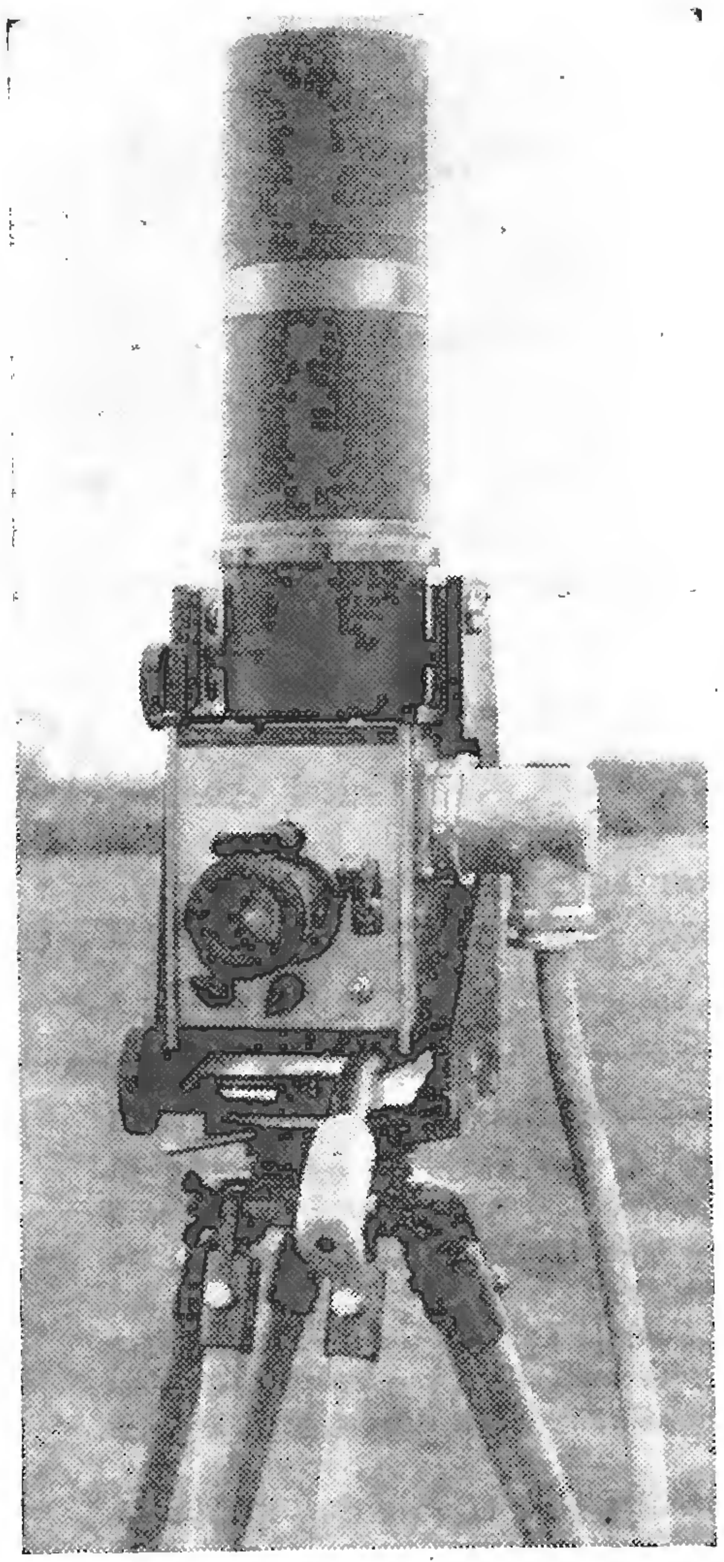
A useful optional accessory is the graticule projector. This eliminates parallax error in graticule measurements by causing an image of a graticule, or other specially drawn scale, to be superimposed on the face of the c.r.t.; both being viewed through a gold-sputtered mirror inclined at 45° to the tube face.

7WW 304 for further details



Above: Marconi Instruments transistorized oscilloscope, Type TF2201, and (below), Graticule projector





G. & E. Bradley laser rangefinder (tank version) mounted on a tripod for demonstration purposes.

Laser Rangefinders

A LASER rangefinder developed for military use is announced by G. & E. Bradley Ltd. Two types have been produced, a rugged tank version (using a periscope) and a lightweight artillery version (with telescope and integral power supply) both capable of measuring to an accuracy of 10 m in 10 km.

Operation is simple. The operator sights the target through a periscope or telescope and, if necessary, sets a range gate to exclude echoes from targets up to 2 km. The laser is then fired and the range read from a display whose image can be seen through the eyepiece.

The ruby laser is Q-switched by a rotating prism and gives a 20 nsec pulse of about 0.2 joule. The tendency of such lasers to give multiple pulses, due to the relatively long dwell time of the prism, is eliminated by use of a Daly-Sims prism interposed between the rotating prism and the light source. The prism is composed of a long quartz plate with Brewster angle windows and is arranged so that only a narrow beam of light is transmitted by total internal reflection, thus giving a laser build-up time fast enough to allow only one pulse to be transmitted. It is intended to include a kryptocyanine Q-switch (a dye which is bleachable at higher energy levels) in later models.

Received pulses are sensed by a photomultiplier and threshold detector, which reduces probability of detection of unwanted echoes. Apart from the variable range gate, a further control is provided to enable the distance of up to four targets within the beam-width to be read with a single laser pulse. The wide dynamic range of sensitivity on a minimal visibility day and the low sensitivity to atmospheric backscatter is provided by varying the receiver gain during the transmission-reception period. This is achieved by applying a linearly increasing voltage with time to the photomultiplier.

The address of G. & E. Bradley Ltd. is Electral House, Neasden Lane, London, N.W.10.

7WW 305 for further details

Electronic Stethoscope

AN amplifier able to produce up to 80 dB of gain (at 80 c/s) is incorporated in the head of the "Medi-O-Scope" stethoscope recently introduced by D. A. Pitman Ltd., 91 Heath Road, Weybridge, Surrey. Four transistors are used in the amplifier, which is driven by two 1.3 V mercury batteries that provide over fifty hours continuous operation. The net weight of the stethoscope is 200 grams.

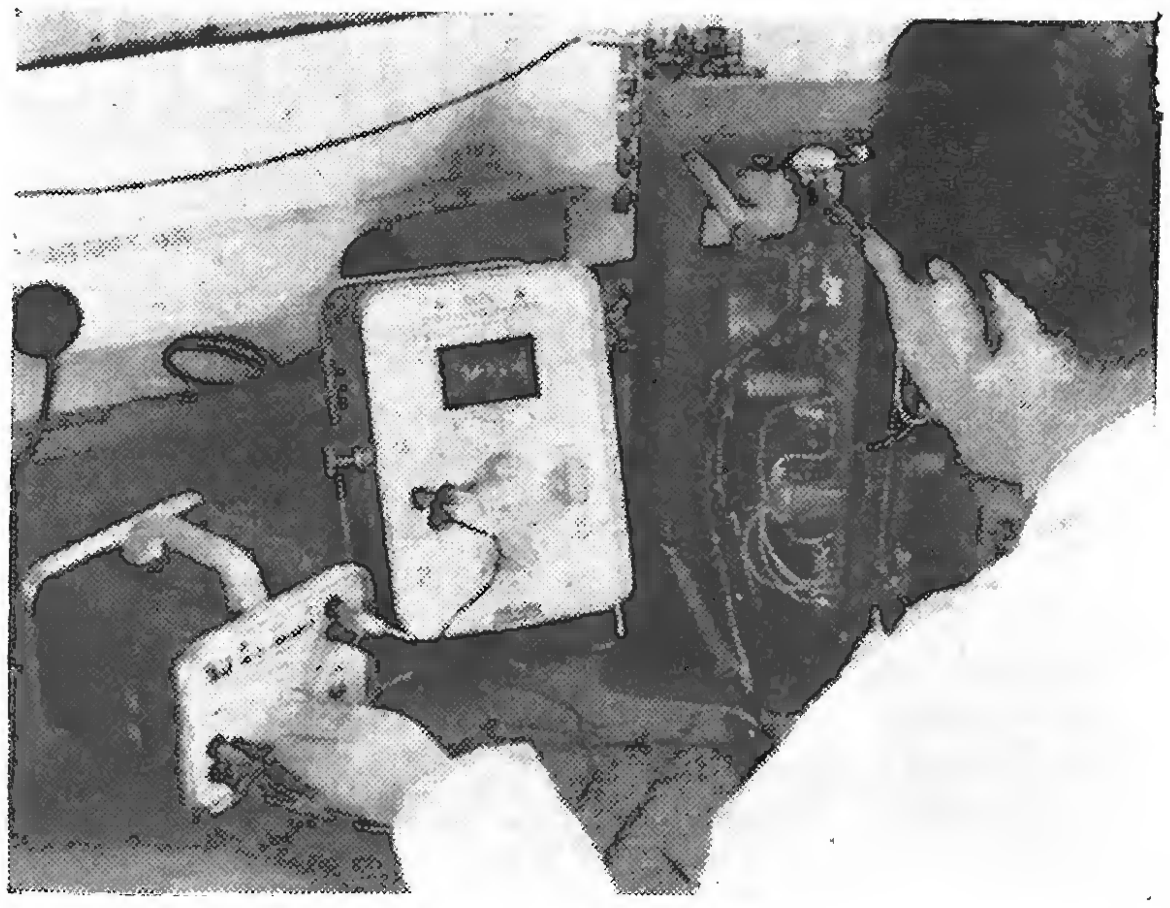
7WW 306 for further details

Optical Micrometer

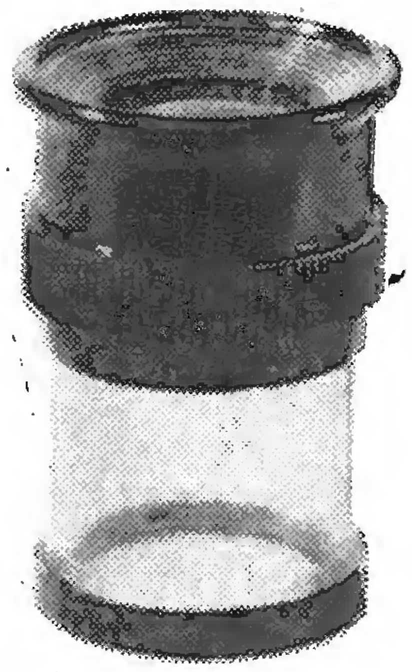
A POCKET-SIZED optical micrometer, consisting of a cemented three-element 7X magnifying lens on a clear plastic mounting-cell fitted with an interchangeable measuring reticle, is being offered by Proops Bros. Ltd., of 52 Tottenham Court Road, London, W.1. The reticles are of optically flat glass on which comprehensive sets of reference scales, angles, circles, radii, etc., are etched. To give an example of the scales provided, one of the five reticles available has the following markings: 0-10 mm in 0.2 mm divisions; 0-0.5 inch in 0.005 in divisions; angles from 0° to 90° in 5° steps; radii in increments of $\frac{1}{32}$in from $\frac{1}{16}$ to $\frac{3}{8}$in; circles of $\frac{1}{64}$ to $\frac{1}{16}$ in diameter in increments of $\frac{1}{64}$ in; thickness widths in $\frac{1}{64}$ and $\frac{1}{32}$in steps from $\frac{1}{64}$ to $\frac{1}{4}$in; and circles in decimal diameters from 0.005 to 0.050in.

The retail price of these micrometers, complete with carrying case and one reticle, is £2 15s. Additional reticles are available at £1 each.

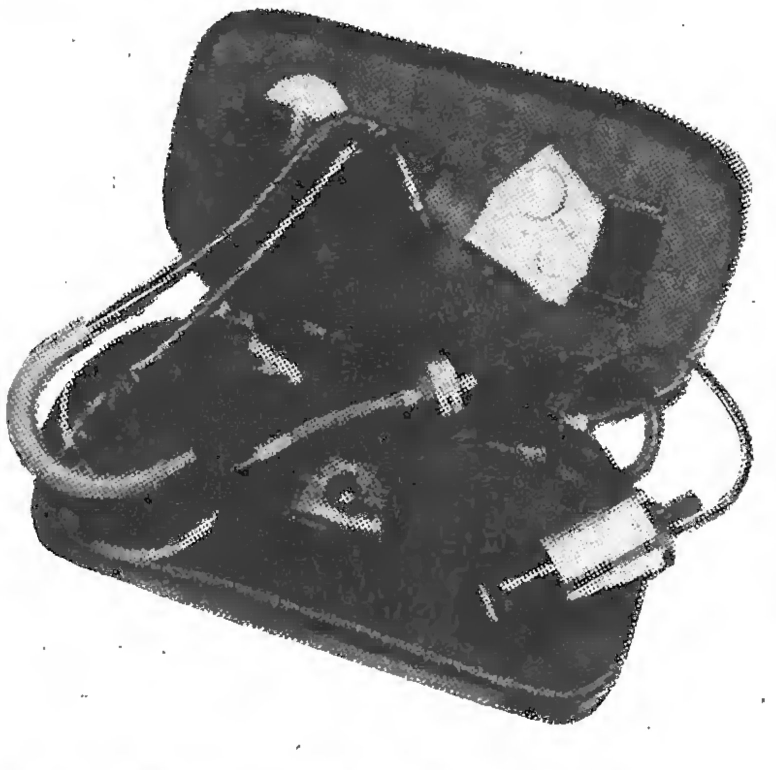
7WW 307 for further details



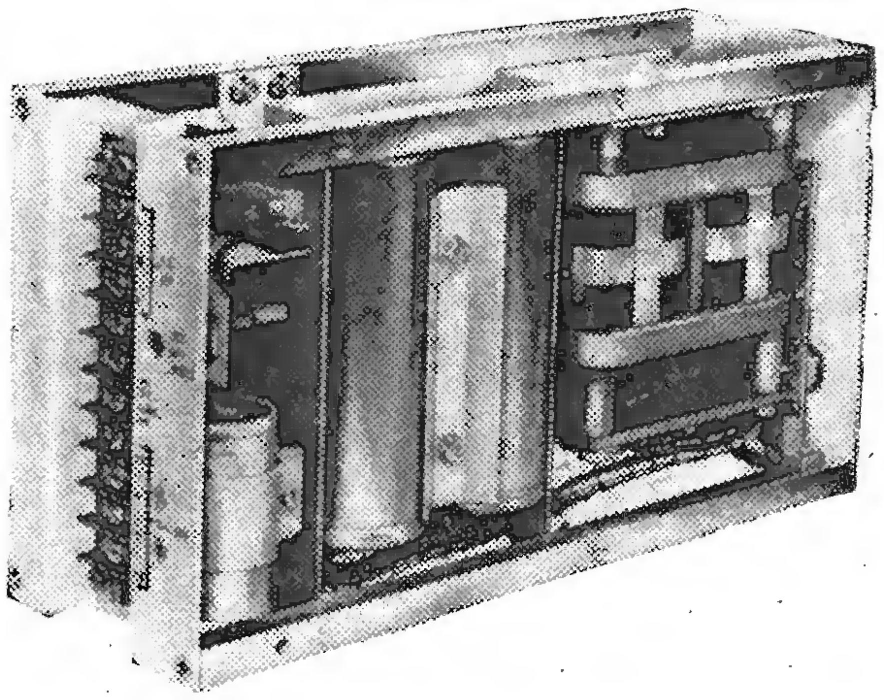
Dawe Type 652A digital voltmeter being used with the a.c./d.c. converter Type 653.



Optical micrometer from Proops Bros. Five reticles with various sets of reference scales are available.



Electronic stethoscope from D. A. Pitman.



Modular power supply unit with stabilized d.c. output from Advance Electronics.

Digital Voltmeter

A LOW-COST digital d.c. voltmeter and an associated a.c. to d.c. converter have recently been introduced by Dawe Instruments Ltd., of Western Avenue, Acton, London, W.3. Two basic versions of the voltmeter are offered: Types 652A and 652AX. A simple standard cell is used in the first of these for the reference voltage to measure down to 0.2 mV, with an overall accuracy of ±0.2% of maximum readout on each range. The other version employs a zener diode reference to measure down to 0.1 mV, with an overall accuracy of ±0.1% of maximum readout.

Both versions have four ranges (three digit displays) with maximum readouts of 1, 10, 100 and 1,000 V d.c. on mechanical counters with automatic decimal point indication; input impedance is 2.2 MΩ. The average readout time is two seconds but for maximum readout it is five seconds. Dimensions are 11×6×7$\frac{1}{2}$ in, and weight is about 9 lb.

The associated converter, designated 653, can handle inputs (floating or earthed) of up to 500 V r.m.s., at frequencies from 50 c/s to 25 kc/s. Nominal accuracy is ±0.3% of maximum output on each range from 50 c/s

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 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 7WW, and it is then necessary only to enter the number(s) on the card.

Readers will appreciate the advantage of being able to fold out the sheet of cards enabling them to make entries while studying the editorial and advertisement pages.

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.

to 10 kc/s, and within ±0.4% up to 25 kc/s; linearity on all ranges is 0.05%. Dimensions are $5\frac{1}{4}\times6\frac{3}{4}\times7$ in; weight is about 6 lb.

7WW 308 for further details

Modular Power Supply Units

SILICON semiconductors are used throughout the new series of modular power supply units introduced recently by Advance Electronics Ltd., of Roebuck Road, Hainault, Ilford, Essex. Twelve models are included in the "PM" series covering 7 to 50 volts and 1 to 10 amps.

These units are designed for use in customers' equipment and, through the use of silicon semiconductors, may be operated at temperatures of up to 60°C with a temperature coefficient of 0.02% per degree Centigrade. The output voltage is factory pre-set to a specified voltage within the ranges 7-15, 15-30 and 30-50 and a potentiometer is provided to allow fine adjustment of ±0.5 V. Simple modifications to the voltage taps and resistors allow coarse adjustment to be made if necessary.

All the models in the "PM" series incorporate an overload circuit which has an automatic re-set facility that allows the units to resume normal operation once the overload is removed. Specification features include an output ripple of less than 1 mV p-to-p at full load, output resistance of less than 8 mΩ (less than 2 mΩ on some models), an output stability against input voltage change of greater than 1,000:1 and an output impedance of less than 0.25 Ω at 100 kc/s. Unit dimensions range from $5\times3\frac{1}{2}\times5$ to $6\frac{1}{2}\times9\times15$ in, weight from 4 to 44 lb and price from £26 to £88.

7WW 309 for further details

Picoampere Source

CURRENTS of from 10^{-12} to 10^{-4} amps are provided by the new Model 261 picoampere source from Keithley Instruments Incorporated, of Cleveland, Ohio. The output which, is adjustable by three digital dials, has an overall accuracy of better than 1.5% and better than 0.25% from 10^{-11} to 10^{-7}. The precision resistors (with values from 10^5 to $10^{12}\Omega$) used in this instrument are accessible from the front panel and provide a useful means for calibrating high-value ohmmeters and resistance bridges.

Although designed primarily as a source for the calibration of sensitive d.c. measuring instruments, the Model 261 may also be used as an accurate current source for zero suppression and potentiometric current measurements; where, with a suitable detector, currents as low as 1 pA may be measured with an accuracy of ±0.5%. A polarity switch is provided.

Excluding Government import charges, the Model 261 is priced at £180 and is available in the United Kingdom through Livingston Laboratories Ltd., of 31 Camden Road, London, N.W.1.

7WW 310 for further details

Pickup Arms

A SERIES of pickup arms and accessories are being offered by Transcriptors Ltd., of 26 Bloomsbury Way, London, W.C.1, a company which has only recently entered the audio market. Ten- and twelve-inch arms for use with cartridges requiring the universal half-inch fixing centres are available and are suitable for any cartridge designed for tracking up to 5 grammes.

Design features include a modular counterweight system that allows adjustment in the lateral and longitudinal planes, a wheel lifter facilitating the placing of the stylus on to the record, fine balance cursor for precise adjustment of tracking weight, and single-hole fixing to the motorboard.

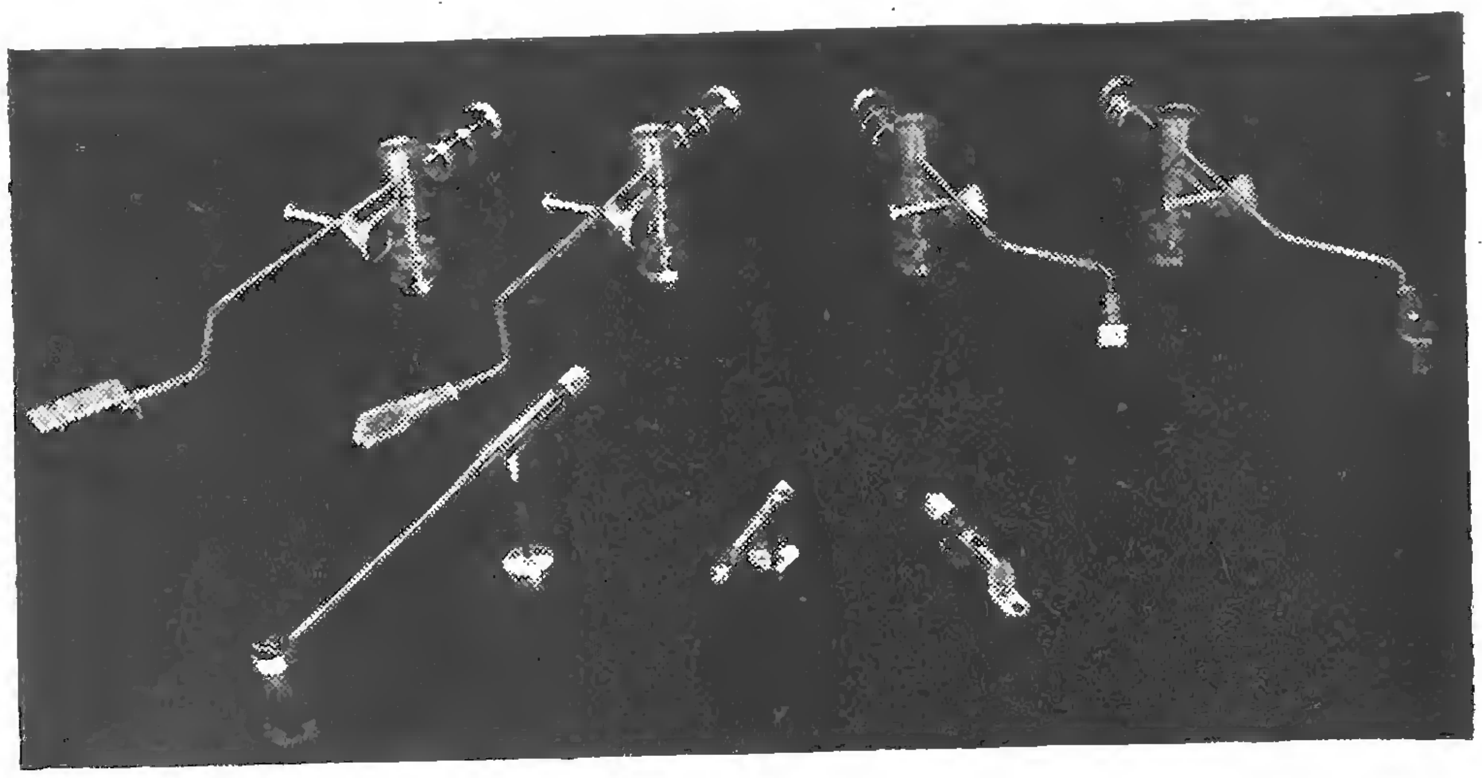
In addition to the universal models, arms are available for the E.M.I. EPU 100 cartridge, the Decca FFSS cartridges and the Decca Deram cartridges. Standard price for all arms is £9 7s.

Among the accessories is a pair of stylus scales weighing up to 5 grammes which have an accuracy of 1/50th of a gramme and incorporate a bubble balance indicator sensitive to 1/100th gramme an adjustable balance cursor A sweep arm that tracks at ¾ gramme and a stylus brush.

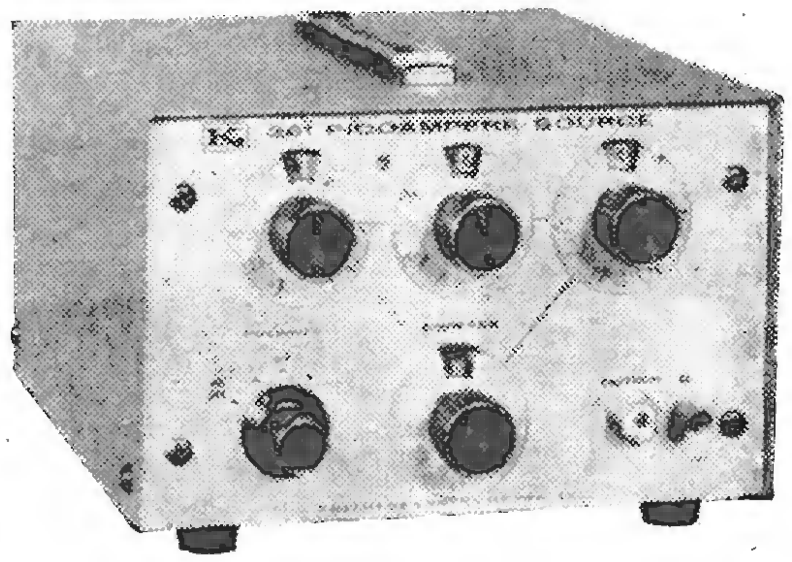
7WW 311 for further details

Portable Gaussmeter

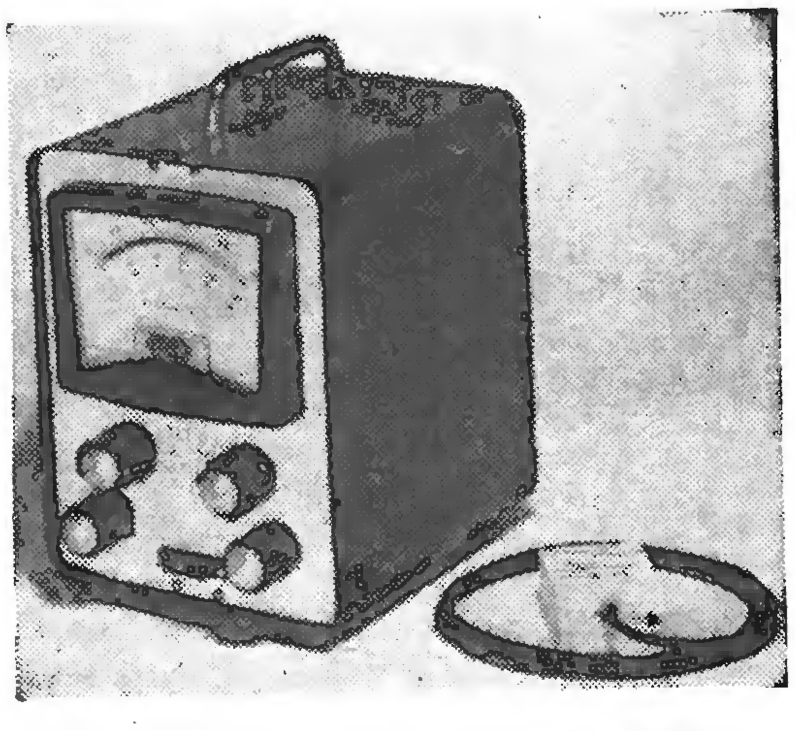
PROVIDING linear static measurements of magnetic field strengths over a wide range—5,000 to 105,000 gauss—the new portable gaussmeter from the Plessey subsidiary, Preformations Ltd., should be of particular interest to the audio engineer. A probe consisting of a small plate of either indium antimonide or indium arsenide is used with this instrument which changes resistance when placed in a magnetic field normal to its surface. The change in resistance is an almost linear function of flux density through the range covered and, irrespective of field polarity, the indica-



"Transcriptor" pickup arms and some of the accessories available.



Model 261 picoampere source from Keithley Instruments Inc. has an adjustable output from 10^{-12} to 10^{-4} amps.



Portable gaussmeter from Preformations.

tion from the probe, which can be as thin as 0.15 mm, is always of a positive nature.

The Fluxmaster, which comprises a transistorized ohmmeter and a d.c. amplifier, was originally developed for research into ferro-magnetic resonance at microwaves, but can also be used in super-conducting solenoids and in apparatus for research in proton resonance, mass spectrometry and plasma physics.

Preformations Ltd., whose products are sold under the brand name Magloy, reside at Cheney Manor, Swindon.

7WW 312 for further details

D.C. Voltage Standards

A SERIES of precision voltage reference sources with accuracies of 0.02 % and 0.001% and maximum d.c. voltages of from 100 mV to 1,000 V are being made by the Electronic Development Corporation, of America. Voltage is selected by means of five digit switches which provide 1 μV steps on the low voltage models and 10 mV steps on the 1,000 V unit.

Features of these instruments include a vernier control that swings through zero without polarity switching (for digital voltmeter and analogue/digital converter applications), and high resolution —1 part in 100,000. All models in the series employ solid state circuitry and are available either as portables or for rack mounting.

These instruments are available in the United Kingdom from Electrautom Ltd., 408 Finchley Road, London, N.W.2. Prices range from approx. £300 to £500, according to model and whether fitted with null meter.

7WW 313 for further details

Colour Tube and Valves

A NEW 25 in 90° rectangular colour tube and a range of valves especially designed for colour timebase and e.h.t. circuits were recently announced by Mullard Ltd. This colour tube does not require an external implosion shield, and like monochrome tubes with this "direct viewing" facility, eliminates annoying multiple reflections from room and window lighting. Comparing the new tube, designated A63-11X, with the earlier 70° round tubes, considerably more picture area is obtained—approximately 1,800 sq cm—and about 4 in can be saved in cabinet depth. The actual screen size is 50.4 cm × 39.4 cm.

Although it has a wider deflection angle no extra scanning power is required for this colour tube, as an improved electron gun is used which has allowed the neck to be reduced in diameter to only 36.5 mm. The A63-11X operates from a 25 kV e.h.t. supply, with electrostatic focusing, and magnetic convergence and deflection. It incorporates the Mullard colour-selection shadow mask with graded holes.

All of the valves in the new range for colour receivers, which incidentally is the first to be produced by Mullard's, have "magnoval" (B9D) bases reducing the seated height and thus simplifying screening problems in a receiver. The line output pentode in the series, the PL505, is of single electrode structure and is rated for a maximum anode dissipation of 34 watts and a peak anode current of 1.4 amps at zero bias and with 160 volts on the anode and screen; the heater consumption is only 12 watts. Overall physical dimensions including the pins and anode top cap are 124 mm × 39.7 mm in diameter.

A three-rod method of anode construction is used in the new e.h.t. rectifier GY501 which has a peak inverse voltage rating of 35 kV and an output current of 1.7 mA. Overall dimensions, again including pins and anode top cap, are 91.2 mm × 30.2 mm diameter. Also included in the range is a booster diode (PY500) with a design-centre anode current rating of 440 mA and a peak anode current rating of 800 mA, and a shunt stabilizer triode (PD500) for line output stages. Design-centre ratings for this valve are: anode voltage 25 kV, negative grid voltage 150 V and anode dissipation 30 W. Overall physical dimensions (including pins and top cap) are 115.2 mm × 39.6 mm diameter.

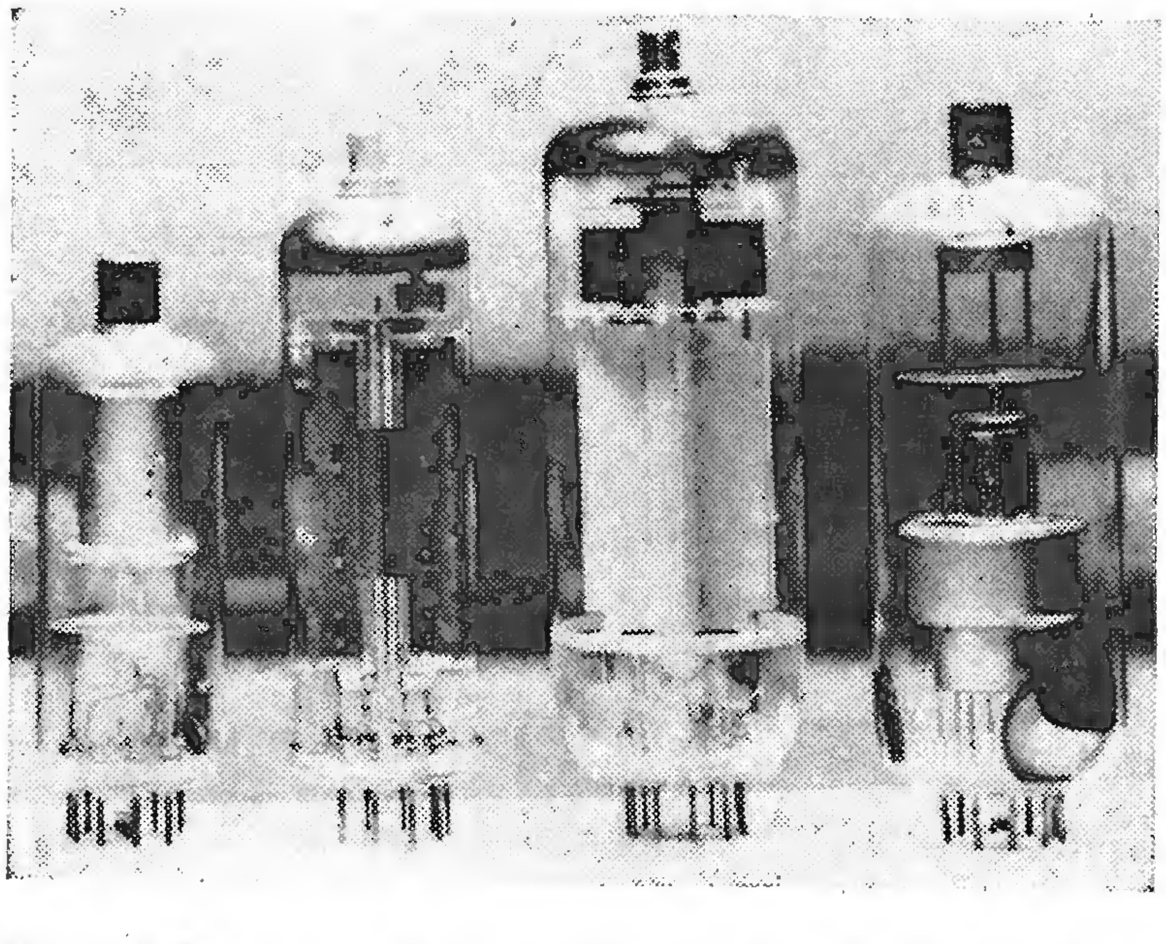
Deflection coil assemblies, line output transformers and convergence yokes, etc., for colour receivers are also being made by Mullard's, whose address is Mullard House, Torrington Place, London, W.C.1.

7WW 314 for further details

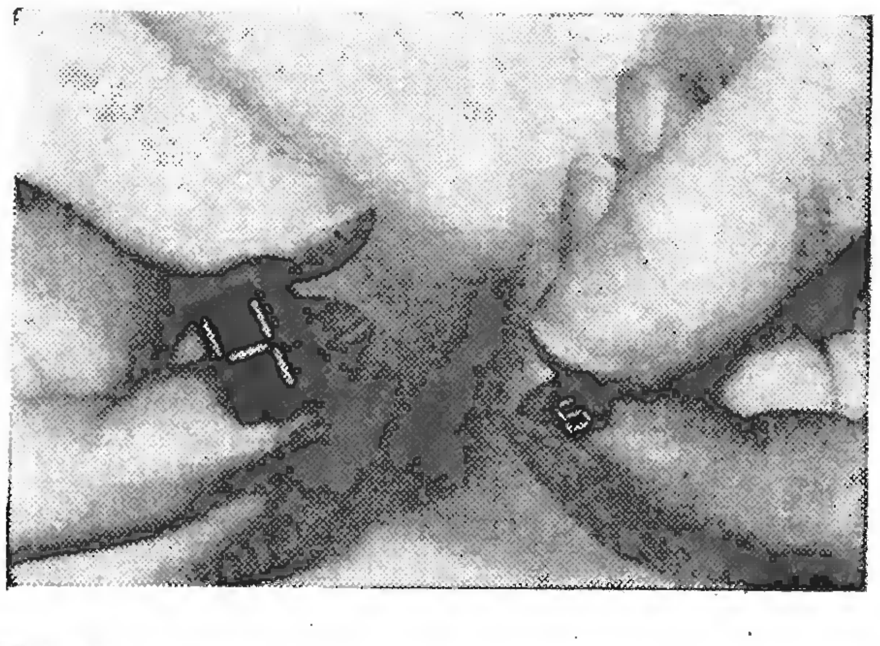
Digital Indicators

MINIATURE, multi-filament digital readout indicators with character heights of from $\frac{1}{8}$ to $\frac{1}{2}$ in are announced by the Pinlite Division of the Kay Electric Company, of Fairfield, New Jersey. These "Midgi-Lites" are, as the trade name implies, very small and employ a seven-filament incandescent lamp to provide the characters.

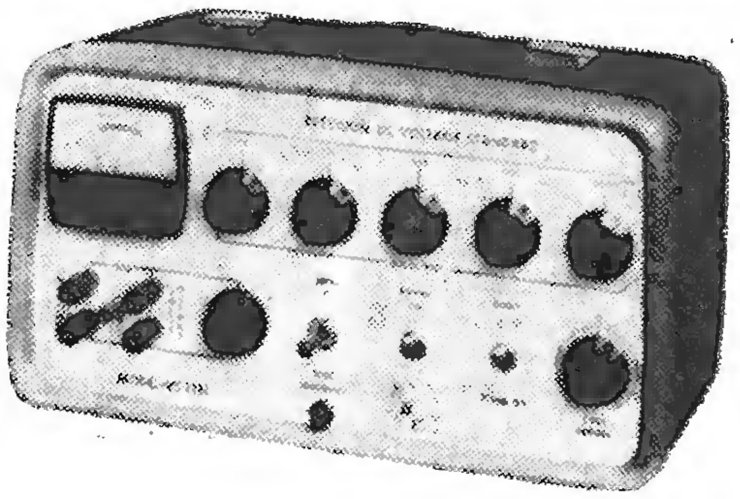
The power consumption with all the segments in use can be as low as 70 mW and potentials as low as one volt can be used. However, to maintain a proper brightness/contrast ratio under varying ambient conditions, including sunlight, the supply voltage and current can be increased to bring up the bright-



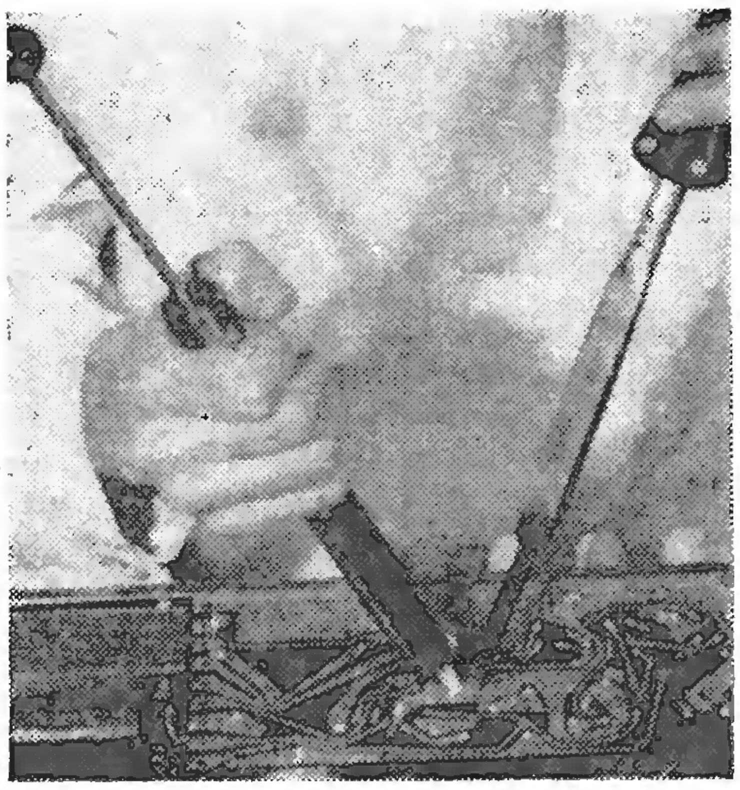
Mullards first range of valves designed specially for time base and e.h.t. circuits of colour television receivers. From left to right: E.H.T. rectifier GY 501, booster diode PY 500, line output pentode PL 505 and shunt stabilizer triode PD 500.



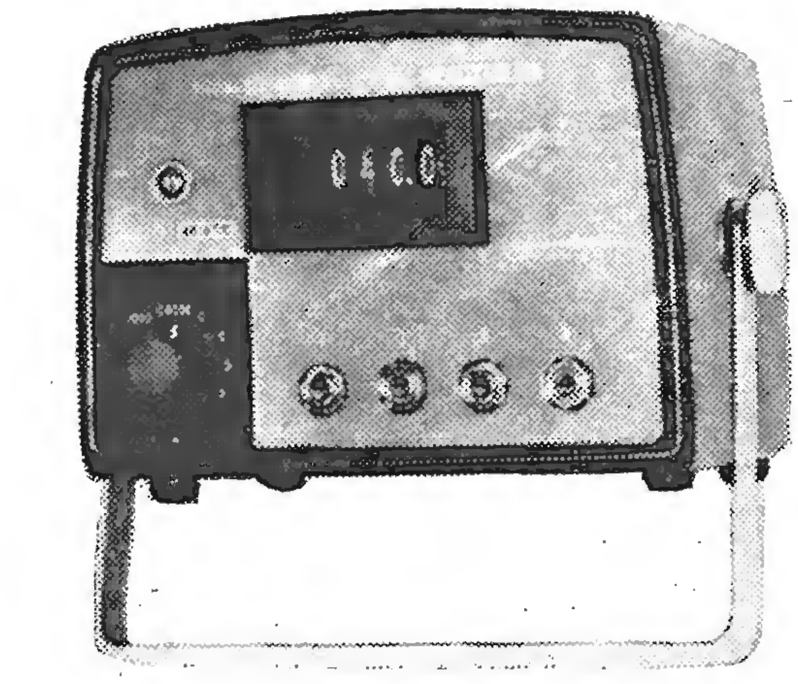
Right: Miniature multi-filament digital readout indicators from the Kay Electric Company. Character heights range from $\frac{1}{8}$ to $\frac{1}{2}$in.



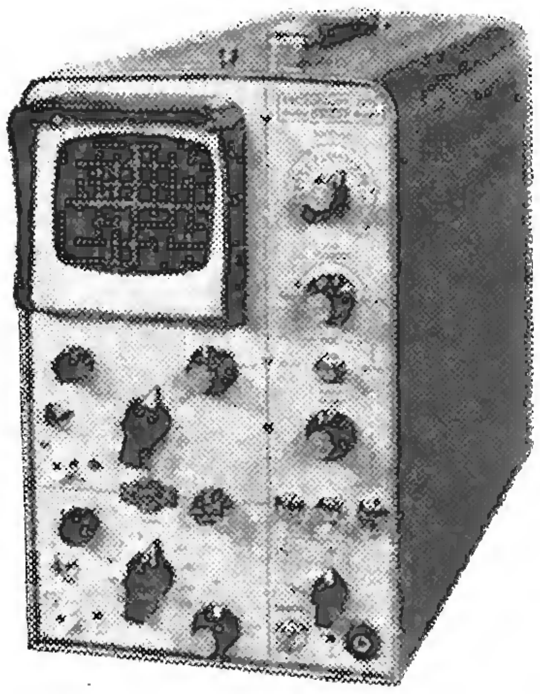
E.D.C. precision d.c. voltage standard. Maximum output of this portable instrument is 11.1111 volts.



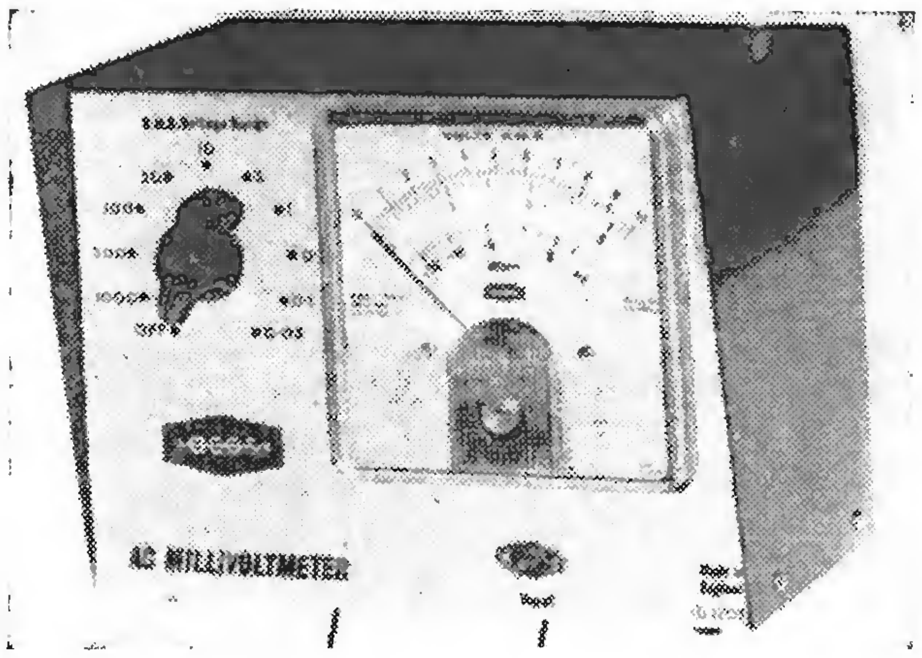
Vacuum hand-operated solder remover from W. Greenwood Electronic.



Digital thermometer made by the United Systems Corporation, of Ohio. This is one of a series of instruments and covers the range 0 to 100°C.



Model 227A double-beam oscilloscope from Compagnie Générale de Métrologie.



Acos ID1203 millivoltmeter from the instrument division of Cosmocord.

ness to 200 ft lamberts on some models.

There are four models in the new range providing the following character heights: Model 02-10, $\frac{1}{8}$ in character; 03-15, 3/16 in; 04-30, $\frac{1}{4}$ in; and 08-60, $\frac{1}{2}$ in.

Life expectancy varies from 20,000 to 100,000 hours according to model. For applications requiring a higher reliability, models with two filaments in parallel for each segment of the lamp are available.

7WW 315 for further details

Double-beam Scope

A NEW double-beam oscilloscope with an adjustable sensitivity from 50 mV to 50 V p-to-p/cm is announced by the Compagnie Générale de Métrologie, B.P. 30, Annecy, France. The vertical amplifiers of the Metrix Model 227A, which uses a single-gun tube, are identical. Maximum display, free from distortion, is 6 cm. Bandwidth at 3 dB down is from 5 c/s to 7 Mc/s with an a.c. input and from 0 to 7 Mc/s with a d.c. input. Voltage measurement is read by means of a graticule.

The horizontal deflection amplifier has a bandwidth at 3 dB down of 10 c/s to 200 kc/s at maximum gain and of 10 c/s to 400 kc/s at minimum gain. Sweep width is 8 cm and sensitivity is adjustable from 0.3 V to 2 V p-to-p/cm; input impedance is 1.5 MΩ shunted by 20 pF.

7WW 316 for further details

Digital Thermometers

A NEW range of digital thermometers that provide bi-directional tracking without the use of stepping switches or relays is announced by the Wayne Kerr Laboratories Ltd., of Sycamore Grove, New Malden, Surrey. All of the instruments in the range, which are made by the United Systems Corporation, of Datum, Ohio, are direct reading either in degrees Fahrenheit or Centigrade and have four-digit illuminated displays. Continuous variation is provided by the final digit which is attached to a revolving disc carrying calibration marks, that may be used to determine an intermediate reading with accuracy.

Special models with a five digit presentation that cover a specified 20°C or 40°F temperature span within the ranges −50° to +150°C and from −58° to +302°F respectively are also available. Solid state circuitry is employed in all models. They can readily be adapted to provide a binary coded decimal output if required, a further option is a re-transmitting potentiometer for external scaling.

Seventeen thermistor probes, which are interchangeable and should meet most demands, are available. Up to four of these may be connected to any of the instruments at one time; a switch is provided on the front panel for probe selection.

Excluding import charges, the instruments range in price from £150 to £181.

7WW 317 for further details

Solder Remover

A SIMPLE-TO-USE solder remover is announced by W. Greenwood Electronic Ltd., of 677 Finchley Road, London, N.W.2. It operates in a similar fashion to a cycle pump, sucking solder into the body of the instrument through a p.t.f.e. nozzle when a push-button is depressed to open a release valve. The body of the spring-loaded device is of anodized aluminium and a plastic disc is attached to the bottom of the plunger to which the molten solder tends to adhere. The price of this tool is £3 19s 6d.

7WW 318 for further details

A.C. Millivoltmeter

AN input impedance of 100 MΩ is quoted for the Acos Model ID1203 a.c. millivoltmeter from Cosmocord Ltd., of Eleanor Cross Road, Waltham Cross, Herts. This ten-range instrument covers 30 mV to 1,000 V f.s.d. over the frequency range 10 c/s to 50 kc/s and has a decibel scale extending from −20 to +2 dB.

Transistors are used throughout this portable instrument which measures $4\frac{1}{2} \times 6 \times 4\frac{1}{2}$ in. An internal battery is used to power the ID1203 and has a life of 400 to 500 hours. The price of this instrument is £48.

7WW 319 for further details

Photo-cell Kit

EIGHT different photoconductive cells with dissipation ratings from 50 mW to 1 W are being offered as a kit by Photain Controls Ltd., of Randalls Road, Leatherhead, Surrey. Cadmium sulphide and cadmium selenide cells, with maximum voltage ratings of 200 V (up to 150 mV dissipation) and 300 V (for the larger units), are included in the kit, which retails at £3. Resistance at 0 Lux is from 3MΩ to 5MΩ and at 100 Lux from 1 kΩ to 16 kΩ according to type.

7WW 320 for further details

Transistor Cascade Crystal Oscillator

By **F. BUTLER**, O.B.E., B.Sc., M.I.E.E., M.I.E.R.E.

QUARTZ vibrators of different types can now be made to operate over a frequency range between about 400 c/s and 200 Mc/s. The crystals exploit every possible vibrational mode, longitudinal, transverse, flexural and shear, and a dozen or so well-known circuits, valve and transistor, have been developed to sustain continuous oscillations.

This article describes yet another transistor oscillator circuit. In its basic form it is extremely simple and reliable but there is scope for refinement and development, as a result of which it might prove suitable for use in a frequency standard, as a clock source or as the drive oscillator for a frequency synthesizer. The oscillator works particularly well over the frequency range 100 kc/s to 5 Mc/s with the crystal operating on its fundamental frequency, as distinct from an overtone mode. Standard frequency sources commonly operate at 100 kc/s, 1 Mc/s, 2.5 Mc/s or 5 Mc/s so that any of these crystals would be suitable for use in the oscillator with no (or only minor) circuit changes.

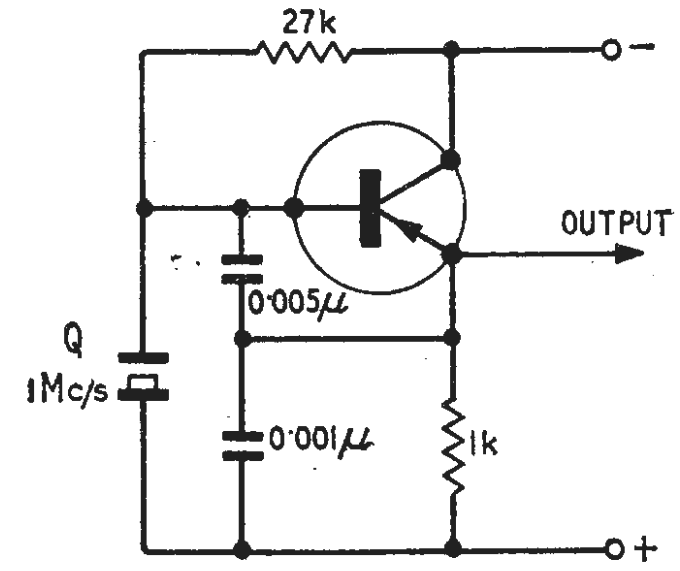


Fig. 1. Colpitts oscillator.

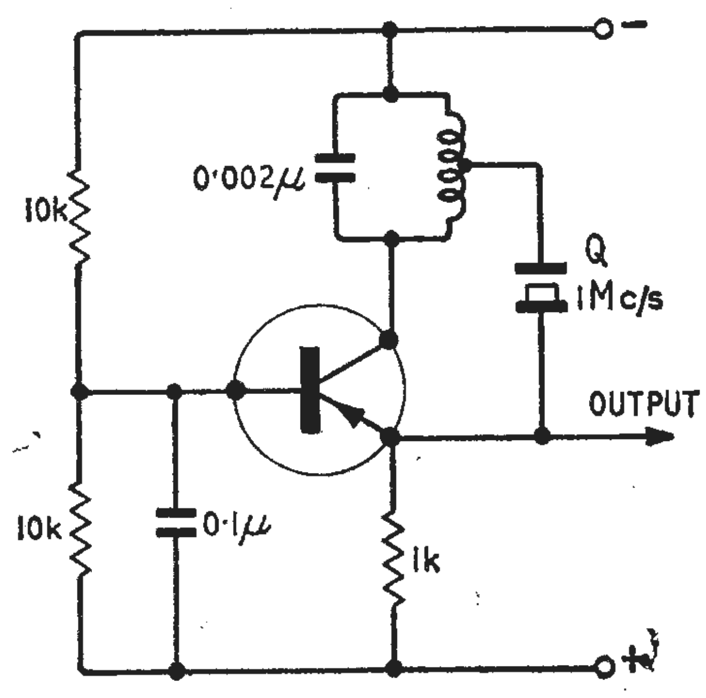


Fig. 2. Common-base tuned circuit oscillator.

Design of stable oscillators

It is convenient to regard an oscillator as the combination of three basic units. They comprise an amplifier with feedback from output to input, a frequency-determining element such as a tuned circuit and an amplitude limiter of some kind.

Ideally, the amplifier should have purely resistive input and output impedances, sufficient power gain to overcome losses in the frequency-fixing element, zero or 180 degrees phase shift (depending on the feedback configuration), and a bandwidth extending from well below the oscillation frequency up to the highest practicable limit. It should be linear and hence free from amplitude distortion and its gain, phase-shift, input impedance and output impedance should be independent of supply voltage and environmental changes. What all this means in practice is that the amplifier must be very well designed in the first place, after which the required characteristics can be achieved by the use of heavy degenerative feedback.

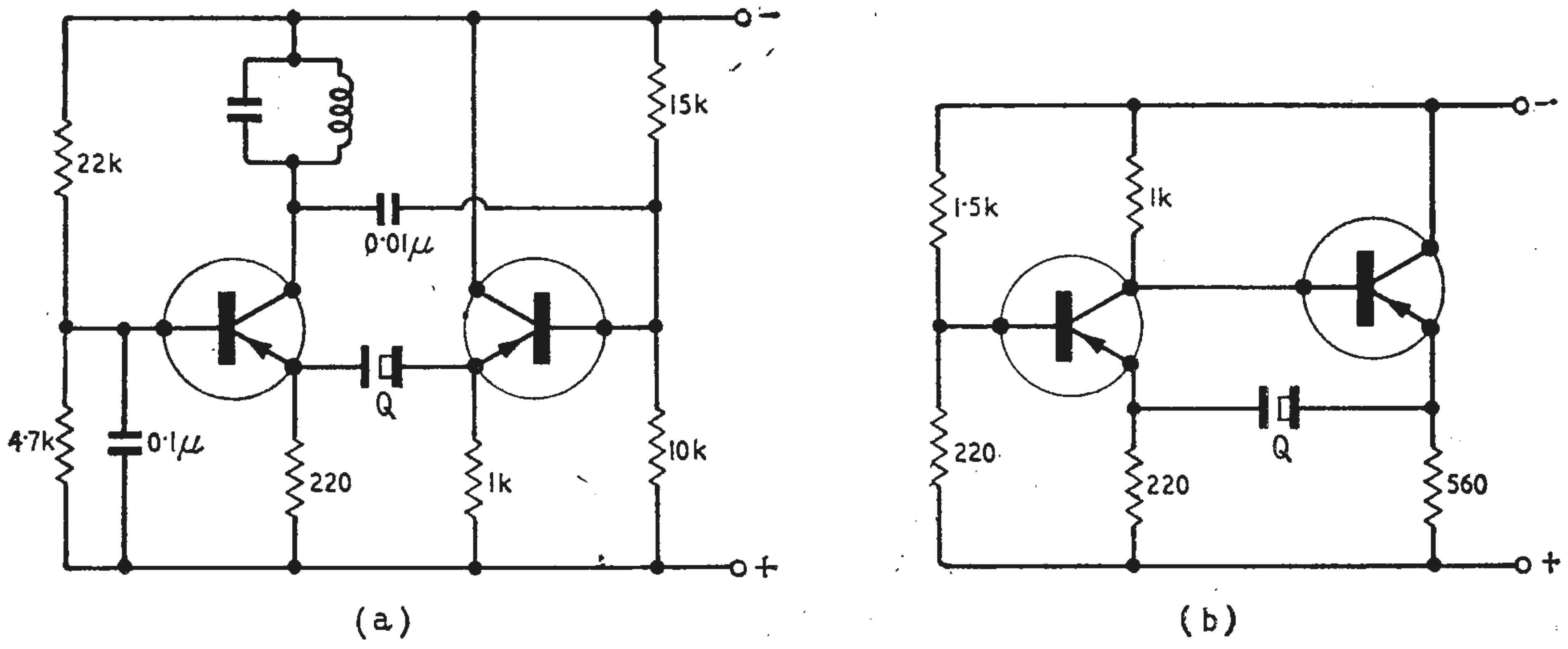
The frequency controlling element (quartz crystal, series or parallel tuned circuit) should be physically and electrically stable, and should have an extremely high rate of change of phase with frequency around the resonant frequency. This amounts to saying that the Q-factor must be very large indeed and when extremely high stability is needed there is no simple substitute for a good quartz crystal.

As regards the amplitude limiter the requirement here is that the amplifier must not be overloaded. If it is, the output will be distorted and will contain harmonics which can beat together, giving fundamental frequency components of indeterminate phase. These can combine with the desired fundamental frequency and swing its phase, causing an equivalent shift of frequency. Unfortunately most practical limiters are prone to generate unwanted phase shifts and on balance it may be preferable to allow the amplifier to perform its own clipping or limiting. For this procedure to be acceptable the amplifier gain should be only marginally greater than that required to maintain continuous oscillation. In this event, limiting is "soft" and causes little instability of the generated frequency.

In many practical oscillators the maintaining amplifier includes tuned circuits. These serve several purposes. They give selectivity and increased gain, they can be used to suppress parasitic modes of oscillation of the quartz vibrator or they can pick out some desired overtone of the fundamental frequency. The objection to the use of tuned circuits is simple and basic. Near the resonant frequency the phase is changing rapidly. Variations in L or C due to temperature or humidity changes, mechanical vibration or other effects will cause a phase change through the amplifier. This must be compensated by phase changes of the opposite sense in the frequency-control element (the quartz plate) since the total loop phase shift must be zero at the frequency of oscillation. The compensating phase shift requires the crystal to oscillate at a slightly different frequency, the precise value of the change depending on the Q-factor of the quartz vibrator.

These various points are best exemplified by studying some simple and well-known oscillator circuits. Fig. 1 shows a Colpitts arrangement which operates at a frequency between series and parallel resonance of the crystal. Here the crystal reactance is inductive and it

Fig. 3. Two versions of emitter-coupled oscillator.



(a) (b)

resonates with the series combination of the two capacitors, both of which are stable and large enough to swamp the transistor input capacitance. By using a v.h.f. transistor these stray capacitances are kept small, as is the resulting amplifier phase shift. By proper design, this simple circuit can be made to give a good performance. A great deal depends on the stability and permanence of the two capacitors on the output loading and on the constancy of the supply voltage source. With the capacitor values and ratios shown, the amplifier may be overdriven. Increasing the capacitor sizes and making them more nearly equal will help to improve the stability.

Fig. 2 shows another common circuit. Good points are that it uses a common-base amplifier circuit, it operates the crystal near series resonance and high bias-stability is given by the resistors shown. It oscillates readily, even at high frequencies, and can use overtone modes of the crystal. Because of the tuned circuit, its stability is not so good as a well-designed version of Fig. 1.

Fig. 3 shows two versions of an emitter-coupled oscillator. The arrangement at (a) makes use of a resonant circuit tuned to the crystal frequency. It is an energetic oscillator and will work well with almost any crystal between 50 kc/s and 20 Mc/s or so. Circuit (b) shows how the oscillator must be modified to give much higher stability. The amplifier is aperiodic and has much less gain than (a). Because of this, it will only work with high-Q crystals which must not have spurious frequencies of resonance since there is nothing in the amplifier to discriminate against undesired modes. In both cases, amplitude limiting is set by amplifier overload. Clipping is much harder in (a) than in (b) because of the higher gain.

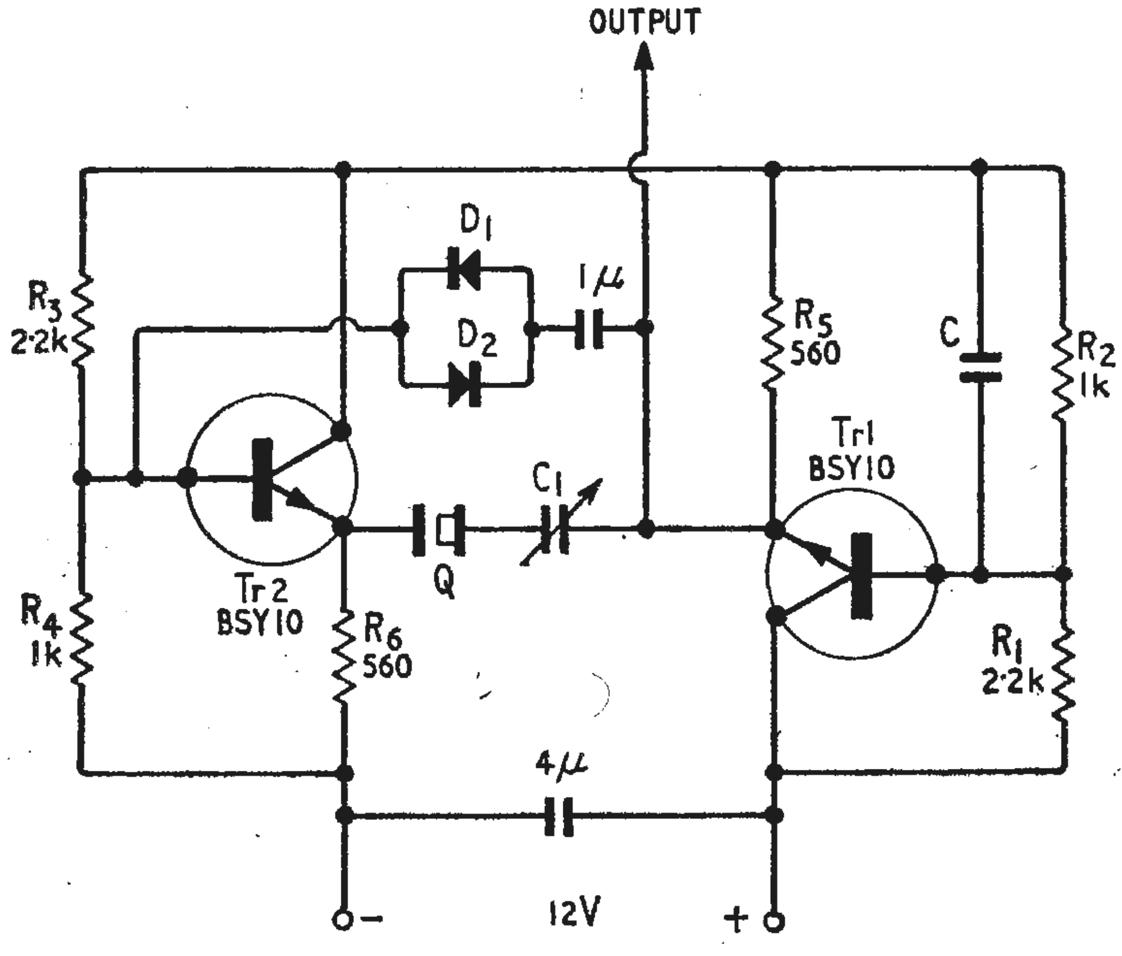


Fig. 4. Series bootstrap crystal oscillator.

The bootstrap cascade circuit

Reasoning along the lines of the preceding section suggested the new circuit shown in Fig. 4. In simplicity it is on a par with Fig. 3 (b), but its performance is rather better. The oscillator makes use of v.h.f. n-p-n silicon transistors, the types actually used for experimental work being Mullard BSY10. The circuit is a bootstrap arrangement in which Tr1 and R_5 form the collector load of Tr2. Both transistors are used in the common-base connection though this may not be apparent from the circuit diagram. In the ordinary way, large capacitors would be connected across R_2 and R_4 to get the maximum possible amplifier gain. Omitting one or both of them gives feedback which improves the amplifier performance but reduces the gain. Good crystals between 100 kc/s and 2 Mc/s will oscillate without bypass capacitors. Between 2Mc/s and 7Mc/s a small capacitor shown as C in Fig. 4 may be required across R_2. At still higher frequencies, capacitors are required across both R_2 and R_4. Output is taken from the emitter of Tr1, preferably through a high resistance or small capacitance, in order to give low loading of the oscillator.

Small adjustments of the frequency may be made by variable capacitance or inductance in series with the crystal.

The combination of a pair of high gain transistors and an extremely active low-frequency crystal may give rise to an excessive amplitude of oscillation. This can be corrected by negative feedback from the emitter of Tr1 to the base of Tr2 through a blocking capacitor and a suitably chosen feedback resistor. In principle it would be possible to use a thermistor in the feedback path to give some measure of automatic amplitude control, but the oscillator output power should be kept low in the interests of stability, and in this case the available power in the thermistor would be too small to exercise decisive control. Another method is to connect two diodes back-to-back as shown and place them in series with the feedback resistor and capacitor, adjusting the resistor value to give the desired low output level.

As a final measure to flatten the frequency response of the amplifier it is worth including two small inductances in series with the emitter load resistances, their value being set by trial to equalize the gain up to the highest possible frequency.

If it turns out that the oscillator crystal has spurious

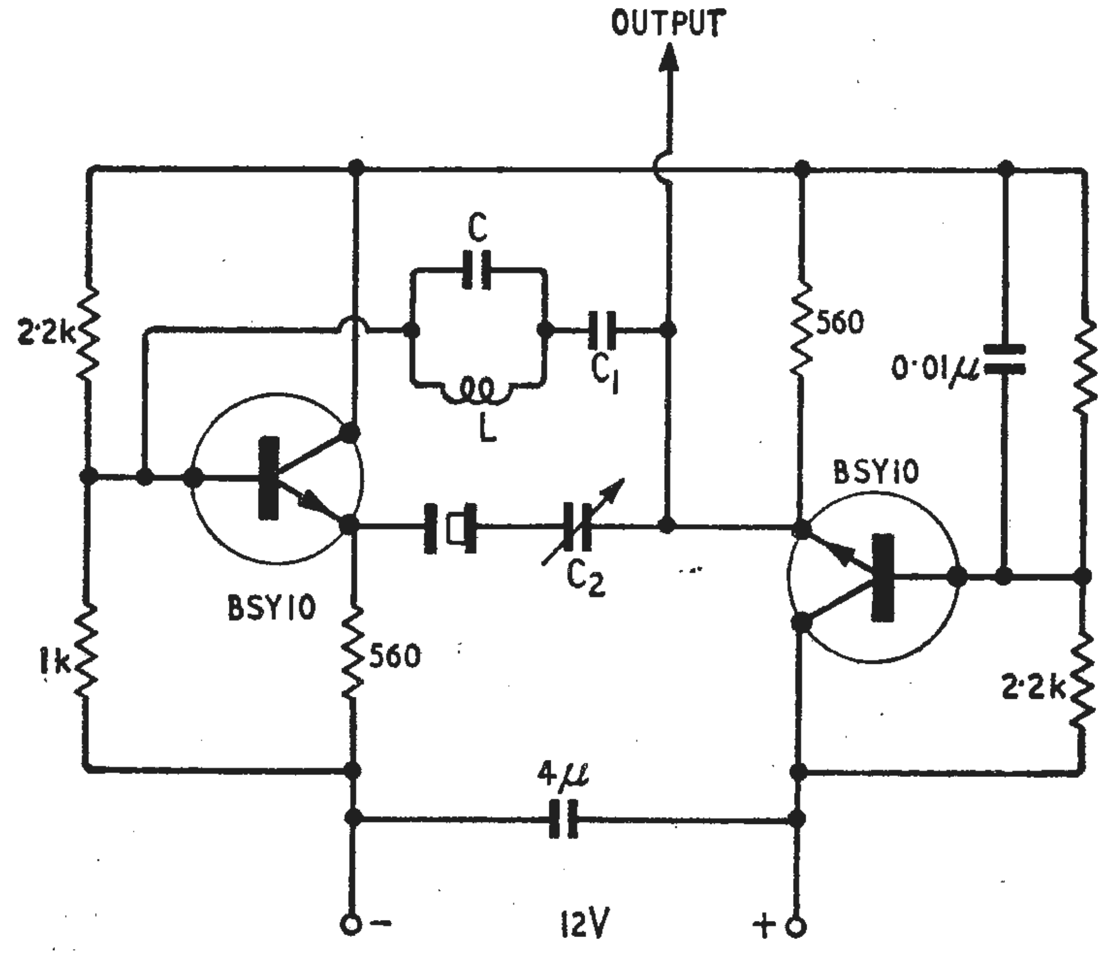


Fig. 5. Suppression of undesired oscillations by frequency-selective feedback.

resonances at undesired frequencies (and this sometimes happens with low-frequency GT plates) it should be rejected as unsuitable for use in a precision standard. If such a crystal must be used, it is possible to suppress the unwanted modes by the use of frequency-selective feedback as shown in Fig. 5. The additional components are a blocking capacitor C_1 and a tuned LC circuit which is parallel-resonant at the desired crystal frequency. At this frequency there is negligible feedback; at all others there is strong degeneration. Use of selective feedback gives the amplifier an undesirable phase characteristic and degrades the oscillator stability. The main claim for the circuit of Fig. 4 is that it seems capable of development into a good frequency standard using a single high-grade quartz vibrator. Since the amplifier is untuned it is equally suitable as a multiple-frequency source using a number of separate crystals switched into use as required. Aside from small instabilities attributable to the switch the performance should be nearly as good as for the single-crystal version.

Power supply regulation and temperature control

All highly stable oscillators must be run from regulated power supplies. For most purposes a simple Zener diode arrangement is good enough for the circuit of Fig. 4.

As regards temperature regulation, modern practice with primary standards of frequency calls for the use of 2-stage thermostatically controlled ovens. The inner unit contains the crystal and associated critical components. The outer oven contains the oscillator circuit elements, including transistors. All the components in Fig. 4 can be assembled on a small circuit board which fits easily into a small oven space. No circuit adjustments need to be made except for the trimming control of the crystal frequency.

Provided that stable components are used in constructing an oscillator, that loading on it is low and constant and that the power supplies are well regulated it is true to say that the ultimate performance in respect of stability is set by the accuracy and precision of temperature control. This circumstance tends to cover up possible shortcomings in the basic oscillator design. A better approach is to start with an oscillator circuit which uses no critical components or techniques and then to refine its performance by close voltage regulation and precise temperature control.

Performance tests

The performance of the best frequency standards available today is so good that it would be unreasonable to expect any dramatic improvements in the near future. In particular, crystal oscillators have approached close to the limit of their capabilities. The basic circuit of Fig. 4 is put forward as something new, simple and versatile. As with any fresh idea, it would require intensive development to explore its possibilities and discover its limitations. If for no other reason it is worth considering for use as a multiple-frequency source. No tuning adjustments are necessary, the desired output frequency being obtained by switching in different quartz crystals as required.

To get some idea of its performance, an oscillator was built as in Fig. 4, using a high grade GT-cut quartz plate designed for use with a series capacitance of about 700 pF. By adjustment of this the frequency could be set exactly to 100 kc/s. Two limiter diodes were used with a 1 μF blocking capacitor but without any external series resistance. With the crystal alone in circuit, the series capacitor being short-circuited, the crystal current was 2.8mA and the voltage across it was 140 mV, using a 15 V supply source. Under these conditions the energy dissipation in the quartz plate is about 400 μW, small by ordinary standards but still considerably more than in some precision oscillators. To reduce it further a pair of reverse-connected backward diodes may be used. These diodes, which rely on the quantum mechanical tunnelling effect, have a much lower forward voltage drop and a lower slope resistance than conventional diodes.[1]

With 700 pF in series with the crystal, adjusted to set it exactly on 100 kc/s, the voltage across crystal or capacitor rises to 4 V r.m.s. At this frequency the crystal reactance is inductive (about 3 mH at 1 Mc/s) which accounts for the rise in voltage. A rough check on the frequency stability was made by setting the second harmonic of the oscillator to zero-beat with the 200 kc/s carrier of the B.B.C. Droitwich transmitter. On raising the supply voltage from 15 to 30 V the change in frequency was less than 1 part in 2 million.

Another test was made by substituting for the crystal a series tuned LC circuit, set to 1 kc/s. The same change in supply voltage caused a frequency shift of about 1 part in 1,000.

REFERENCES

1. "Measuring Alternating Voltages with Backward Diodes", B. Stuttard, *Industrial Electronics,* February 1965, p. 78.

2. "Unique Current-Controlled Negative-Resistance Generator", A. H. Marshak, *I.E.E.E. Trans. Communications and Electronics,* March 1964, p. 182.

APPENDIX

There are two ways of regarding the action of any oscillator which uses a 2-terminal circuit to fix the operating frequency. One, already mentioned, is to consider the passive network as a feedback element between the output and input terminals of a power amplifier. The other is to picture the amplifier as a negative resistance source coupled to the passive network. This theme was developed by Thomas Roddam in an article "Oscillators: A Monistic Approach" (*Wireless World,* January 1963, p. 33).

A. H. Marshak (reference 2 above), has described a current-controlled negative resistance source using the circuit

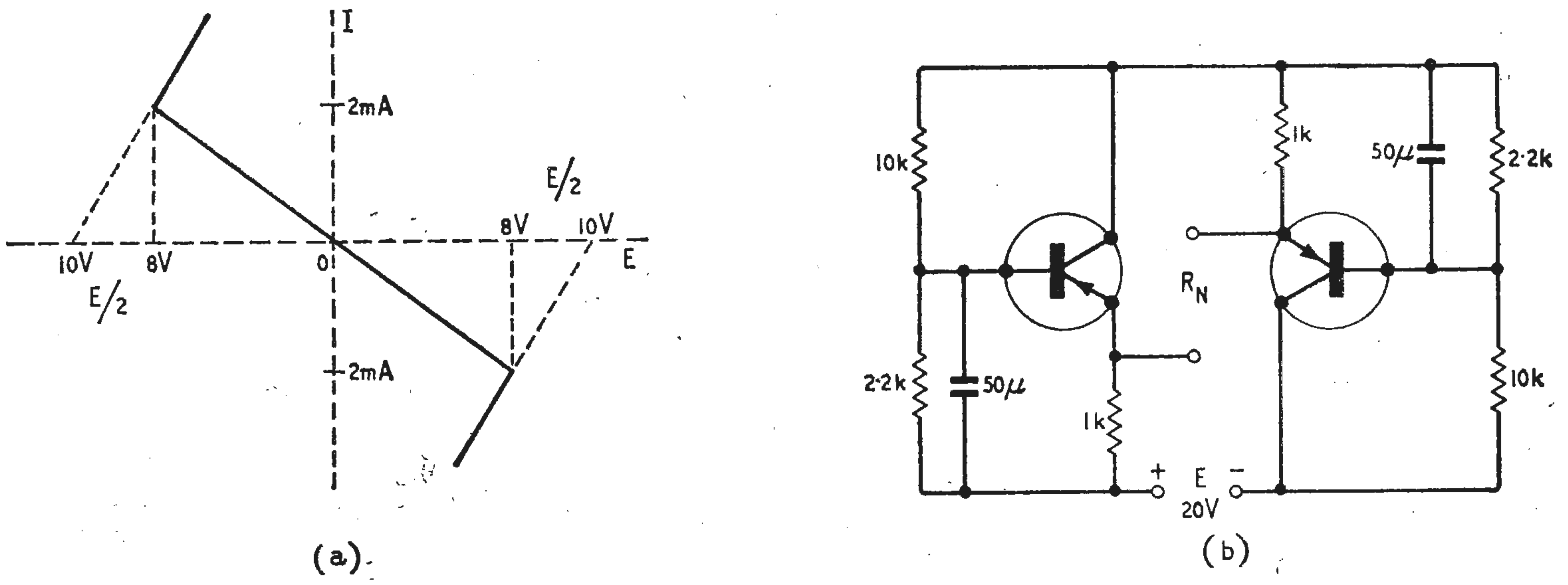


Fig. 6. Current-controlled negative resistance circuit due to A. H. Marshak. (a) Negative resistance characteristic (n-type). (b) Practical circuit.

shown in Fig. 6. It resembles Fig. 4 except in respect of component values. It has an n-type characteristic with well-defined turning points which sharply limit the amplitude of oscillations in a tuned circuit coupled to the negative resistance terminals. This characteristic may well account for the good performance of an oscillator which uses this type of maintaining amplifier. It is believed that a similar circuit has been developed for use as a relaxation oscillator, a capacitor being connected across the terminals of the negative resistance. The reference to this arrangement, due to Frühauf, has proved impossible to trace. Perhaps some reader can supply this, since it is of intrinsic interest and it is also the link between the negative resistance source and the sinusoidal oscillator.

Electronic Laboratory Instrument Practice

7.—OSCILLOSCOPES

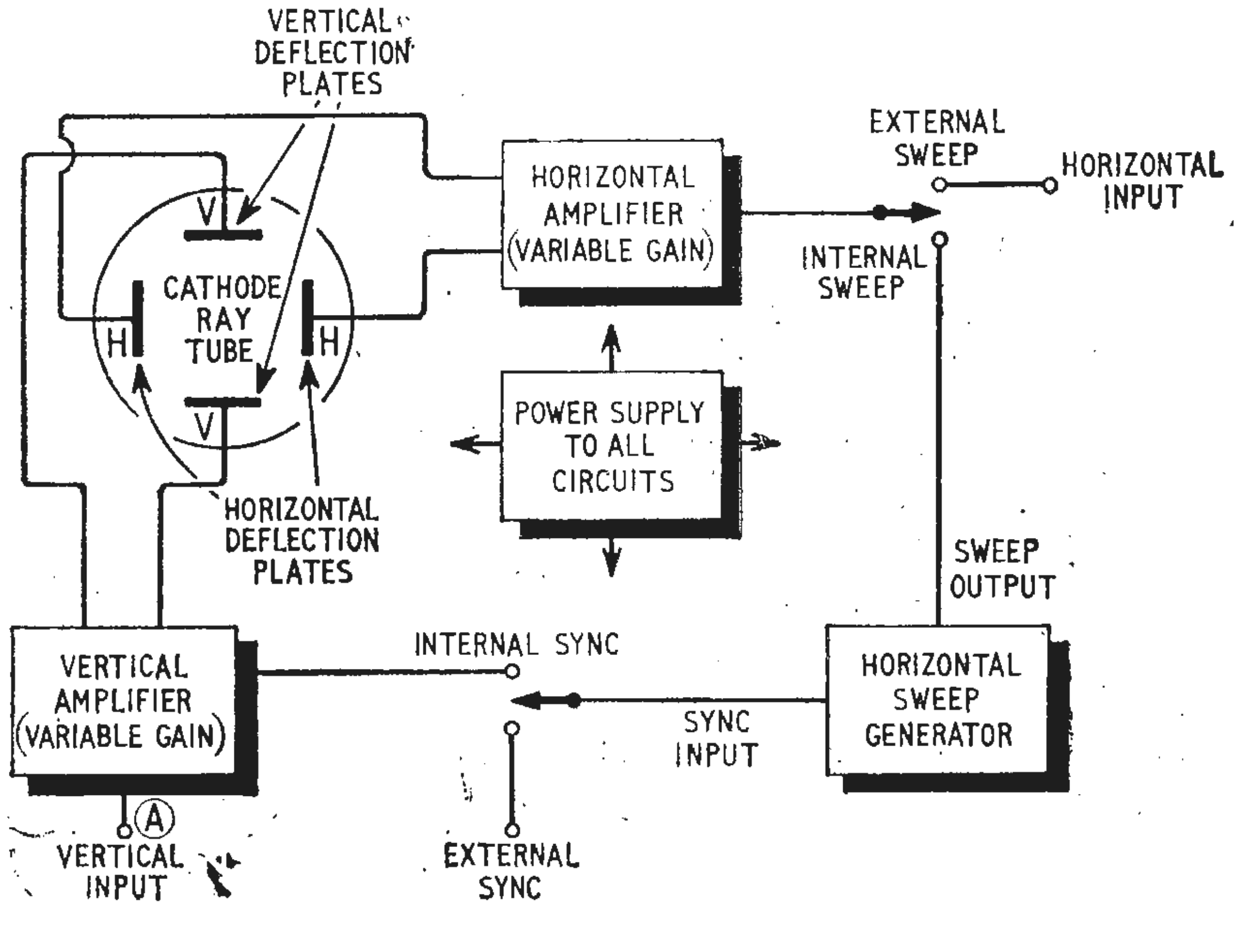
By T. D. TOWERS,* M.B.E., A.M.I.E.E., A.M.I.E.R.E.

SIMPLY, the oscilloscope (or "scope" as it is now commonly called) is an instrument that lets you see what is going on inside an electrical circuit by displaying voltages on the screen of a cathode ray tube (c.r.t.). The electronics industry uses it widely in any field where a phenomenon can be converted into a voltage signal.

If you are a tyro, the scope's massive array of controls with strange titles is frighteningly complex. You can be forgiven for fearing that something disastrous might happen if you set a control wrong. Be of good cheer! The modern scope is nearly foolproof, and you will be surprised how soon you become adept at "changing the gears".

The emphasis in this article will not be so much on how the scope works as on how to use it. To set the stage, however, a simplified diagram of the basic parts of a scope is given in Fig. 46. The voltage signal to be examined is applied to the vertical input terminal A. After amplification in the "vertical amplifier," it is applied in push-pull to the two vertical deflection plates, V-V, of a c.r.t. (often known as the "Y" plates). These deflect an electron beam in the c.r.t. so that the spot appearing on the fluorescent screen moves up and down in synchronism with the applied signal. At the same time, the horizontal sweep oscillator gives a sawtooth output which is amplified through the horizontal amplifier and applied to the horizontal deflection plates, H-H, in the c.r.t. (also known as "X" plates). This causes the electron beam to sweep back and forth, so that the vertical, or Y, input signal is displayed spread out in the form of a curve. The various switches permit the horizontal sweep oscillator to be free running, or synchronized with the input signal, or with some other external signal.

Fig. 46. Diagrammatic outline of oscilloscope system.



---

*Newmarket Transistors Ltd.

To use a scope, it is not really necessary to know much more than this about the system of operation. However, if you want further details, you should consult such textbooks as the "Encyclopaedia on Cathode Ray Oscilloscopes and their Uses" by J. F. Rider and S. D. Uslan (Rider Publications, New York) or "The Oscilloscope at Work" by A. Haas and R. W. Hallowes (Iliffe Books, London).

Specifications of oscilloscopes

Scopes can be divided into three main classes: (1) *"bench" general-purpose* for unexacting use around the lab, (2) *"lab" general-purpose,* for precision run-of-the-mill measurements, (3) *"special-purpose,"* for measurements not normally possible with the first two types. Before we go on to look at specific examples of these three main groups, we shall take a look at the general features of a scope specification.

The first and most important specification is the "bandwidth," i.e., the range of frequencies over which the scope internal amplifier gain does not drop to less than some stated fraction (usually 0.707) of the midband gain (at, say, 1 kc/s). It is obviously useless to look at a 30 Mc/s signal with a $\frac{1}{2}$ Mc/s bandwidth scope, as there would be virtually no response at 30 Mc/s.

Bench scopes usually have a bandwidth less than 10 Mc/s; lab. scopes' bandwidths are usually in the range of 10-100 Mc/s, and special purpose scopes can extend up to about 4,000 Mc/s at the time of writing.

The next most important characteristic of the scope is its sensitivity. In a meter, you specify its sensitivity by the mA or μA required for full scale deflection. In a scope, you specify the mV/cm of vertical displacement. A figure of 50 mV/cm has become a fairly standard specification for wide-band instruments. Scopes with restricted bandwidths can be made much more sensitive, and some low-frequency professional instruments have a vertical sensitivity of better than 0.01 mV/cm (10μV/cm).

What does 50 mV/cm mean in terms of the ordinary displays usually met with? A common size of c.r.t. used in scopes is 5 inches in diameter, and this provides 8 cm of vertical display. On such an instrument, a 50 mV/cm sensitivity means that it needs a 400 mV peak-to-peak signal to fill the screen vertically.

Always look at scope sensitivity specifications carefully. Manufacturers usually give it in peak-to-peak terms so there will be no misunderstanding. R.m.s. values can be misleading. A scope with a 50 mV r.m.s. sensitivity is the same as one with a 140 mV peak-to-peak specification.

The next most important part of the scope specification is for the timebase. It used to be common to characterize the timebase (horizontal sweep) in terms of its maximum repetition rate, but nowadays the manufacturer usually specifies the maximum sweep speed in μs/cm. This is particularly important in measuring switching times of pulse waveforms.

More important than the timebase maximum speed is how it is synchronized with the applied signal. There are two main types of sweeps used—"recurrent" and "triggered." In the recurrent, the generator is free-running and will synchronize with the input signal only when its frequency is carefully adjusted to be marginally slower than the frequency with which it is to be locked. In the triggered type of sweep the input signal exerts a more definite control over the repetition frequency of the sweep within very wide limits, and hence the sweep pattern is forced to synchronize with the input signal and thus provide a stable pattern within these very wide limits. Good-quality scopes nowadays usually employ a triggered sweep system.

Scopes coming on the market now are usually "d.c. scopes." Early instruments could be used to inspect only a.c. waveforms because it was difficult to make an economical stable d.c. amplifier. A d.c. input considerably extends the use of a scope, and many instruments now have switched d.c. or a.c. input coupling. In transistor work particularly this is almost essential. Only d.c. scopes can do some jobs such as providing a high-impedance null-detector for a d.c. bridge, making low frequency phase measurements, or displaying characteristic curves of valves and transistors.

Calibrated controls are desirable in a scope. This means that both the vertical sensitivity and the horizontal sweep rate should be capable of accurate setting by scaled controls on the front panel. Most good quality scopes provide this, and also have internal facilities for checking the accuracy of these controls.

So far, we have assumed only one trace appearing on the screen, and most scopes are, in fact, single-beam instruments, showing a single trace. Where you want to display two signals together, you can use a double-beam scope. These have been available for years; many readers will remember affectionately the Cossor double-beam scopes that became "bits of lab furniture" during the 1950s. However, nowadays single-beam scopes have been adapted to give a double display also and are then known as "dual-scopes." In these, an internal circuit rapidly switches the display between two inputs and produces a separate display for each.

Some companies (e.g. Marconi) also market separate electronic switching adapters, which can be used to convert a single-beam scope to a dual display type.

Another class of multitrace scopes uses separate c.r.ts for the different channels with a common timebase, e.g. Airmec's Type 249, four-channel oscilloscope.

Another facility now common in lab scopes is a "delayed sweep." In this the timebase is arranged so that the scope display starts at some point on the waveform after the point initiating the sweep triggering. With a variable delay of this sort you can bring any point of a display into view for close examination.

Since many scopes without sweep-delay facilities are in use, some firms (e.g. Philips) produce separate trigger-delay units which can be fitted on to a scope without sweep delay.

Normally you use a scope to display a voltage vertically against a period of time horizontally and this tends to make you forget that the scope is really a two-dimensional display of two voltages against each other. Special instruments known as "X-Y scopes" (using d.c. coupled amplifiers with equal horizontal and vertical sensitivities) are sometimes used when it is desired to display two external voltages against one another, but many modern general-purpose scopes can be arranged for use as X-Y scopes by switching out the timebase.

Some scopes have provision for amplitude modulating the intensity of the electron beam, and thus varying the brightness of the screen trace. This intensity modulation (which is commonly known as "Z-axis" modulation), makes it possible to give a "three-dimensional" display to a set of three voltages. One useful application is to use the output from a known-frequency oscillator to give bright spots on the trace to verify the calibration of the horizontal timebase.

So far, we have really only been considering the display of periodic waveforms. However, most modern scopes can be used for "single-shot" operation. In this the

(Continued on page 361)

timebase is arranged so that one event on the input to the Y amplifier will trigger the timebase and give a single trace across the screen.

If this single-shot operation can be combined with a long-persistence c.r.t., the shape of the single event can be inspected at leisure, even though it occurs in an extremely short time. This brings us to a whole class of instruments known as "memory" or "storage" scopes, which can hold a trace on the screen for hours.

Another very specialized scope is the "digital-readout" type. This has controls fitted which are used to adjust the location of the waveform on the screen, and then make it possible to read off the required information from the control settings. They are calibrated to display a series of digits. This gives, in effect, analogue to digital conversion. It finds particular use on production lines where unskilled operators cannot be expected to interpret waveform shapes, but can read off numbers on dials.

While we are on the subject of position of the trace on the scope face, it is worth pointing out that most modern good-quality scopes have "trace position indicators," i.e. small lights which tell you in what direction the scope trace is displaced (if it is not visible). This saves you having to guess which way to move the X or Y shift controls to bring the trace on to the screen.

Bandwidth and risetime

Bandwidth has long been a standard method of specifying the capabilities of a scope to present a change on the screen. At first, scopes were designed for a maximum bandwidth independent of transient reponse. Today a valve voltmeter is the instrument normally used to measure a c.w. sinewave signal, and the scope is used mainly for changing waveforms. Most scopes are now adjusted for a so-called "Gaussian" response to reduce spurious "ringing" on the trace. The 3 db (0.707) bandwidth criterion for judging fast scopes is becoming obsolete. The preferred specification is the 10-90% risetime in response to an ideal step input, with a permissible overshoot if not more than a few per cent.

It is of interest to note how risetime is affected if a theoretically perfect square wave is transmitted through two or more devices in cascade. Let device A operating alone have a risetime T_A, and device B alone T_B. If a true square wave is fed into the two devices in cascade, the risetime T_{AB} of the output is given approximately by $T_{AB}=(T_A^2+T_B^2)^{1/2}$. As an example, two amplifiers with 3μs and 4μs risetimes in series will have a combined risetime of only about 5μs—not the 7μs you might intuitively expect. This is why, if you want to observe the risetime of a waveform accurately, you should use a scope with a risetime small compared with the waveform risetime.

Ideally, for measurements of 2-3% absolute accuracy, the scope used should have a risetime at least five times faster than the waveform being measured. However, for comparing risetimes, scopes with risetimes about the same as those of the waveforms can be used. For example, to measure a 25ns risetime absolutely, you require a scope with better than 5ns risetime, but to compare two such pulses you can use one with a 25ns risetime.

To measure the risetime characteristics of a device, say of a transistor, the following method is used. Observe directly on the scope the risetime, T_0, of the square wave output of the generator used to drive the transistor. For this measurement, terminate the generator in an impedance (including the scope input impedance) equal to the input impedance of the device you are going to measure. This time, T_0, is the "equivalent risetime" of the scope and generator together. Now drive the device under test from the square wave generator, and observe the risetime, T_1, of its output waveform. For this observation, terminate the device with a load (including the scope input impedance) similar to the load into which the device normally operates. The actual risetime, T_2, of the device under test can be computed from $T_2=(T_1^2-T_0^2)^{1/2}$.

Something that often puzzles people is the relationship between scope bandwidth and risetime. As a fair approximation, a scope of bandwidth B Mc/s has a risetime of the order of $T=(350/B)$ns. Conversely, a scope with a risetime of Tns will have a bandwidth of $B=(350/T)$ Mc/s. About 3.5ns risetime (=100 Mc/s bandwidth) has been hitherto the practical limit for scopes using conventional amplifiers to obtain high sensitivity. Apart from the bandwidth limitation of any amplifier used, the only real limit to risetime speed is the c.r.t. itself with its few hundred picoseconds risetime.

Faster risetimes can be obtained in three general ways: (1) with transistorized amplifiers and improved c.r.ts (down to 1ns); (2) with distributed amplifiers (down to a few tenths of a nanosecond); (3) with sampling techniques (down to less than 0.1ns).

So far we have been considering the voltage sensitivity of scopes without really considering what impedance they present to the circuit under examination. In general, the average scope input looks like a megohm shunted by about 30 picofarads (although u.h.f. instruments look like 50 ohms). It is well to remember this when you are using a scope to look at signals in tuned circuits; the megohm may not damp the circuit much, but the 30pF can easily throw it widely off tune and give quite erroneous results.

Commercial "bench" oscilloscopes

Earlier we attempted to divide scopes into three main categories: (1) bench; (2) lab; and (3) special-purpose.

Some manufacturers (e.g. Cosmocord, Dartronic, Daystrom, Metrix-STC, Philips, Solartron, Tektronix, Telequipment) market economical bench scopes adequate for mundane duties around a laboratory. Fig. 47 illustrates one example—the Telequipment Serviscope Minor designed particularly for educational establishments. Using a 2¾-in c.r.t., it is a a.c./d.c. instrument with a bandwidth of 30 kc/s and a sensitivity of 200 mV/cm.

Although bench scopes usually have few of the refinements of a lab type, they are useful around a laboratory because of their small size, lightness and robustness.

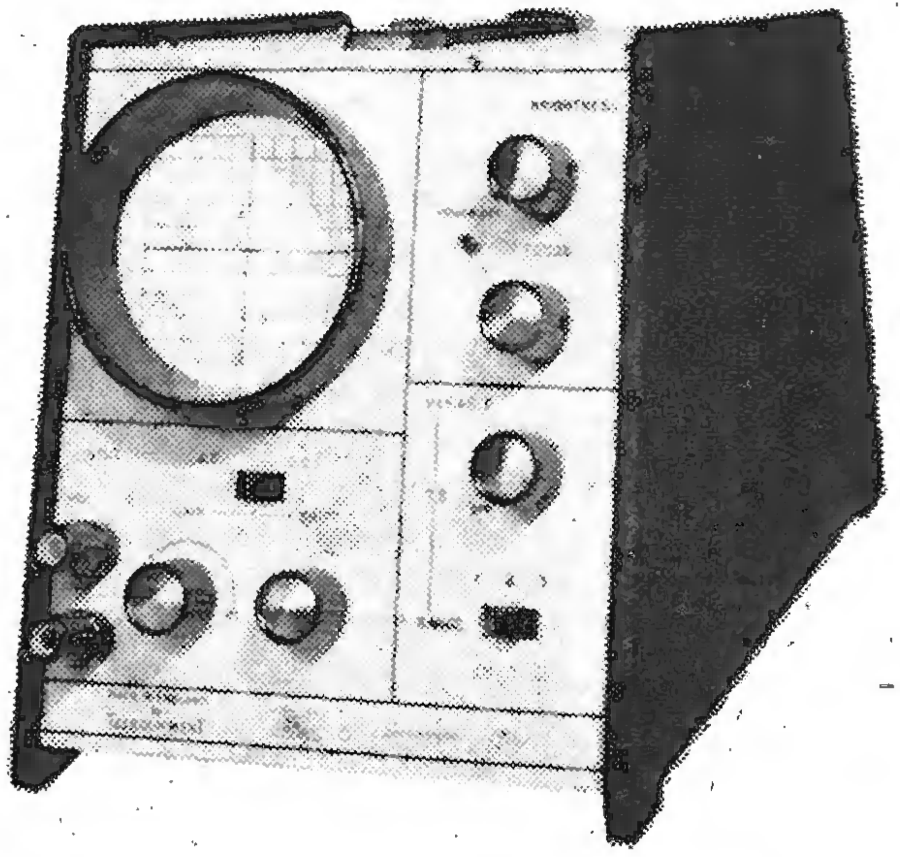


Fig. 47. Typical "bench" general-purpose scope: Telequipment Serviscope-Minor "school" scope.

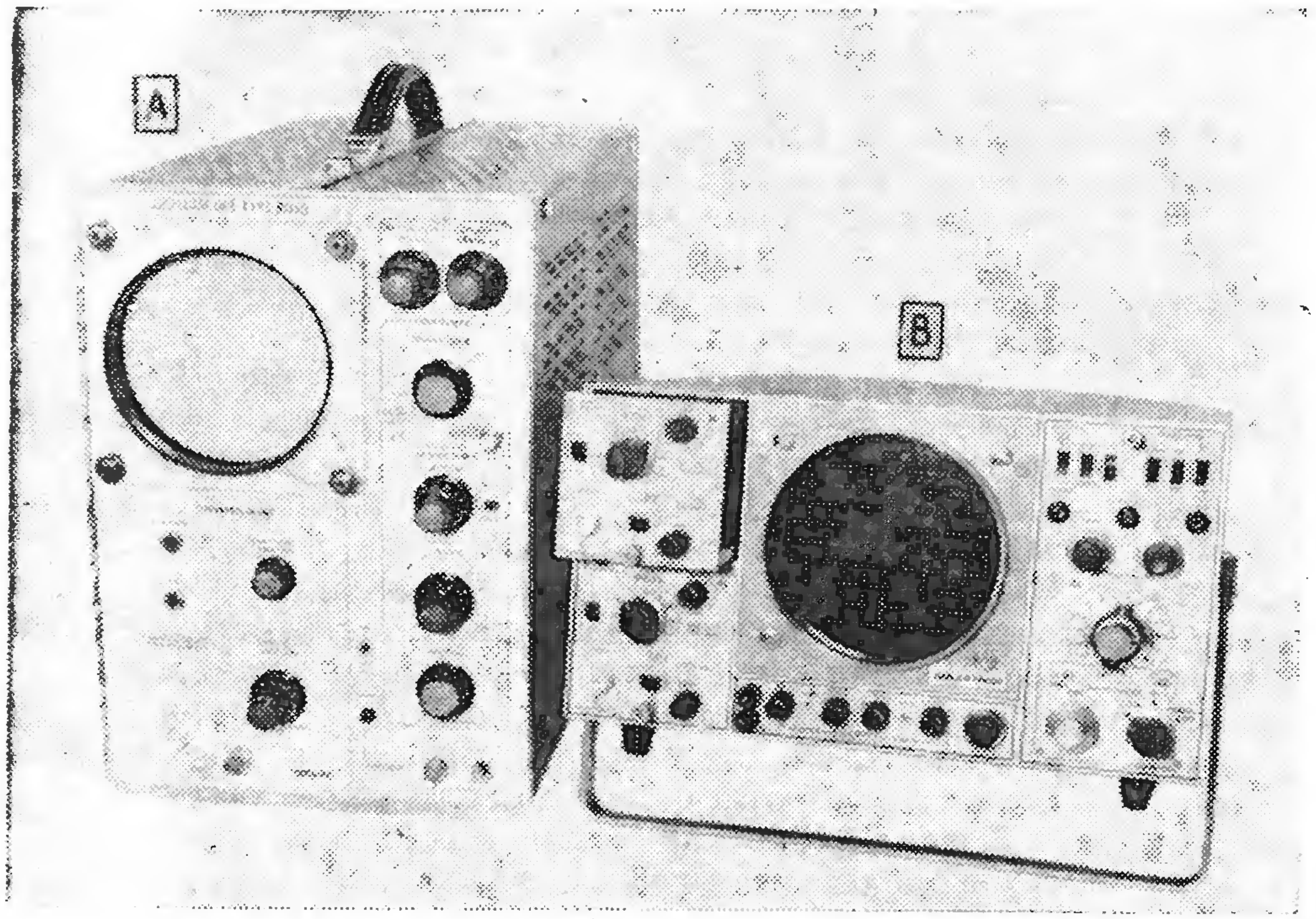


Fig. 48. Typical 15 Mc/s laboratory general-purpose scopes: (a) Roband R055, (b) Solartron CD1400.

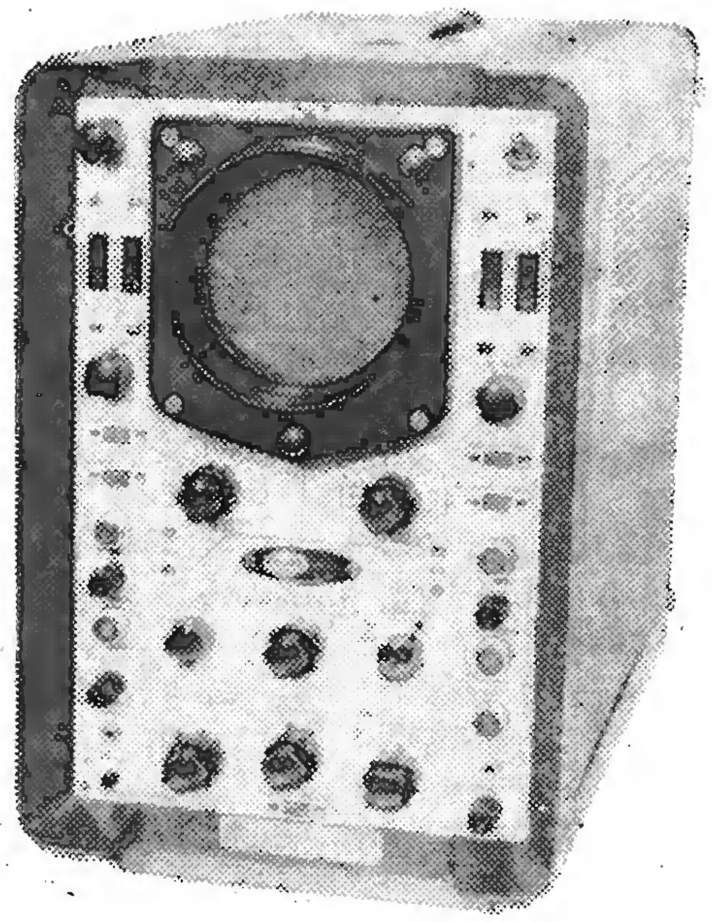
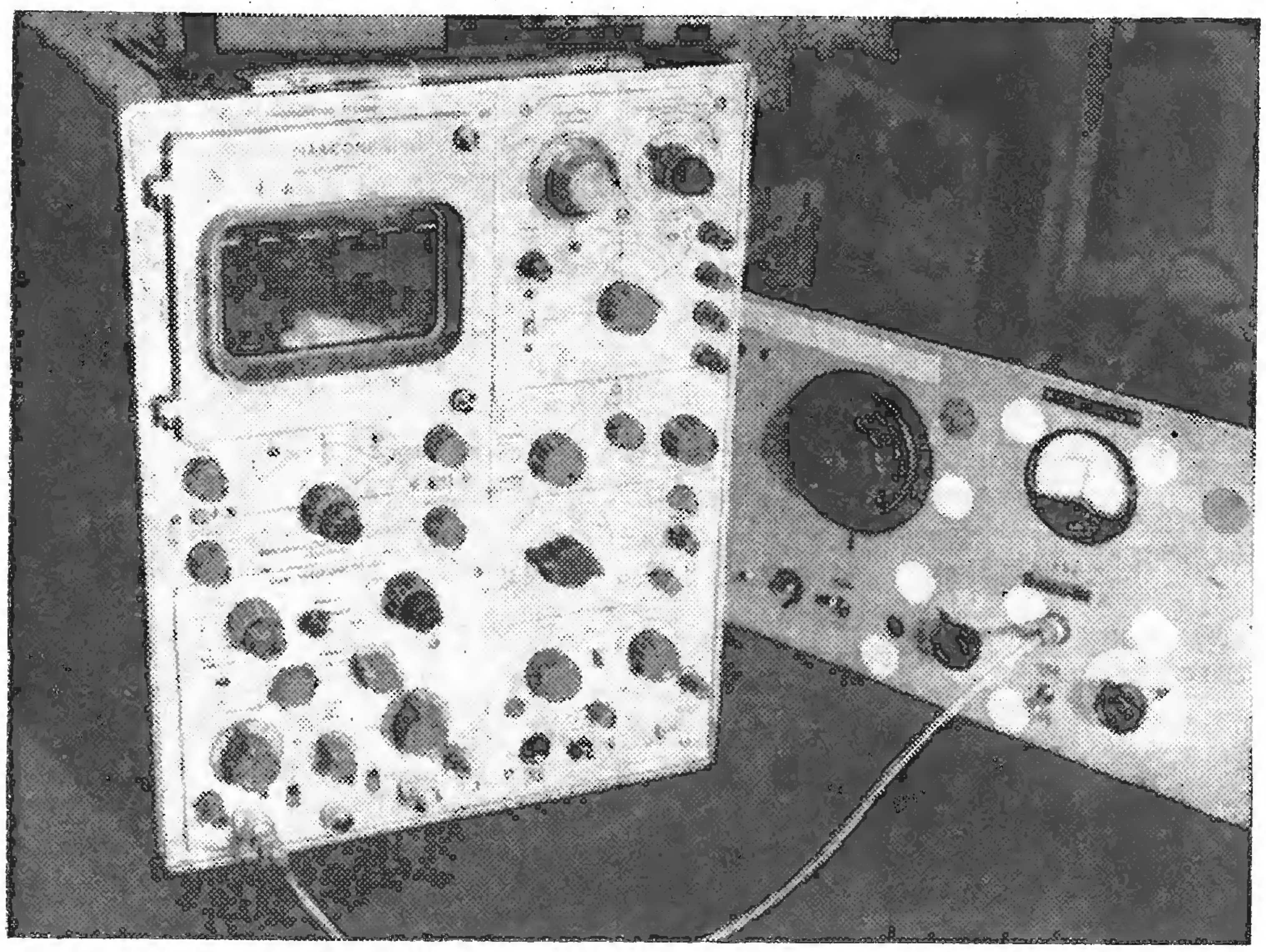


Fig. 50. Typical high-sensitivity double-beam laboratory general-purpose scope: Cossor 2300A.

Fig. 49. Typical 40 Mc/s laboratory general-purpose scope: Marconi TF2200A.



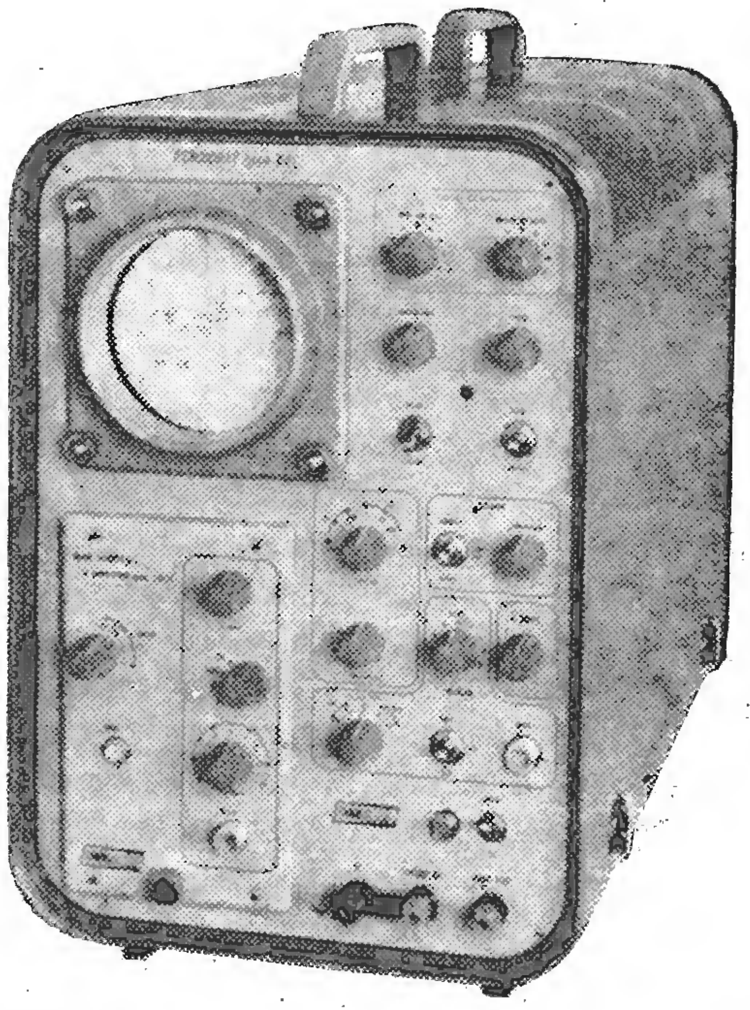


Fig. 51. Example of "memory" or "storage' oscilloscope: Dawe (Cawkell) Remscope Type 741.

Commercial "lab" oscilloscopes

For precise laboratory measurements, more sophisticated instruments are marketed by firms like Advance, Airmec, Cossor, Dartronic, Dawe, EMI, Furzehill, Hewlett-Packard, Marconi, Metrix-STC, Microcell, Philips, Roband, Solartron, Tektronix and Telequipment.

Typical of such lab scopes is the Roband Type RO55 illustrated on the left in Fig. 48. When fitted with a Type 5 series plug-in unit (as shown) it offers a basic d.c. to 15 Mc/s bandwith (21 ns rise time) with 50 mV/cm sensitivity and sweep speeds up to 0.1 μs/cm. A built-in calibrator, versatile triggering, and Z-axis modulation are other normal features of this instrument.

The Solartron CD1400 illustrated on the right in Fig. 48 is another good example of the professional general-purpose oscilloscope. In the photograph you will notice that I have left the top left-hand panel pulled out to illustrate that the various amplifier units are modular. Both the X and the two Y amplifiers plug in. The CD1400 is unusual in that it is a true double-beam scope with a double-gun structure. It has two separate plug-in Y amplifiers on the left, and a single timebase module on the right. With the CX1441 type of Y amplifiers shown fitted in the illustration, the CD1400 becomes a d.c.-15 Mc/s scope with a sensitivity of 100 mV/cm. But it also has provision for switching to a narrower bandwidth of d.c.-750 kc/s when its maximum sensitivity improves to 10 mV/cm. The CX1444 timebase and X-amplifier module shown fitted on the right of the CD1400 can give a horizontal display down to 0.5 μs/cm and a sweep delay range up to 100 ms.

Another widely used oscilloscope in the 10-100 Mc/s class of a more advanced specification is the Marconi TF2200A illustrated in Fig. 49. The basic scope can be

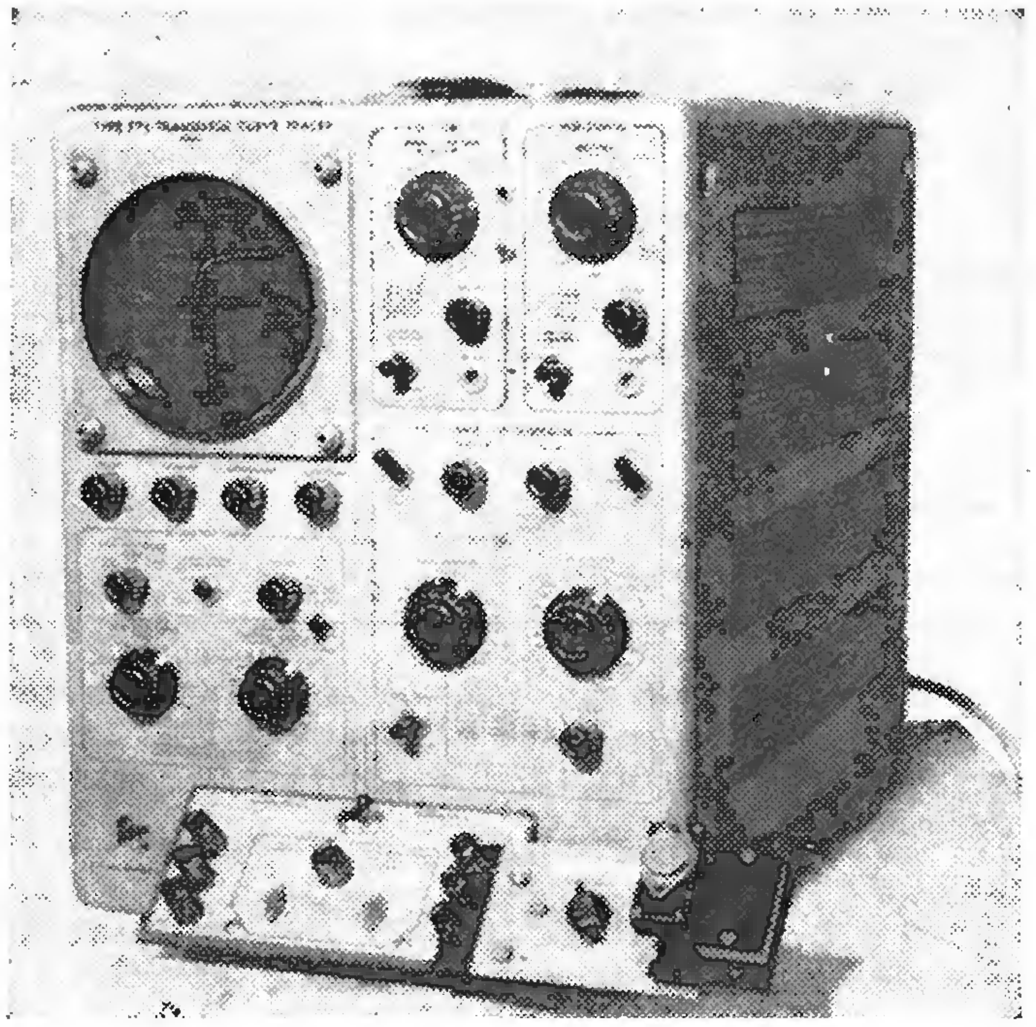
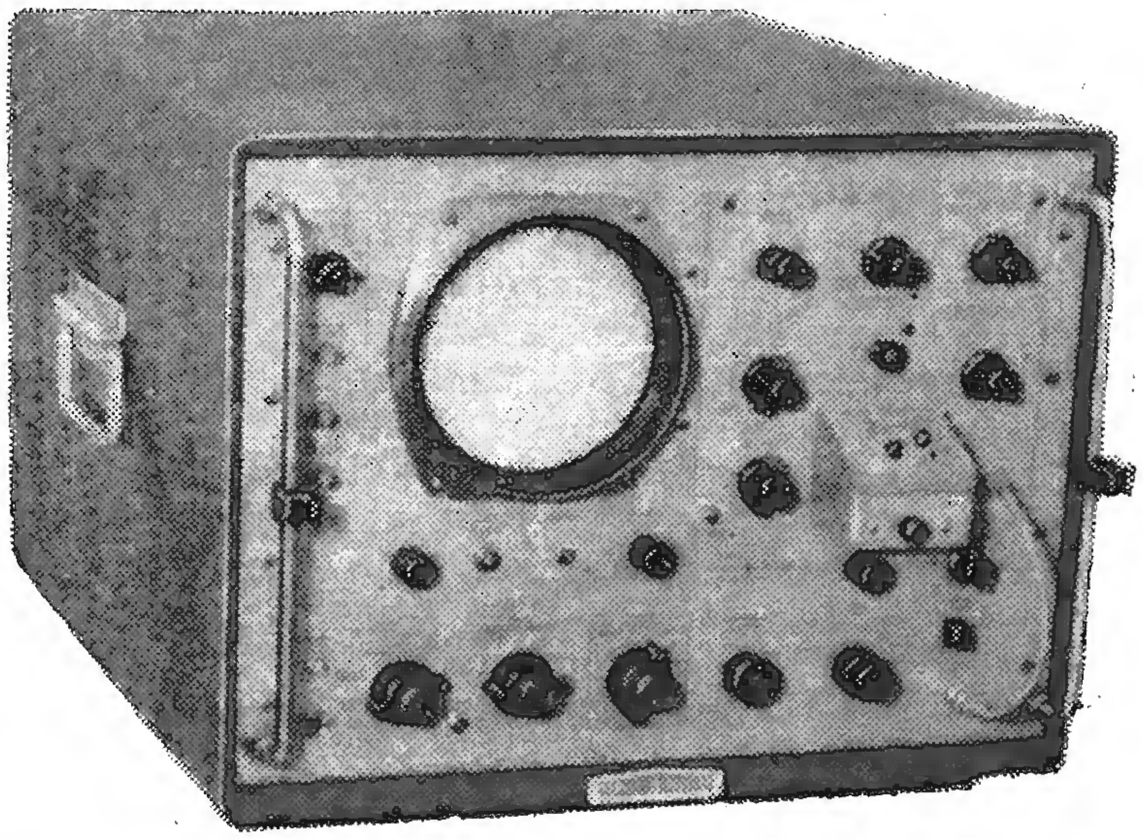


Fig. 52. Transistor curve-tracer scope system: Tektronix Type 575

Fig. 53. Transistor high-speed switching-time tester: Hewlett Packard Type 185B scope fitted with Type 186A transistor switching time test module.



fitted with a number of alternative preamplifier plug-in units, one of which gives a d.c.-40Mc/s bandwidth at 50mV/cm. As it appears in the photograph, the instrument is fitted with a TM6456A dual-trace preamplifier module, which has a 35Mc/s bandwidth at 50mV/cm and which incorporates an electronic switching arrangement whereby two inputs can be displayed together.

Commercial special-purpose oscilloscopes

Double-beam scopes have some advantages. The high-sensitivity Cossor 2300A illustrated in Fig. 50 is the latest in a long line of such instruments; it has a bandwidth of 200kc/s, a sensitivity of 1mV/cm, and automatic triggering.

Earlier we mentioned storage or memory scopes. In the U.K., engineers who have occasion to use such an instrument will recognise the well-known Dawe (Cawkell) Remscope 741 illustrated in Fig. 51 which is a good example of this type of instrument.

"Curve-tracer" scopes are used to display the characteristic curves of components. Probably the best-known is the Tektronix Type 575 Transistor-Curve-Tracer shown in Fig. 52. At present this is almost a "must" in any lab which is doing serious work on semiconductors.

"Switching-time-tester" scopes too are spreading in use. The commercial availability of 1000Mc/s transistors now calls for equipment to display the switching times of such devices in the nanosecond region. The Hewlett-Packard Type 185B scope illustrated in Fig. 53, fitted with a type 186A Transistor Switching Time Tester module, is of this type. The Type 186A plug-in contains a fast-risetime pulse generator, a wideband vertical amplifier for the 185B and two d.c. bias supplies for the transistor under test. Thus with one plug-in you can make self-contained measurements for various bias and pulse drive conditions. The equipment can measure rise-times of the order of 2ns, and can compare risetimes of the order of $\frac{1}{2}$ns between two devices.

Tektronix too are notable for their equipment suitable for measuring the switching times of fast transistors. For example, the Type R Transistor-Rise-Time plug-in unit (illustrated in a previous article in use with the type 545 oscilloscope) uses a measuring pulse with a risetime of less than 5ns which has been adequate for many present day transistors. However, in the higher speed field covered by the Hewlett-Packard Type 186A, Tektronix also market a Type 290 Transistor Switching Time Tester, which, used in conjunction with their Type 519 gigacycle scope, can measure transistor switching times of the order of a nanosecond.

"Sampling scopes" are specialized new-generation fast instruments with bandwidths out to some 4,000 Mc/s at sensitivities of some 10mV/cm. The Tektronix Type 290 and Hewlett-Packard Type 185B mentioned above are of this type. For most general lab purposes, however, the sampling scope has just "too many horses under its bonnet."

Scope accessories

Apart from the range of plug-in units provided by manufacturers with their basic scopes, a number of useful separate scope accessories are on the market.

For example, scope manufacturers normally provide a wide variety of leads or probes. Although these may be given many different names, they tend to fall into three main classes: (1) the direct probe (or test cable); (2) the "×10" circuit isolation or voltage divider probe; and (3) the detector (or demodulator) probe.

The simplest probe is the direct probe in the form of a shielded coaxial cable. It avoids the stray pick-up that can be troublesome when low-level signals are being examined. In using the direct probe on a high impedance or high frequency circuit, remember that the shunt capacitance of the probe and cable is added to the input impedance and capacitance of the scope itself.

To reduce the undesired circuit loading by the excessive capacitance of the lead, the ×10 probe is used to decrease input capacitance and increase input resistance. It usually reduces the scope's input capacitance by ten to one, but also correspondingly reduces its sensitivity. Where low input capacitance is needed without the severe signal attenuation imposed by the ×10 probe, a cathode-follower probe is used.

Finally a detector probe is useful in analysing the response to high frequency modulated signals in television receivers, etc. This probe separates the lower frequency modulation component from the high frequency carrier and allows you, with a scope capable of audio frequency response only, to carry out signal tracing on v.h.f./u.h.f. communication equipment.

An important accessory for the scope that is often overlooked is the trolley. Now that scopes are becoming transistorized and very much lighter than they used to be, trollies are perhaps not as necessary as they once were. But even with a modern light-weight professional scope, it pays you to use a trolley to protect it from unnecessary bumps and damage.

With the development of "instant-picture" Polaroid cameras, the use of cameras to make a permanent photographic record of a waveshape on an oscilloscope screen is now commonplace, and most oscilloscope manufacturers supply accessories for this purpose.

Practical aspects of oscilloscope use

When you come to use an oscilloscope, the first precaution you should take is to confirm that it is satisfactorily earthed. An interesting experiment is to unhitch the earth connection of a scope while you are watching the internal calibration signal derived from the mains; you may find surprising distortion of the trace resulting.

The fan forced-cooling that used to be standard with lab. scopes is beginning to disappear, with the use of transistors in their design. Where you are using a scope with fan cooling, however, always see that the air intake is left clear of obstruction and always ensure that the filter is cleaned out from time to time. This way you will lengthen the life of the instrument.

If you have occasion to dig about in the inside of an oscilloscope, always as a standard practice pull out the mains plug and discharge the high voltage capacitors to earth with an insulated-handle screwdriver before attempting to touch any component with your fingers.

When actually using the scope, always keep the trace brightness at the lowest level consistent with seeing what you want to see. A particular precaution is never to leave the spot stationary on the screen with the brightness turned up. Although c.r.ts are now highly resistant to abuse, this elementary precaution to avoid a burn mark on the screen is always worth while.

Scopes nowadays are usually provided with a graticule, i.e., a grid of ruled lines on or near the c.r.t. face against which the trace can be lined up and measured. Modern practice is to make the graticule with a 1-cm grid. Where the graticule is on a separate screen in front of the tube, always look direct on to it to avoid parallax errors. No damage can be done by turning up the illumination on the graticule too high, if it is of the illuminated type, but you will find that if you use the scope for a long period an overbright graticule can become tiring on the eye.

Always explore the full potentialities of your scope, however modest its specified performance. You will be surprised how much you can achieve with even the simplest of instruments. It is rather like using cameras. Photographs under extreme lighting conditions may be impossible without a super-performance camera, but in over ninety per cent of ordinary cases perfectly adequate photographs can be taken with the simplest of box cameras, if sufficient skill is employed. When you have become used to an oscilloscope, it often pays you to go back and read the handbook once again, because you will often discover potentialities of the instrument that you had missed in your early studies.

In any laboratory, if you can afford it, it pays to have at least two scopes available—a general-purpose modest-performance bench instrument, highly portable, which can take on the bulk of the routine lab. measurements, and a professional high-precision scope, which is kept free for applications really requiring it. This way too, you can hold the high-grade instrument as a standby calibration check for your bench instrument.

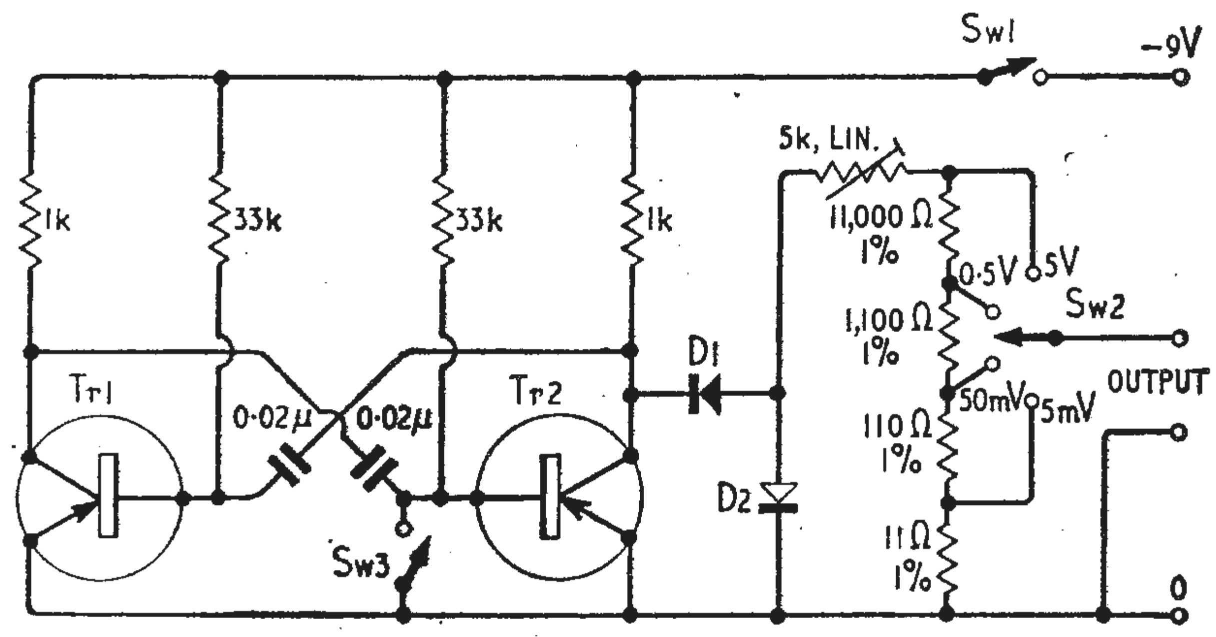


Fig. 54. Vertical sensitivity calibrator circuit for oscilloscope. Tr1 and Tr2 are germanium alloy 7 Mc/s r.f. types (e.g. NKT 128); D1 is a germanium diode (e.g. NKT 149 B30); and D2 is a 6V (approx.) low power zener diode.

If your scope is not fitted with vertical and horizontal internal calibration, you can buy commercial units to provide calibration signals for this purpose. On the other hand, it is quite easy to "knock up" suitable units for this. In the case of horizontal timebase calibration, a useful accessory is a small 1 Mc/s crystal-controlled oscillator which provides one cycle in a microsecond. At the low frequency end, you can check the horizontal sweep against one cycle of the mains frequency.

For vertical calibration (which is usually much more often called for than horizontal calibration) you can make up a simple calibrator on the lines indicated in the circuit of Fig. 54. Battery-driven, it has an on/off switch SW1 push-button operated so that current is consumed only when making a calibration. The output selector switch SW2 is arranged to provide 5 mV, 50 mV, 500 mV and 5 V peak-to-peak in its four positions. The multivibrator Tr1, Tr2 is arranged to switch about 1 kc/s, well within the bandwidth of all normal scopes. The switch SW3 enables the multivibrator to be switched off and thus provides d.c. output voltages identical with the peak-to-peak voltages available when the multi is running.

Doing work of other instruments

We have touched upon the trends in oscilloscope design over the last decade. Transistorization, the widespread use of plug-in modules for versatility, portability, miniaturisation, and the extending knowledge of the instrument all mean that in many cases the scope is taking over much of the work formerly done by multimeters, valve voltmeters, etc. Once you have become accustomed to handling a scope, you will be surprised how often you find yourself turning to it.

The oscilloscope suffers some disadvantages when compared with the multimeter and the valve voltmeter. It is usually larger, heavier, and more complex to work and interpret. Also it is more expensive. But it has many compensating advantages. In all branches of the electrical and electronic industries, we are concerned with varying voltages and currents. Through the eye of a scope we can look at rapid changes in these better than by any other method yet devised. Any changing phenomenon which can be represented by a voltage or a current can be studied with this "visual slide rule."

RAMP GENERATOR

TRANSISTOR CIRCUIT GIVING TRIANGULAR AND SQUARE WAVES

By B. L. HART,* B.Sc.(Hons.), A.M.I.E.R.E.

THIS article describes how the design of a conventional emitter-coupled monostable circuit may be modified to enable it to give a sawtooth output waveform, of known duration and short flyback/run-up ratio, in addition to the rectangular output pulse which is normally produced upon receipt of an input trigger.

Circuit Operation

The operation of the circuit† (see Fig. 1), in which $E_1 > E_2 > E_3$, is as follows:—

Initially D1 is held in conduction by the current in R_2 and RV_1; The forward voltage drop of D1 is greater than the forward base-emitter voltage drop of T1 when the latter is conducting, thus the emitter of T2 is less positive than the base voltage of T2, *viz* E_2, with the result that T1 is conducting and T2 is cut-off.

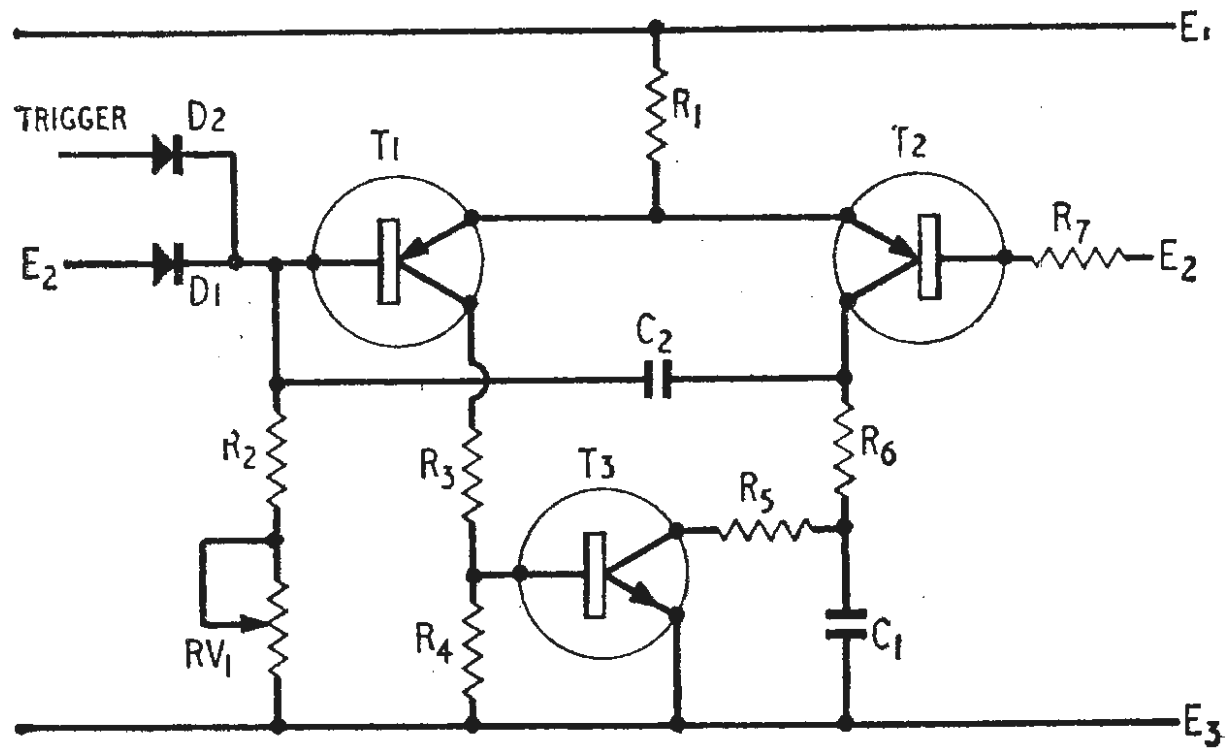


Fig. 1. Basic circuit of ramp generator.

Since the base voltage of T1 is approximately at E_2, its collector current is nearly $(E_1 - E_2)/R_1$ and this flows into R_4 and the base emitter circuit of T3. The current in R_6, and thus the collector of T3, is only the leakage current of T2, so T3 is heavily saturated, the potential difference across C_1 being almost zero.

Let us assume that a trigger pulse of suitable polarity, amplitude, and duration is applied to the circuit (e.g., a pulse positive with respect to E_2 at the anode of D2, or a pulse negative with respect of E_2 at the base of T2). T1 cuts off and T3 ceases to conduct, allowing the capacitor C_1 to become unclamped.

A constant emitter current $(E_1 - E_3)/R_1$ produces a voltage step across R_6. Since the charge on C_2 cannot change instantaneously this step is transferred to the base of T1, and is of sufficient magnitude to ensure that T1 stays cut off when T2 starts to conduct.

If we designate the constant current in T2's collector I and the current in R_2 by i then conventional circuit analysis gives the formula:—

$$i\left(\frac{1}{C_1}+\frac{1}{C_2}\right)+\left(R_6+R_2+RV_1\right)\frac{di}{dt}-\frac{I}{C_1}=0$$

Thus if circuit component values are chosen such that

$$i=\frac{IC_2}{C_1+C_2},\ \text{then}\ \frac{di}{dt}=0;\ \left[\text{since}\ (R_6+R_2+RV_1)>0\right]$$

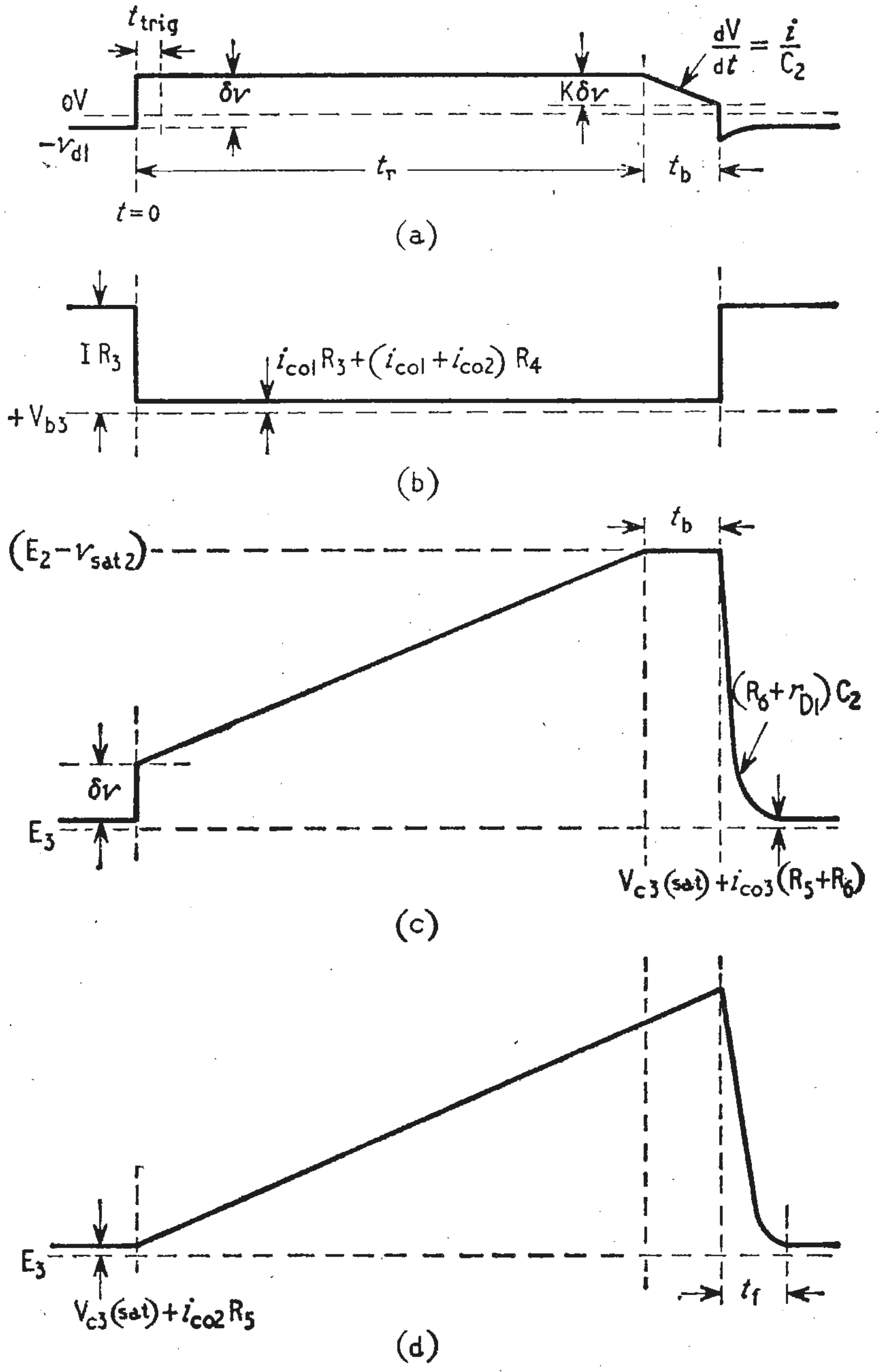


Fig. 2. Waveforms in circuit of Fig. 1. At (a) base of T1 (V_{b1}); (b) collector of T1 (V_{c1}); (c) collector of T2 (V_{c2}); (d) voltage across C_1.

---

*Lecturer, West Ham College of Technology.

†Patent applied for.

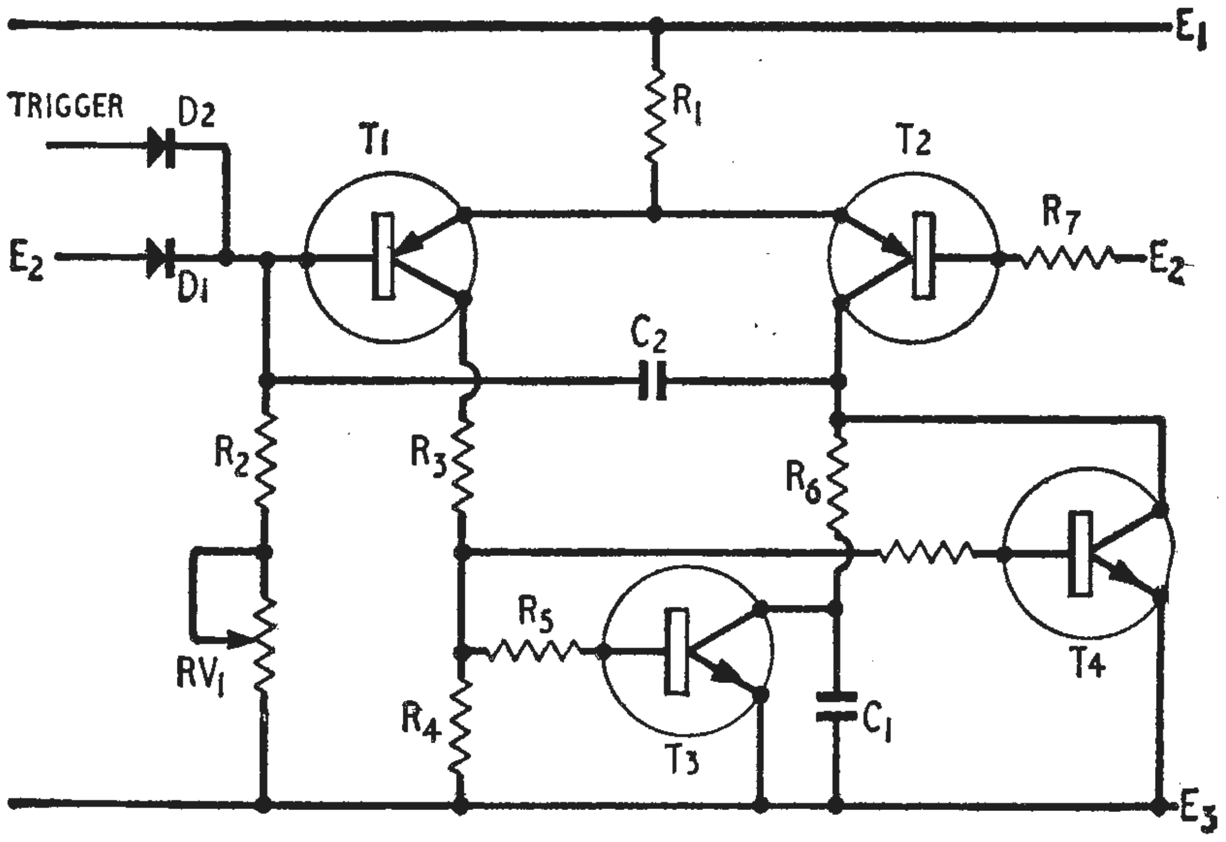


Fig. 3. Addition of T4 to reduce recovery time of C_2.

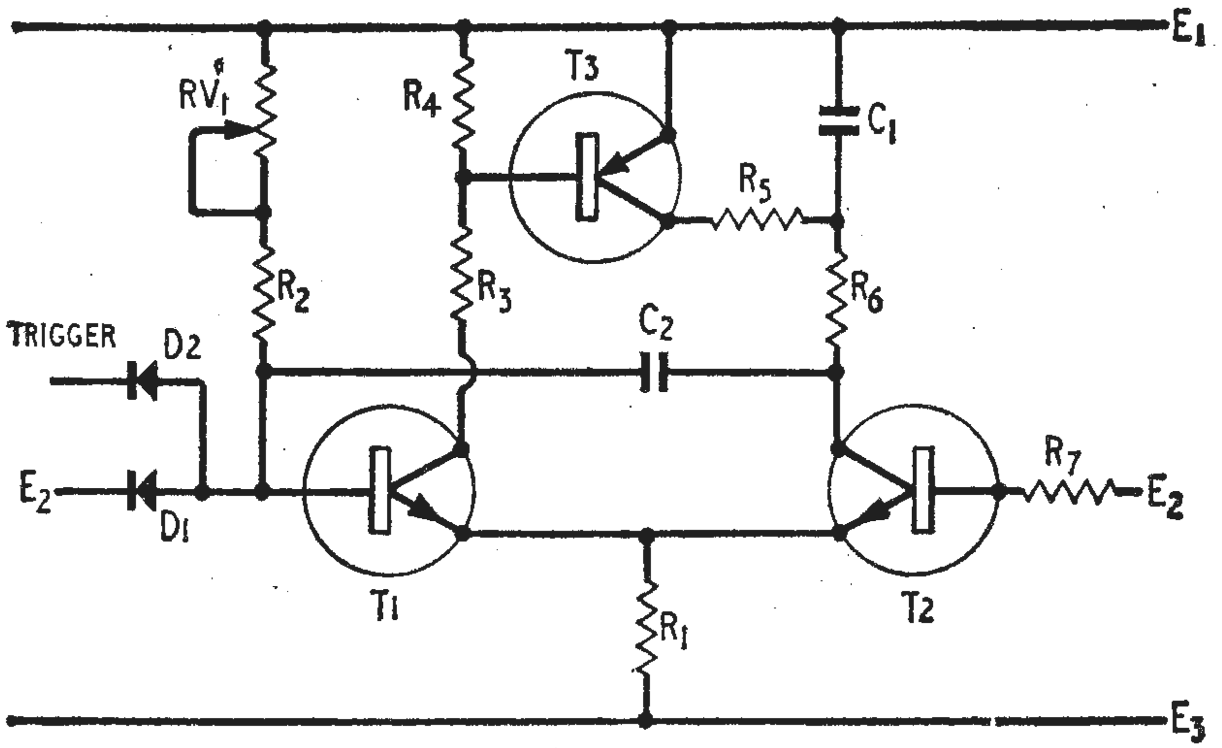


Fig. 4. Re-arrangement of Fig. 1 to use n-p-n transistors.

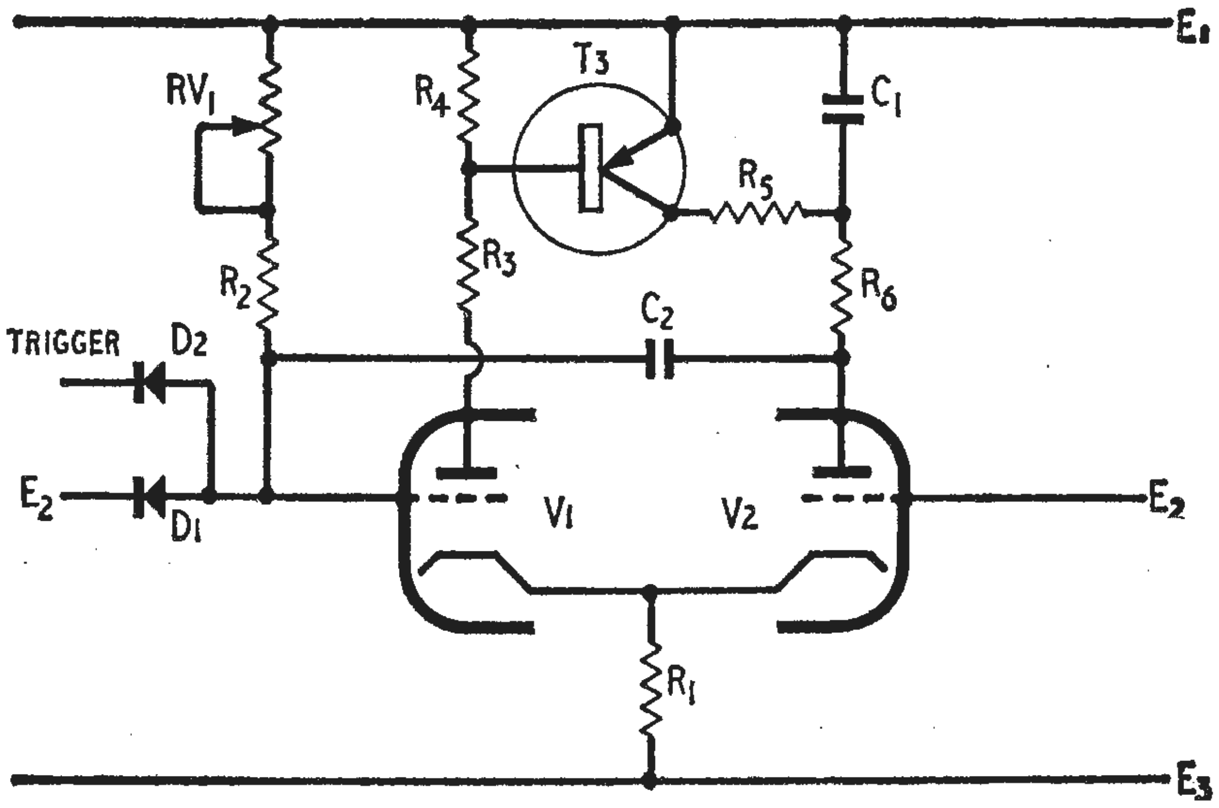


Fig. 5. Hybrid version of Fig. 1 circuit.

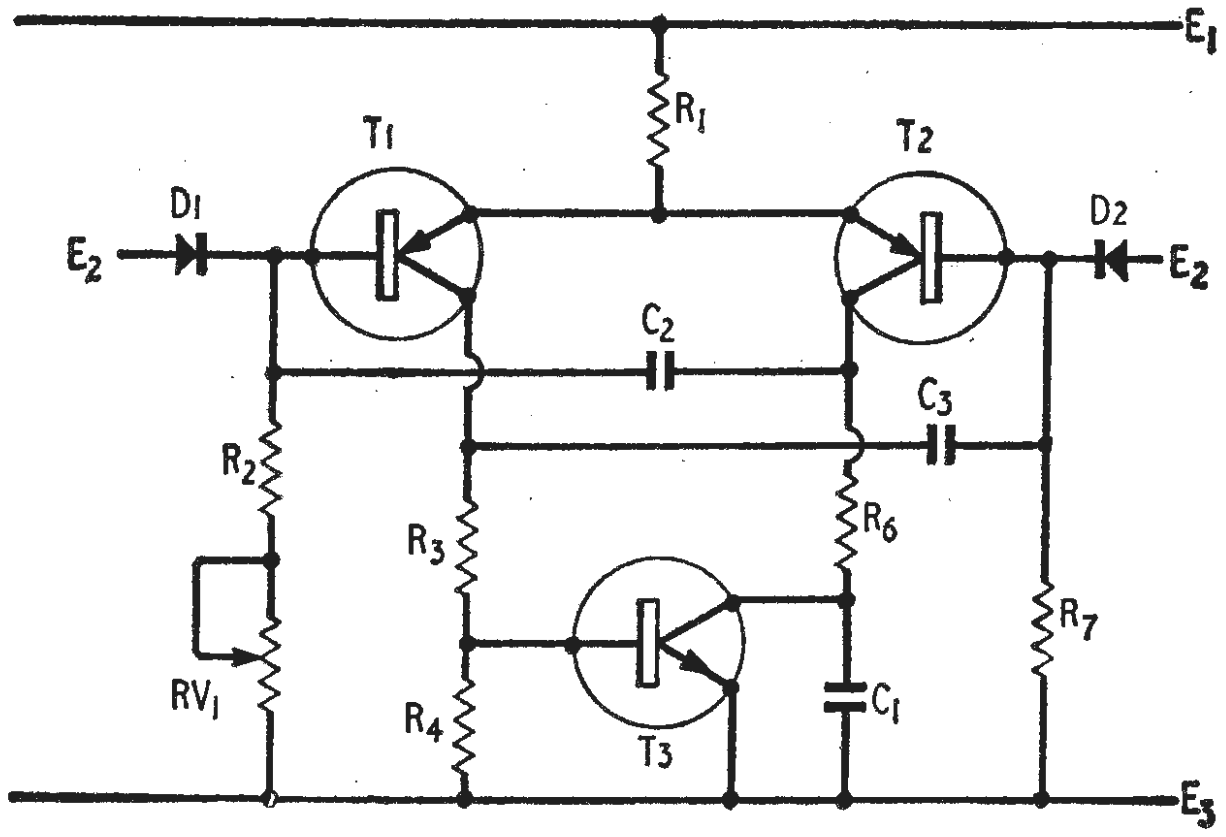


Fig. 6. Free-running ramp or sawtooth generator.

This means that the linear rate of voltage rise, $I/(C_1 + C_2)$, at T2's collector produces a constant voltage at the base of T1: by design this is of sufficient magnitude to hold T1 cut-off when the trigger pulse is removed.

When T2 saturates its collector voltage is held at approximately E_2. The voltage at the base of T1 now falls at a rate i/C_2 and T1 starts to conduct. This in turn causes T3 to conduct. T1 and T3 now function as a complementary switching arrangement causing a regenerative switching action and rapid switch on of T1, and T3. C_1 is thus rapidly discharged.

The collector of T2 recovers with a time constant C_2 R_6 and the circuit awaits the next trigger pulse. R_3 and R_5 are not essential to the operation of the circuit but may be incorporated for the following reasons. R_3 provides a load from which a square output waveform may be taken. R_5 limits the discharge current of C_1.

R_7 makes T2's base amenable to triggering. The small resistor R_4 ensures that T3 is held in a low conduction state when T1 is cut off. RV_1 is incorporated in order that possible adverse component tolerances may be cancelled out and is so adjusted that the waveform at T1's base is flat-topped whilst T2's collector voltage is rising (i.e., adjustment ensures that the relationship $i = IC_2/(C_1 + C_2)$ is satisfied).

The circuit functions in the same way if the rising waveform at T2's collector is inhibited by means other than T2's saturation. For example, if the anode of a "catching" diode is connected to the collector of T2, or the junction of R_2 and C_2, and the cathode of the said diode is connected to a low impedance voltage which may be varied, then the quasi-stable time of the circuit may be set as required. The charging current of C_1 is known and the voltage swing across it are both known so the time period is calculable. Although E_1, E_2 and E_3 are shown as separate voltage supplies they may be referenced against each other by means of Zener diodes, in order to minimize variations in time period with temperature change.

Waveforms and Timing

The waveforms of Fig. 2 refer to the circuit of Fig. 1. It is assumed that the waveform at the base of T1 is flat; then as shown above

$$i = \frac{IC_2}{(C_1 + C_2)}$$

After an interval t_r, T2 bottoms and C_2 starts to discharge. Providing $\delta v << V$ then the discharge rate is approximately constant at i/C_2: t_b is determined by the time taken for the base of T1 to fall by $K\delta v$ and T1 to start conducting. By design $K \simeq 0.5$, though it will not be precisely known. It is shown in the appendix that $t_b = K\ C_1\ R_6$.

Referring to Fig. 2 (c), when T2 bottoms the charging current of C_1 decreases with time; in fact for $t_r < t < (t_r + t_b)$ the voltage across $C_1 = V - \delta v\, e^{-t/C_1R_6}$, where $V = E_2 - E_3 - V_{C2(sat)}$ and hence after $t = t_b$ this reduces to

$$(V - \delta v\, e^{-k})$$

It can be arranged that $t_b = 0$; by adjusting RV_1 so that the base voltage of T1 has a negative slope in the interval t_r. In this case the timing is governed by T1 starting to conduct before, or just as, T2 saturates. However the charging of C_1 is no longer linear and t_r is not so precisely defined.

The waveforms shown correspond to a negative trigger applied at the base of T2. If a positive pulse is applied at T1 base it will be coupled via C_2 into the collector circuit of T2 and thus cause an increased charging rate of C_1 during the period of the trigger.

Monostable circuits using the principle described have the advantage over conventional monostable circuits of not requiring transistors with large reverse base-emitter voltage ratings since the base is never reverse biased by more than about 1V.

Best practical results are obtained with transistors with low saturation voltages and by having $(E_1 - E_2)$, $(E_2 - E_3)$, as large as possible.

For Fig. 1 typical values are as follows:—

$R_1 = 4.7\text{k}\Omega$
$R_2 = 15\text{k}\Omega$
$R_3 = 1\text{k}\Omega$
$R_4 = 1\text{k}\Omega$
$R_6 = 1\text{k}\Omega$
$R_7 = 1\text{k}\Omega$
$C_1 = 0.5\mu\text{F}$
$C_2 = 0.2\mu\text{F}$
D1, D2 : 1N 914
T1, T2 : ST 8034
T3 : 2N 708

Fig. 3 shows how the recovery time of C2 may be reduced. The small resistors in the bases of T3 and T4 facilitate current sharing.

Fig. 4 shows the n-p-n version and Fig. 5 the valve counterpart to the circuit of Fig. 1. Components fulfilling the same function are similarly labelled throughout.

The addition of an a.c. coupling from the collector of T1 to the base of T2, (see Fig. 6) enables a free running sawtooth to be obtained. In this the off time of T2 is governed by R_3, R_7, C_3.

APPENDIX

I = Collector current of T2.
i = Current in $R_2 = \left(\dfrac{IC_2}{C_1 + C_2}\right)$ for case considered.
$\delta v = (I - i)\, R_6$
$V = E_2 - E_2 - V_{C2(sat)}$
α_2 = d.c. common-base current gain of T2.
β_3 = d.c. common-emitter current gain of T3.

(i)

For linear charging of C_1,

$$\frac{V - v}{t_r} = \frac{(I - i)}{C_1}$$

or

$$t_r = \frac{R_1\,(C_1 + C_2)}{(E_1 - E_2)}\,(V - \delta v) \qquad \cdots \quad \cdots \quad \cdots \quad (1)$$

This can be reduced further:—

$$\frac{V - (I - i)\, R_6}{t_r} = \frac{(I - i)}{C_1}$$

or

$$t_r = \frac{1}{\alpha_2}\, R_1\,(C_1 + C_2) \left(\frac{E_2 - E_3}{E_1 - E_2}\right) C_1R_6$$

If, as is probable in practice $E_2 - E_3 = E_1 - E_2$
(e.g., $E_1 = +\,12V$, $E_3 = -\,12V$; E_2 = earth)

then

$$t_r = \frac{1}{\alpha_2}\, R_1\,(C_1 + C_2) - C_1\, R_6 \qquad \cdots \quad \cdots \quad \cdots \quad (2)$$

(ii)

$$t_b = C_2\, \frac{K\delta v}{i} = KC_2\, \frac{(I - i)}{i}\, R_6$$

or

$$t_b = KC_1R_6 \qquad \cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad (3)$$

(iii) Since

$$t_r = C_1\, \frac{(V - \delta v)}{(I - i)} \text{ and } t_b = C_2\, \frac{K\delta v}{i}$$

$$\frac{t_r}{t_b} = \frac{1}{K}\left[\frac{V}{\delta v} - 1\right]$$

if

$$\delta v = 1V, \quad V = 12V, \quad K = 0.5$$

then

$$\frac{t_r}{t_b} \simeq 22 \qquad \cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad (4)$$

(iv) At the commencement of period t_b, the current in R_6 is $(I - i)$: this decreases as C_1 charges up through R_6. In fact for $t_r < t < (t_r + t_b)$ the voltage across C_1 is given (assuming $R_6 \gg r_{sat}$ of T2).

$$V - \delta v_e{}^{-t/C_1R_6}$$

Since $t_b \simeq K\, C_1\, R_6$ this reduces to,

$$V - \delta v_e{}^{-K}$$

(v) When T3 is switched on its base current is approx I, and its collector current (assuming R_5 is omitted) is $\beta_3 I$. Hence C_1 is discharged, approximately linearly, in a time t_f where,

$$t_f = \frac{C_1\,(V - \delta v_e{}^{-K})}{\beta_3 I}$$

Further

$$\frac{t_r}{t_f} = \frac{(C_1 + C_2)\,(V - \delta v)}{I} \cdot \frac{\beta_3 I}{C_1\,(V - \delta v_e{}^{-K})}$$

or

$$\frac{t_r}{t_f} \simeq \beta_3 \left(\frac{C_1 + C_2}{C_1}\right)$$

Commercial Literature

A booklet outlining the **microelectronic services** offered by the Marconi Company has been produced by the Microelectronics Division, which is based at Witham, Essex. Several application reports have also been produced by this Division including "A microelectronic frequency divider with a variable division ratio," "An introduction to microelectronics," "Microelectronics in equipment design," "Modern trends in microelectronics," and "Semiconductor integrated circuit building blocks for linear systems."
7WW 301 for further details

"**Signal Generators and other Signal Sources**" is the title of a 75-page publication produced by Rohde and Schwarz and obtainable (only a limited quantity available) from the U.K. agents Aveley Electric Ltd., of South Ockendon, Essex. It includes chapters on the applications of equipment as well as information on their own instruments.
7WW 302 for further details

"**Heat Sinks for Semiconductor Power Rectifiers and Thyristors**" is the title of a 14-page booklet from S.T.C. that lists and illustrates the ranges of cast aluminium heat sinks they offer ready drilled to take standard semiconductor studs. Power dissipation curves for the various heat sinks showing conditions for convection cooling and forced air cooling are included. Copies of this publication (MF/187X) are available from the S.T.C. Semiconductor Division (Rectifiers), Edinburgh Way, Harlow, Essex.
7WW 303 for further details

Real and Imaginary

By "Vector"

"Many Strange Birds"

WHEN Spring is sprung and grass is riz and butterflies are mating, up in their London officiz the visitor-birds are waiting. And when the sun shines high and hot and isobars are melting, down to our sequestered spots the flocks come madly belting. It could be that they feel an urge for new techniques to bite on; it could be that we're on the verge (or perimeter) of Brighton.

The Hove side, of course. Anyway, that's quite enough of that; at least it's out of my system and every doggerel must have its day. But where were we?

Oh yes—the visitor-birds (*Inquisitivus Impossibilis*). Until the post-war period these creatures were comparatively rare in this country and it was not until electronics manufacturers elected to go bucolic and build their edifices in charming olde-worlde nooks like Soap-behind-the-Ears or Furnish-out-of-Income, that the numbers of the visitor-birds began to show a significant increase. There are now several varieties which are native to this country, while others are migrants, paying fleeting visits only during that short period which is laughingly called summer. All are comparatively harmless, having, at worst, a certain nuisance-value at times. They are not to be confused with another genus, *Proboscis Inquisitorus* or Ministerial Snooper which can, without warning, descend in hordes like a plague of locusts, spreading chaos and ruin, and for which there is no antidote known to science.

Among the less-common of the native visitor-birds is *Inquisitivus Politicus* and the species is eagerly encouraged by Company Chairmen as harbingers of good fortune (possibly a K.C.B.), by Managers (a C.B.E.) and by Wash-Room Attendants (a B.E.M.). Their arrival is presaged some weeks in advance by the appearance of a flock of elderly secretary-birds who have the curious habit of flapping about the place waving pieces of paper in front of the Management.

As some of the rarer of the species dislike fuss and ostentation, everything possible is done to ensure that a normal working-day routine is adhered to. It is just coincidence that an army of painters, plasterers and interior decorators will have been working round the clock for the previous month, covering the whitewash which has done duty for the past decade with a decor of cool jade picked out with gold. It just so happens that Old Joe, the senior sweeper-upper has been sent off on an advanced driving course preparatory to operating the King-size vacuum cleaner which has turned up on the same day as a red carpet—one of those knee-deep pile affairs—in the foyer. It just so happens that although the Managing Director has for years intended to have such a carpet installed, he has somehow only just got round to it three days before The Arrival.

It also just so happens that Angus MacHinery who is unquestionably the best capstan lathe operator in the business, but who has a flow of invective which can on occasion be considered unfortunate, is unaccountably seconded to the Accounts Dept. for a week's stint, his place being taken by the renegade son of an Earl with a theory about democracy, and a Berkeley Square accent. And if perchance it is on the programme that the visitor-bird shall taste the canteen soup then the canteen staff are, to a man, stricken with a one-day palsy hitherto unknown to medicine, while a firm of West End caterers steps into the breach. But apart from these and a few other trivialities, everything is exactly as normal.

The overseas variety of the species (*Inquisitivus Wileorientalgentlemanus*) is much less predictable. Specimens of these are imported from time to time by the Central Office of Information, usually after large deposits of oil or uranium have been discovered on the birds' natural breeding grounds.

The first crisis occurs two hours before the estimated time of arrival when realization dawns that nobody has the foggiest idea what the national flag of Chinpak looks like. After a flurry through the pages of the "Encyclopædia Britannica," the Managing Director is seen pedalling furiously at Mach 0.95 down to the village drapers for some remnants of the right colours. Mission accomplished, there follows a spirited return to base (uphill) and some intensive work with the surgery sewing machine.

He need not have panicked. Foreign potentates are never less than four hours late and the Press boys knew they were on a safe bet when they cut down to Hove for a swim. The entourage arrives just when all right-minded citizens have their ears cocked for the bell tolling the knell of parting day. The distinguished visitor-bird in full oriental plumage waddles out from his Rolls accompanied by a bevy of long-stemmed Birds of Paradise (dedicated technical advisers, no doubt) and a dyspeptic little man who turns out to be the C.O.I. interpreter.

The Chairman, standing on the front steps, delivers a welcoming oration in pidgin English, to which the distinguished guest replies suitably in impeccable Etonian, and the tour is on. The most educational aspect of this is the expression on the C.O.I. interpreter's face as it becomes clear that his journey has not been really necessary. However, his is not to reason why. His orders were to interpret, and interpret he does; his struggle to render "epitaxially grown monolithics" in fluent Chinpak is a joy to behold. We now know why he is dyspeptic.

The day terminates with an adjournment to the Hotel Fabulous, where a fiesta has been arranged in honour of the distinguished guest, his entourage, his legation, his oil wells, his uranium deposits and all that therein is. For the occasion, some of the more comely Company secretaries have been persuaded to doff their double-knit cardigans and pour themselves into hired gowns in order to act as hostesses.

As summer progresses, the influx of visitor-birds increases with rise of temperature and on really hot days the establishment is indistinguishable from a holiday camp. This despite the fact that the more experienced of the species merely touch down, put in a telephone call to the Head Nest to establish that their beaks are well down on the old grindstone and then flap quietly away beachwards to tuck their heads under their expense accounts until sundown.

A notable exception is *Inquisitivus Scribus Technicus* or Greater Genned-up Scribbler (not to be confused with *Scribus Vulgaris*, or Common Yellow Newsbird, which it superficially resembles). Most Genned-up Scribblers are young, terribly earnest and completely harmless; in view of their innocuous disposition it is most unfortunate that physicists and engineers have a built-in horror of having one within miles of them—a phobia which has been traced to an irrational fear of being misquoted. Many a sober, God-fearing physicist has awakened screaming in the night, having dreamt that *Wireless World* has splashed its front cover with a colour picture of himself and a laboratory assistant who looks remarkably like Miss Brigitte Bardot in one of her more evocative attitudes, the whole being surmounted by a banner headline which screams:—

"'EINSTEIN WAS WRONG!' DECLARES PHYSICIST"

In fact there is only one member of the species of which the young engineer or physicist should beware. This is the female Golden-haired Honeybunch, who arrives looking so lost and bewildered that the protective instinct of even the most embittered misogynist is imediately aroused.

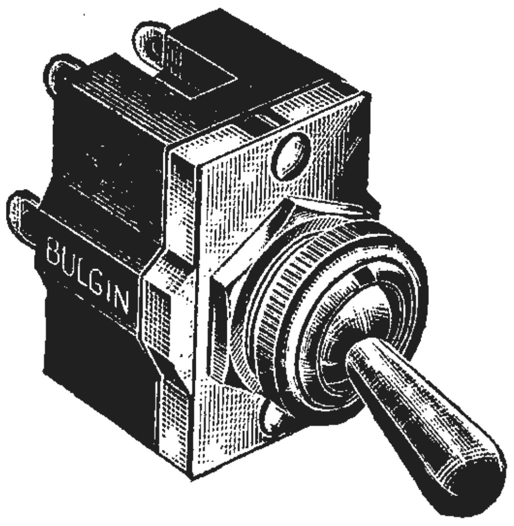
She timorously asks you a question about lasers; now, lasers aren't your subject but why should the Chief of Optical Frequencies have all the fun, so you tell her all you know (which isn't much) and spin it out with what you can improvise as you go along (which is a lot more). She listens, with rose-bud lips slightly parted and big baby-blue eyes open wide. Encouraged, you pull out the stops, blinding her with science and letting her know by implication that if Clerk Maxwell had been living today he would have had competition. . . .

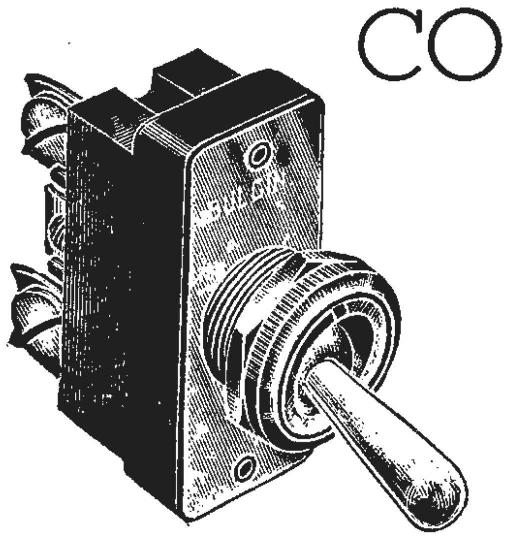
It is at this point that she sees the whites of your eyes and lets you have it right between them:—

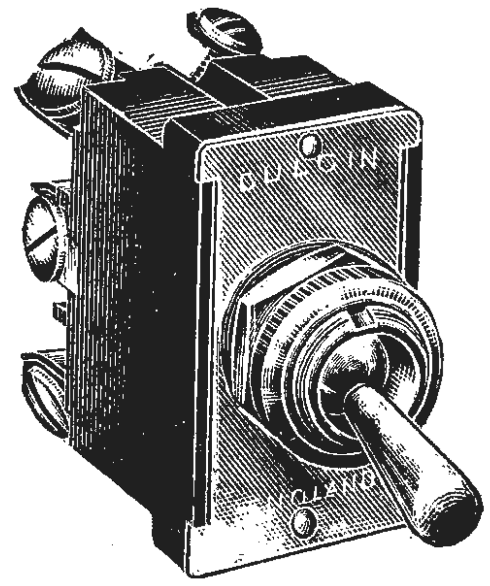
"What about the Mössbauer Effect?"

Ah—what, indeed? The trap has been sprung and you are floundering in a miry pit of your own digging. What on earth is the Mössbauer Effect? You've heard of it vaguely, but for the life of you you can't place it. How dare he come barging in with his wretched Effect to break up a beautiful friendship? And while you're stuttering and bumbling, that bewitchingly helpless little girl has covered a blackboard with equations which send you scuttling into a crack between the floorboards. Only the providential arrival of the Chief of Optical Frequencies restores order and puts Mössbauer back in his gamma-ray-proof cage, from which, it seems, he never should have been allowed out, as that dear little girl knew only too well.

In the gathering dusk you sit glumly in the now deserted lab. vainly trying to mend the puncture in your ego and reflecting that the late Mr. Phineas T. Barnum may not have known much about lasers either, but that his statistical analysis of the birth-rate of such as yourself was bang on target. It isn't until the next day that you find out that the Golden-haired Honeybunch is a Ph.D. with all the possible trimmings.







Colour and Stereo Broadcasting Discussed at this Year's R.T.R.A. Conference

MEMBERS of the Radio and Television Retailers' Association at their annual conference held recently in Scarborough, heard from the B.B.C's director of engineering, F. C. McLean, of recent happenings on the colour television front and also of the work being done in stereo broadcasting.

During question time Mr. McLean was asked how long the Country would have to wait for a decision on colour. Not being able to answer for the Postmaster-General, he said that he could not give a date, but in his opinion it was very unlikely that all countries in Europe would ever agree on a common system.

This brought a resolution from Mr. B. Proffitt, of Bolton, "urging the Postmaster-General to introduce a colour television service as soon as possible and in default of agreement at Oslo next year, that we should, in Britain, go it alone."

Colour Television Situation

The colour situation at present is pretty much the same as before the Vienna Conference, Mr. McLean told R.T.R.A. delegates. Referring to the counting of heads in favour of one system or another at the end of the Vienna Conference (see May issue, page 229), he pointed out that while some of the countries represented have done, and are still doing, considerable work on colour systems, others have no operational experience, nor have they undertaken any investigational work. In a number of cases the countries represented have not even a black-and-white service! Among those who have done work on colour, few supported SECAM compared with the number for N.T.S.C. and PAL, which were fairly equally divided.

Outlining the advantages and disadvantages of the different systems, Mr. McLean stressed that the design problems of N.T.S.C. have been well studied—not only as regards the studio and transmission equipment but particularly on receivers. Another significant point came to light when he told delegates "I think it is true to say that a receiver for the N.T.S.C. system has the minimum number of components, giving the greatest reliability and the lowest cost."

Coming very close to the N.T.S.C. system, Mr. McLean stated, is PAL, but receivers will cost more as additional functions have to be carried out if the optimum form of delay-line PAL is used. It was also explained that in areas where multipath effects occur (causing ghosting), PAL has some advantage over N.T.S.C. and thus, it may possibly be easier to secure European agreement on the basis of PAL than N.T.S.C. Another series of B.B.C. experimental transmissions using the PAL system began on 24th May (see "World of Wireless").

Mr. McLean told the conference that, in his opinion, SECAM does not give such a good colour picture, nor such a good compatible black-and-white picture as N.T.S.C./PAL, and receivers would cost appreciably more. He also stated that the advantages claimed for SECAM in recording are of little value and that those claimed for transmission over long distances are quite unattainable in the presence of multiple distortion.

Concluding his remarks on colour Mr. McLean told delegates that all the BBC-2 transmitters have been engineered so that they can take any colour system, and the Post Office is providing lines on the same basis. Only the minimum of modification is necessary to studios. Once a decision has been taken, Mr. McLean said, the B.B.C. would do everything possible to expedite a nation-wide colour service.

Stereo Broadcasting

Turning to stereo broadcasting, the B.B.C's director of engineering told delegates that the Vienna Conference provisionally accepted two systems for stereophonic transmission. The first of these, the polar-modulation system was accepted for use in areas using 50 kc/s deviation (the Eastern Bloc) and the pilot-tone system, the adopted name for the Zenith-GE system, for areas using 75 kc/s deviation (Western Europe).

Other systems, Mr. McLean continued, were put forward at Vienna, but none was thought to be sufficiently advanced to be adopted. He did say, however, that there will be another chance of putting a system forward at the meeting in Oslo next year, should one become sufficiently advanced.

"What people are looking for, and what is not given so far by either of the systems adopted," Mr. McLean said, "is the ability to use stereophonic transmission for two separate programmes at such times that stereophonic transmissions are not in progress." He then told delegates that countries with more than one language would welcome this facility, which could also be used by other countries for putting out subsidiary programmes.

A reference to a system developed by a Swedish engineer, G. R. Burgland, that employs compression and expansion techniques, was made by Mr. McLean. This, he stated, has been tried by the B.B.C., but so far has not proved very successful and the equipment is being returned for modifications. Although the Swedish system has better cross-talk characteristics (necessary for dual programme transmission), he pointed out that more complex receivers are required which would cost appreciably more.

Closing his address, the B.B.C.'s director of engineering said that as no decision to start a regular stereophonic service in the United Kingdom had yet been made, the choice of system was still open.

Guarantee Terms

During the open forum, one of the delegates told the conference that the new guarantee terms offered by Decca were one of the finest things introduced in the trade for many years. Mr. D. M. Keegan, the Association's director, endorsed the delegate's statement and said he looked forward to the time when more manufacturers could offer similar terms. Representatives from other manufacturers said this was not possible until the component makers could offer better terms.

The Decca guarantee is for one year on all parts (including valves and c.r.t.s where applicable) for television receivers, radiograms and record players, and for two years on transistor radio receivers. It should not be necessary for dealers to make a charge whilst equipment is under guarantee, as, to quote from the Decca booklet outlining the guarantees, a payment of £2 will be made "to the retailer to offset labour costs which might possibly be incurred by the retailer in discharging, on behalf of Decca, service activity."

Mr. N. A. Twemlow, a director of Pye Ltd., told the conference that at present some parts of a television receiver were guaranteed for 12 months, while others were for six months and others were for three months. He also added the success of the Decca venture had been placed in the laps of the dealers, and many other manufacturers would be watching with great interest.