

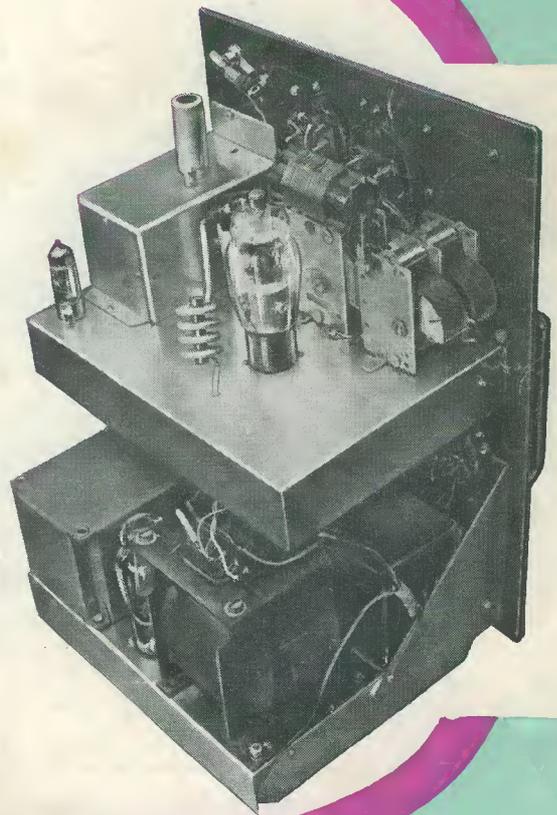
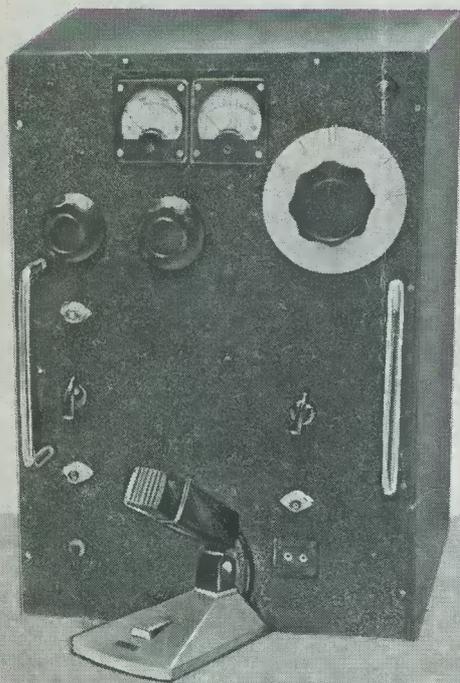
THE
RADIO CONSTRUCTOR

Vol 21 No 3

OCTOBER 1967
2/6

A DATA PUBLICATION

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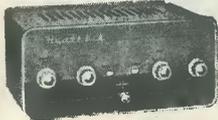
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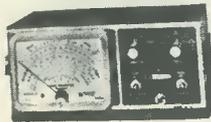
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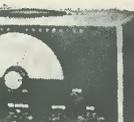
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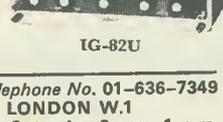
V-7A

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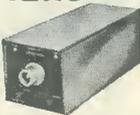
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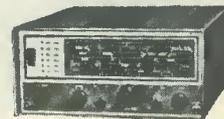
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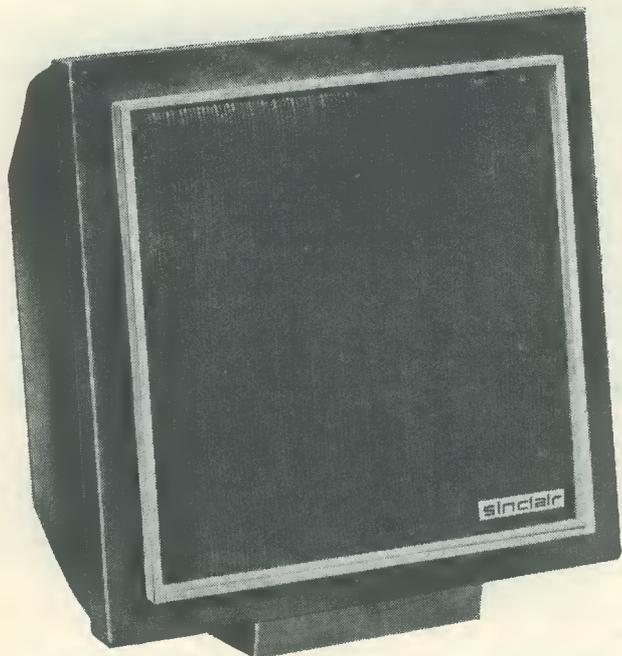
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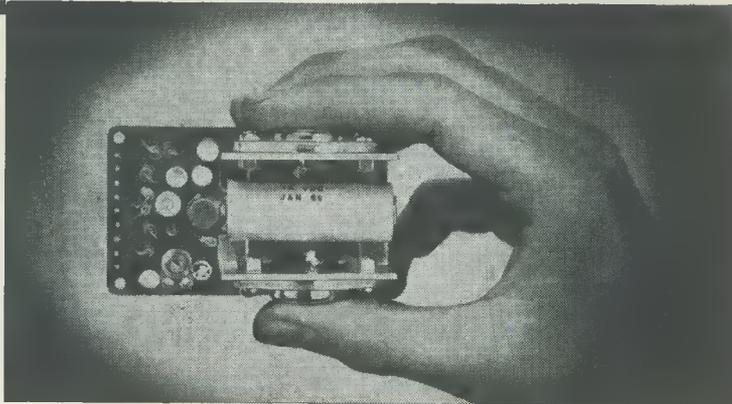
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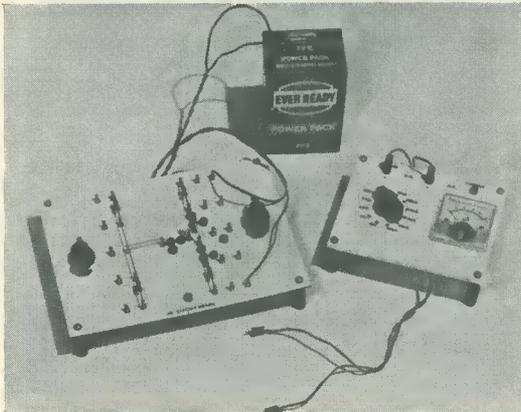
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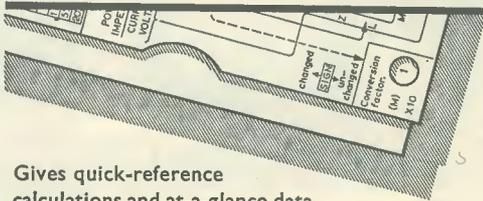
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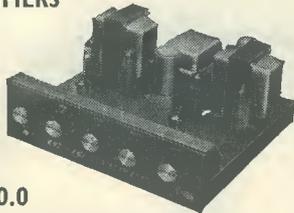
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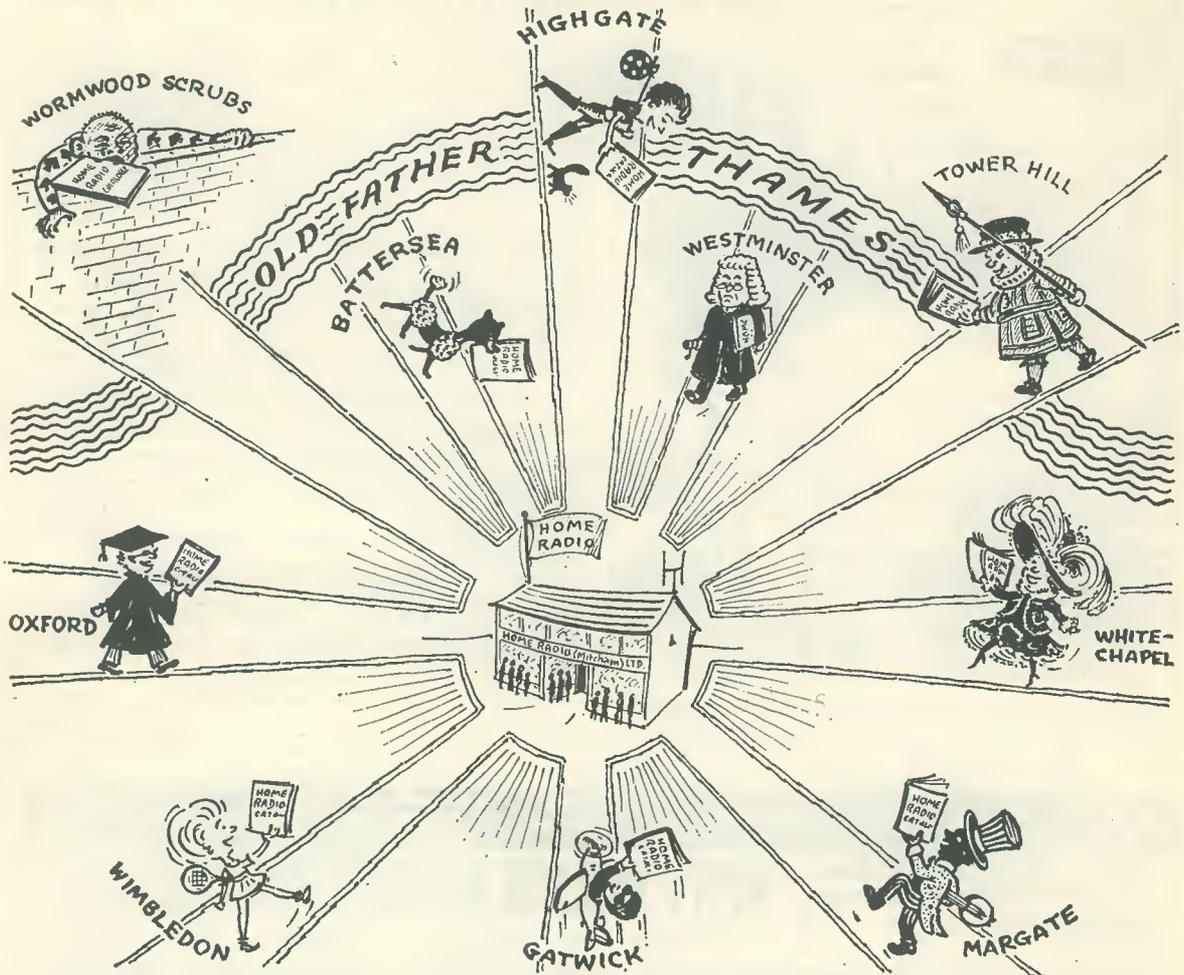
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Microminiature Audio Amplifier <i>by A. J. McEvoy, B.Sc.</i>	138
Parallel-R Series-C Computer (Suggested Circuit No. 203) <i>by G. A. French</i>	142
Can Anyone Help?	145
Miniature Tunnel Diode Oscillator <i>by A. D. Williams, B.Sc.</i>	146
News and Comment	148
Four-Stage Voice-Operated Switch <i>by L. J. Moore</i>	150
The Beta Meter <i>by Sir Douglas Hall, K.C.M.G., M.A. (Oxon)</i>	153
Water Level Alarm Unit <i>by W. Kemp</i>	156
Recent Publications	159
40 Watt 80 Metre Phone Transmitter <i>by F. G. Rayer, G3OGR</i>	160
Step Recovery Diodes <i>by J. B. Dance, M.Sc.</i>	169
Understanding Radio (Output Stages and Phase Splitters) <i>by W. G. Morley</i>	171
In Your Workshop	175
When Beta Doesn't Matter <i>by G. Short</i>	180
Trade News	181
Radio Topics <i>by Recorder</i>	183

Microminiature Audio Amplifier

By A. J. McEvoy, B.Sc.

Integrated circuits are now available to the home constructor at fairly low cost, and can be employed for experimental applications in which their tiny dimensions offer particular advantages. This article describes how a logic silicon integrated circuit—whose 16 transistors and 12 resistors fit in a package measuring 0.25in square—may be pressed into service as an a.f. amplifier

ABOUT TEN YEARS AGO THE TRANSISTOR EMERGED from the laboratory and entered the field of radio for the first time, making the first challenge to the valve in forty years. It does not seem, however, that the transistor's reign will last as long, since current developments in microelectronics threaten to displace it from its recently won position. We have already seen the emergence of computer systems based on microelectronic devices, and all the indications are that the present year will be, for the amateur enthusiast, the analogue of the 1957 year of the transistor revolution, with

the availability of the first integrated circuits in small quantities and at competitive prices.

Integrated Circuits

First, a word about these devices and their mode of operation. The transistor differed from the valve in that it substituted a current in a semiconductor for the motion of electrons in a vacuum, and all solid-state work since has followed on this line, taking in such exotic units as F.E.T.s, tunnel diodes, and so on. There is no corresponding breakthrough with the new integrated circuits (or I.C.s);

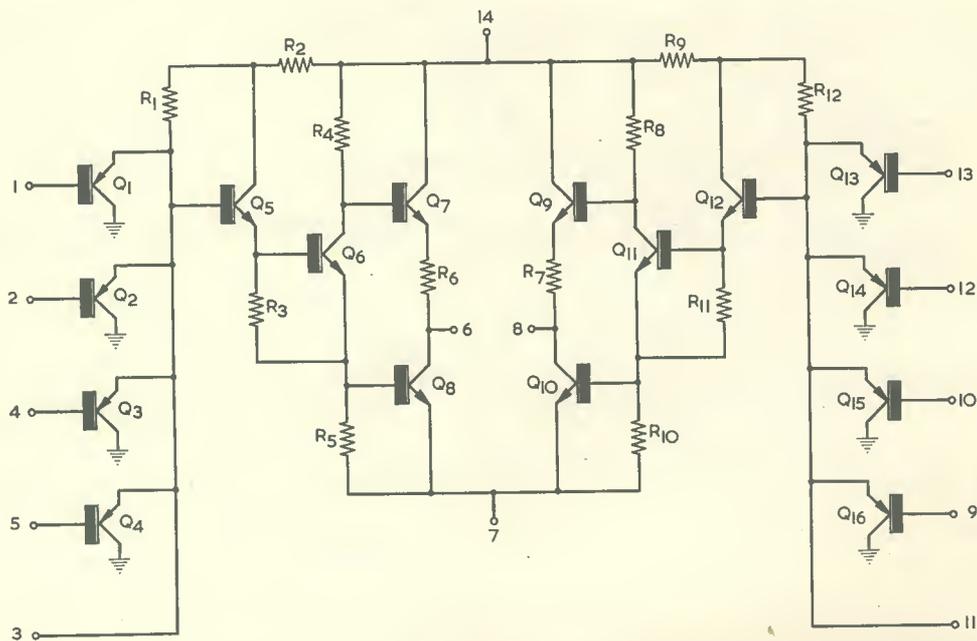


Fig. 1. Circuit diagram of the R.C.A. integrated circuit type CD2200. Terminal 7 is assumed to have the same potential as the earth symbols

they are merely the result of the manufacturers' increasing competence in the fabrication of semiconductor devices, and so all the advantages and experience gained with transistors are retained. For example, the currents and voltages are approximately the same as in any familiar transistor circuit and, of course, there is no heater supply required. The constructor is therefore spared the difficulty of learning a complete new technology, which many remember as a significant problem with the earlier transistor circuits. The integrated circuit is so called because it integrates, or incorporates within itself, components equivalent to a whole range of separate components normally used in electronics—transistors, resistors, capacitors and diodes.

There are two main types of integrated circuit. Thick film and thin film circuits represent one main type and these are composed of small, controlled areas of conductors deposited on an insulating base so that they form resistors and capacitors. The active elements—transistors and diodes—are added afterwards as small chips of semiconductor. It can be understood how a fairly complex system can be assembled within the volume usually occupied by a single transistor when it is remembered that the active volume of such a transistor is only about 1% of the size of its can.

The term "monolithic" refers to the alternative type of integrated circuit. This represents a more advanced approach which proceeds from an understanding of the semiconductor, silicon. The pure semiconductor is practically an insulator but, by adding suitable "impurities", conduction may be initiated, current being carried by electrons or "holes". A diode is simply the junction between two such sections of a silicon crystal, and a transistor a sandwich of three of them. Of course, a slice of crystal, doped but lacking a junction, is equivalent to a resistor, and a sandwich with an insulating filling is a capacitor. A monolithic I.C. (or "silicon integrated circuit") incorporates all these functions in separate zones of the same crystal. The reduction in size given by this technique, when compared with conventional circuitry, is dramatic.

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R₁ 10k Ω

R₂ 5.6k Ω

R₃ 22k Ω

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C₂ 100 μ F electrolytic, 6V wkg.

Loudspeaker

80 Ω impedance

Integrated Circuit

Type CD2200 (available at £2 5s. 0d. from R.C.A. Great Britain Ltd., Lincoln Way, Windmill Road, Sunbury-on-Thames Middlesex)

COMPONENTS



The amplifier on top of a Vidor VT3 battery

Integrated circuits first found applications in the computer field, because that seemed the best opportunity for the volume of sales required to justify tooling up for any particular design of circuit, since in a single computer the same basic subsystem may be repeated thousands of times. It is principally devices of this nature which are now becoming available to the home constructor, and while that fact enables him to obtain them at a reasonable price with the promise of further reductions as production rises (remember the transistor—£3 for a pair of OC72's in 1957) there is the difficulty that he must adapt what is available to the application at hand, and this will inevitably be something other than what the integrated circuit was originally designed to do.

The integrated circuit amplifier described here represents an example of this approach. In the first place, a computer circuit is designed to rest in

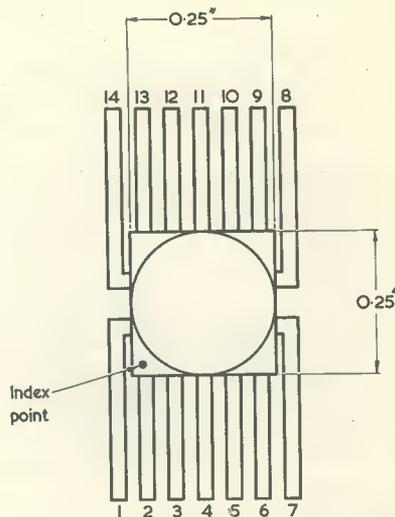


Fig. 2. Despite its complex circuitry, the CD2200 is housed in a container measuring 0.25in square only

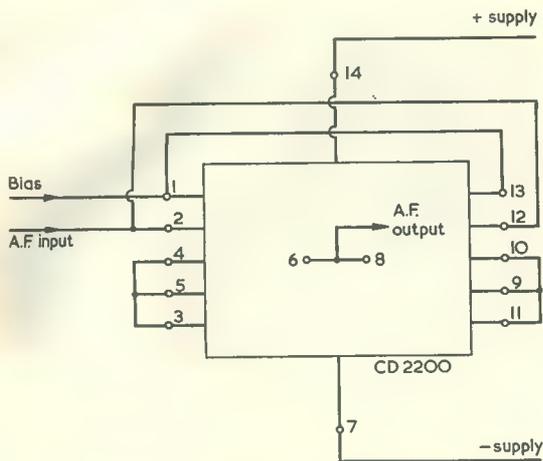


Fig. 3. How the integrated circuit terminals are connected in the a.f. amplifier

one of two states, saturated or cut-off, so that the output will be at earth potential or at the full supply line voltage, representing respectively the zero and unity which are all that is required to specify any number in the binary system. The circuit is expected to be quite stable in either state, and is therefore set to ignore small fluctuations in the voltages applied to it, and to change over only on application of a definitive triggering pulse. This is opposite to the operation of a circuit in a linear mode, as is required for an audio amplifier. In the latter case, the stable state is midway between the extremes of the logic outputs, and the circuit is expected to accept and amplify small signal fluctuations applied to it.

Circuit Type CD2200

These remarks apply to the integrated circuit, which is the subject of this article, the R.C.A. CD2200. This is described as a dual four-

input gate. The circuit diagram, given in Fig. 1, shows that the unit incorporates two identical eight transistor subsystems, each with a series of four p.n.p. input transistors operating in the common-collector mode, followed by a four transistor amplifier section using n.p.n. transistors. All four input transistors operate into a common emitter load, and the signal developed across this enters the base of Q_5 (or Q_{12} in the right hand section).^{*} This again is a common collector circuit, driving the split-load phase splitter Q_6 (Q_{11}), although there must be some overall current gain due to the partial super-alpha pair nature of this configuration. Q_7 and Q_8 (Q_9 , Q_{10}) are obviously a push-pull pair. The reader will note that the same results in terms of gain and output could be achieved with a smaller number of transistors, but a feature of the silicon integrated circuit is that the number of transistors is no longer an important economic feature in the design of a circuit.

With the circuit in question, the possibility was first considered of connecting the loudspeaker across the two outputs while sending in equal signals of opposite phase at the inputs of each gate. This arrangement worked, but inefficiently, due to matching difficulties, and it was finally decided for the sake of simplicity merely to parallel the gates. It was further necessary to ensure that the circuit operated on a linear section of its characteristic, and as the current in R_1 (R_{12}) sets the operating point of the amplifier transistors by controlling the bias of Q_5 (Q_{12}), it was decided that one of the inputs at each gate should be used in the control function, with its bias and therefore its emitter current, fixed by a d.c. potentiometer. The operating point of the circuit was therefore stabilised. A separate input point was used to insert the audio signal. The control and signal input points, as well as the outputs, of the subcircuits are joined together. In all, therefore, four transistors out of the sixteen

^{*}It is, of course, common American practice to employ the letter "Q" to identify transistors.—EDITOR.



The complete amplifier has an area comparable with that of a penny. (The author is resident in Ireland—hence the origin of the coin)

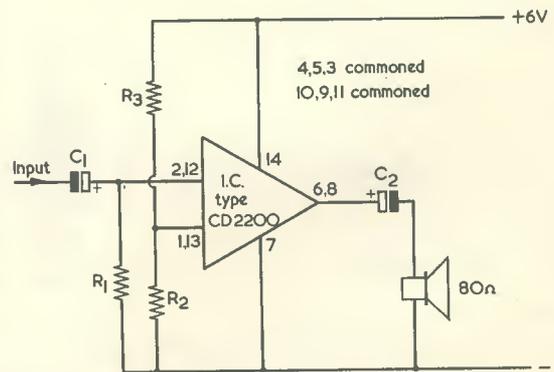


Fig. 4. The complete circuit of the amplifier

in the circuit are unused, as are six of the fourteen connections. It is perhaps unfortunate that R_6 and R_7 are incorporated in the circuit, as there is some loss of output across them, but there is no means of access to them and this drawback must be accepted.

Dealing with the integrated circuit on its own, Fig. 3 shows the basic way in which its terminals are connected for use as an amplifier. Terminals 4, 5 and 3 are joined together, as are terminals 10, 9 and 11. No other connections are made to these terminals. The a.f. input is applied to terminals 2 and 12 joined together. Bias is applied to terminals 1 and 13 joined together. Thus, Q_2 and Q_{14} provide the first a.f. amplifying stage, whilst Q_1 and Q_{13} set the bias conditions. Terminals 6 and 8 are joined together, and the a.f. output is taken from this point. Terminal 14 connects to the positive supply and terminal 7 to the negative supply.

The complete amplifier circuit is given in Fig. 4, in which it may be seen that three external resistors, two external capacitors and the loudspeaker are required to obtain the practical working circuit. It should be noted that supply voltage must *not* exceed 6 volts.

Assembly

There are a number of ways of assembling the amplifier, of which the method illustrated in Fig. 5 is probably the most compact. The I.C. sits on a plastic pad supplied with it, and its terminals are taken through slots cut with a fretsaw in the edge of the strip of Paxolin. Connections are made on the reverse side of the Paxolin. The resulting amplifier gives about 30 to 50mW when driven from the diode of a three transistor superhet tuner—quite sufficient for a loudspeaker under reasonably quiet conditions, and ample for an earphone anywhere. The writer will not try to claim that the I.C. amplifier has anything like the performance

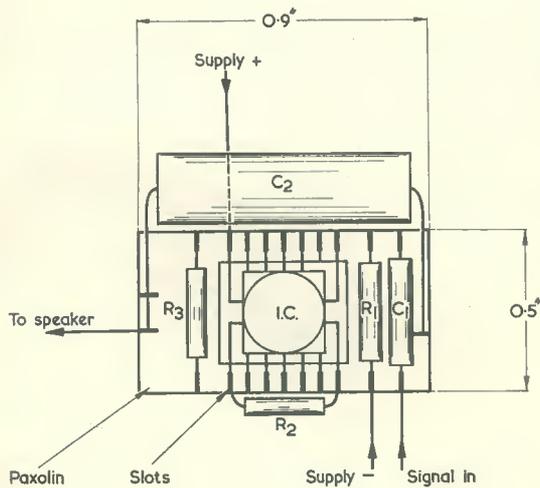


Fig. 5. The layout used by the author

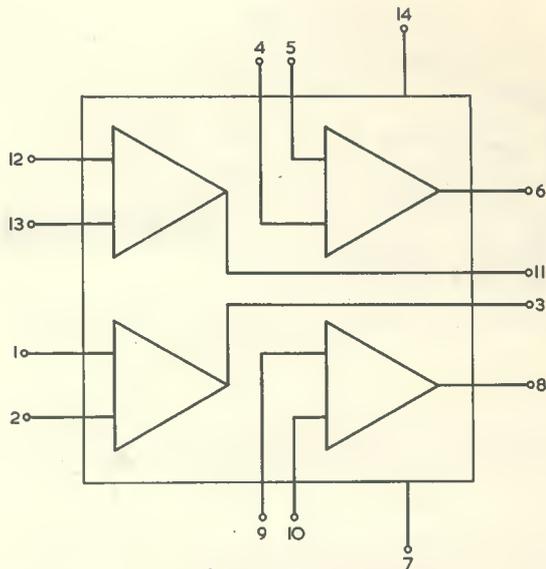


Fig. 6. The basic form of the R.C.A. CD2201 integrated circuit

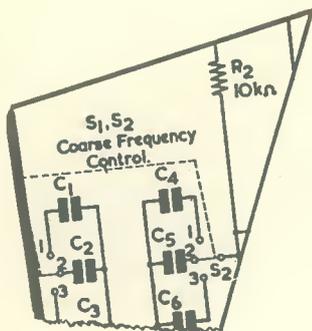
obtainable from a transistor unit of the same price, but no other unit of the same performance and size exists anywhere, and for some purposes that is more important than the price. The quality of the output was surprisingly good and deserves special note; this is perhaps due to the fact that the transistors incorporated in the unit are the equivalent of the best silicon planars on the market, and the fact that they have considerable negative feedback from the unbypassed emitter resistors in each stage.

Availability

The integrated circuit type CD2200 is available from R.C.A. Great Britain Ltd., at the address given in the Components List, at £2 5s. 0d. each. Individual integrated circuits may be purchased.

The enthusiastic experimenter may be interested to learn that R.C.A. also produce a quadruple two-input gate, the CD2201, in which four amplifiers can be paralleled, as shown in Fig. 6. With the CD2201 there are only two inputs to each gate, and all its 24 transistors could be used in an a.f. amplifier application. This I.C. costs only 2s. 6d. more than the dual unit. The writer has not carried out any practical work with the CD2201 although it would seem to be capable of a higher output than the CD2200. However if, like the writer, the reader is mainly interested in experiments, the CD2200, which has access to more points in the circuit, is more attractive. Either way, these R.C.A. units represent as good an introduction to the applications of the silicon integrated circuit as is yet available.





Parallel-R Series-C Computer

SUGGESTED CIRCUIT No. 203

by G. A. FRENCH

AN IRRITATING FEATURE OF CONSTRUCTIONAL and experimental work is the necessity, from time to time, of having to calculate the total value of two resistors in parallel or two capacitors in series. With resistors in parallel, the appropriate equation is:

$$R_{\text{total}} = \frac{R_1 R_2}{R_1 + R_2}$$

where R_1 and R_2 are the values of the individual resistors. The calculation involved is not particularly difficult, but it can be very time-wasting and irritating, especially when the individual resistor values are in the preferred range instead of consisting of round-number figures. The calculation becomes more exasperating if the desired R_{total} is known and one has to find R_1 and R_2 from one's stock of resistors at hand.

For two capacitors in series the equation is:

$$C_{\text{total}} = \frac{C_1 C_2}{C_1 + C_2}$$

where C_1 and C_2 are the values of the individual capacitors. The equation is similar to that for two resistors in parallel, and the same remarks apply.

Simple Computer

The writer felt that it would be interesting to contrive a computing device which would enable the total value of two resistors in parallel, or two capacitors in series, to be found without resort to calculations at all. In its basic form such a device can be quite easy to construct, and two versions, one a little more complex than the other, are described in this contribution to the "Suggested Circuit" series.

The simpler of the two computing devices is shown in Fig. 1. In this diagram, R_1 and R_2 are 20kΩ linear track potentiometers fitted to the panel of a small box. Each potentiometer is provided with a pointer knob or cursor, and a scale, the latter being calibrated in terms of the resistance presented by the potentiometer to the circuit. Calibration is in figures from 1 to 20, these corresponding to 1 to 20kΩ in the potentiometer. Calibration below 1 (=1kΩ) is not provided as calibration units would be difficult to resolve reliably. The two potentiometers are in parallel and connect to two test terminals. These terminals may also be mounted on the front panel, resulting in a layout similar to that shown in Fig. 2.

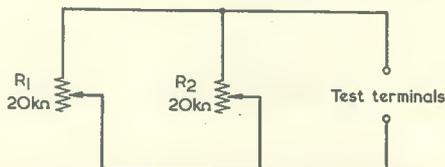


Fig. 1. The simplest form of parallel-R, series-C computer. R_1 and R_2 are calibrated in terms of resistance and a testmeter switched to a suitable ohms range connects to the test terminals

To use the device, any testmeter switched to a suitable ohms range is connected to the test terminals. This testmeter then indicates the resistance offered by the two resistors in parallel.

To take an example of how the unit may be employed, let us assume that we want to find the values of two resistors which, in parallel, will give us 5kΩ. In our stock of resistors we have a 6.8kΩ resistor together with a number of resistors of higher value. One of the latter could provide a second resistor in parallel with the 6.8kΩ resistor to give us a total value of 5kΩ. We commence by setting either of the two potentiometers to 6.8, after which we rotate the other until the testmeter reads 5kΩ. This will occur when the second potentiometer is at 18, whereupon we know that the second resistor must be 18kΩ. Thus, the computer tells us without any waste of time that, for the desired final resistance of 5kΩ, the parallel resistor has to be 18kΩ.

The units with which the potentiometer scales are calibrated, and which are indicated by the testmeter, are in kilohms, but it is very easy to mentally transpose the results to other units. Thus, the exercise just described will similarly indicate that 18Ω and 6.8Ω in parallel give 5Ω, that 180kΩ and 68kΩ in parallel give 50kΩ, and so on. Dealing with capacitances, the exercise also shows that, say, 18pF and 6.8pF in series give 5pF, and that 1800pF and 680pF in series give 500pF.

The two potentiometers in this simple computing device should be good quality wirewound components having physically large tracks and reliable mechanical operation. They

may be calibrated with the aid of the testmeter which is also used for measuring their total resistance. If the 500 Ω to 10k Ω range of total resistances the computer unit offers does not correspond to a conveniently calibrated resistance range of the testmeter, the two potentiometers can be given values other than 20k Ω and be fitted with corresponding scales. The same basic principle of operation will still, of course, apply.

Constant Current Computer

The circuit of Fig. 1 has the advantage of simplicity and low cost, but it suffers from the disadvantage that the resistance scale of a testmeter is non-linear and that it may be difficult to obtain quick and reliable results over sections of the testmeter scale which are cramped. The second, and more complex, computing device to be described this month overcomes this problem by presenting the total resistance reading on a linear meter scale. This involves the addition of a transistor, a diode and several other components, plus a 0-100 μ A meter. However, the 0-100 μ A meter can be dispensed with if a testmeter is available having a sensitivity of at least 10,000 Ω per volt, together with a d.c. voltage range covering 0-10 volts.

The basic principle behind this second device is illustrated in Fig. 3. A constant current is passed through two potentiometers in parallel, a high resistance voltmeter being connected across them. Since the current is constant the voltage across the potentiometers is proportional to the resistance they present to the circuit and may be read directly from the meter.

Let us assume that, as in Fig. 1, both potentiometers have a value of 20k Ω and are calibrated 1 to 20; also that the constant current is 1mA, that the voltmeter draws negligible current and that it needs 0-10 volts. When both potentiometers are set to 20 (=20k Ω) the total circuit resistance is 10k Ω and 10 volts is dropped across them. The voltmeter will then indicate 10 volts. If, following our earlier example, one potentiometer is set to 6.8 and the other to 18, the total resistance in circuit becomes 5k Ω and the voltmeter indicates 5. Thus, the voltmeter now indicates total resistance (in kilohms) in the same way as did the ohmmeter used in Fig. 1, but computations

are much easier to carry out because the total resistance is presented by a meter with a linear scale.

A necessary requirement for the circuit of Fig. 3 to function properly is that the voltmeter should draw a low current compared with that passing through the two potentiometers. With a constant current of 1mA the maximum full-scale deflection drawn by the voltmeter should not be in excess of 50 μ A whereupon, if the voltmeter is to be incorporated in the computer, a 0-50 μ A movement is required. However, it is possible to raise the constant current to 2mA and modify the potentiometer values accordingly, whereupon the voltmeter can have an f.s.d. current of 100 μ A. This means that a less expensive instrument is required for installation in the unit. In the practical version of the computing device, whose circuit is given in Fig. 4, a constant current of 2mA nominal is in fact used.

In Fig. 4 the two potentiometers appear as R_1 and R_2 , and are given values of 10k Ω . Connected across them is a 0-100 μ A meter in series with a 100k Ω resistor, this combination representing a voltmeter reading 0-10 volts.

The constant current is provided by the ACY19 transistor, TR₁,

which operates in grounded base. The base is held about 0.6 volts positive of the lower supply line by way of R_6 and the forward-biased silicon diode D₁. Emitter current is varied by preset variable resistor R_5 in series with the current-limiting resistor R_4 . The constant current of 2mA flows from the collector through R_1 , R_2 and the meter to the negative supply line.

When R_1 and R_2 are set to insert maximum resistance, the total resistance they offer is 5k Ω , whereupon the constant current of 2mA causes 10 volts to appear across them. This is indicated by the meter as 100. In order that the potentiometer scales should correspond, in figures, with the meter indication, R_1 and R_2 are calibrated from 10 to 200, as shown in Fig. 5 (a), with 10 corresponding to 500 Ω in the potentiometer and 200 to 10k Ω in the potentiometer. In other words, the scales correspond to potentiometer resistance in kilohms multiplied by 20. How this method of calibration works out in practice may be readily illustrated. When both potentiometers are set to 200, the meter indicates 100. If, to again use our previous example, one potentiometer is set to 180 and the other to 68, the meter will read 50; thereby

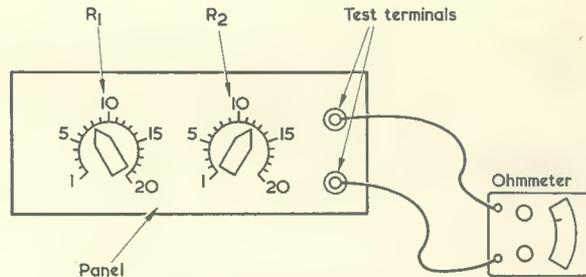


Fig. 2. A practical panel layout for the circuit of Fig. 1. This also illustrates the potentiometer calibration

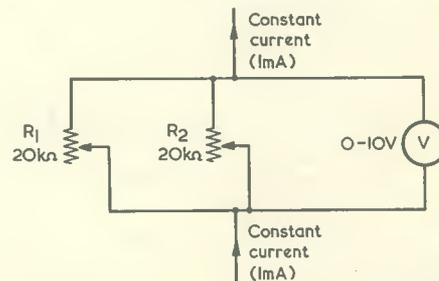


Fig. 3. By passing a constant current through the two potentiometers, their combined resistance may be read from the linear scale of a voltmeter. The circuit values given here are referred to in the text

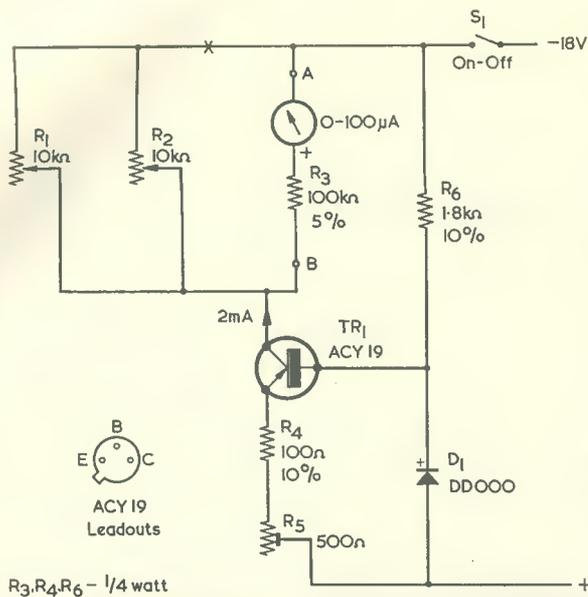


Fig. 4. A practical circuit which employs the constant current principle shown in Fig. 3. R_3 and the microammeter may be dispensed with if a high resistance testmeter with a 0-10 volt range is available, this being connected into circuit at points A and B. The constant current is 2mA nominal

indicating that 180 units of resistance in parallel with 68 units of resistance gives 50 units of resistance, or that 180 units of capacitance in series with 68 units of capacitance gives 50 units of capacitance. The resistance presented by the potentiometer set to 180 will actually be $9k\Omega$ and that presented by the potentiometer set to 68 will actually be $3.4k\Omega$. These two resistances in parallel give $2.5k\Omega$, whereupon the constant current of 2mA causes 5 volts to be dropped across them and the meter to indicate 50. Other combinations of numbers selected by R_1 and R_2 will cause a similarly corresponding number to be indicated by the meter.

If a testmeter having a resistance of $10,000\Omega$ per volt (or better) and a 0-10 volts d.c. range is available, the 0-100μA meter and R_3 are not required, and two test terminals can be added at points A and B of the circuit of Fig. 4. The testmeter may then be connected when required to these terminals, as illustrated in Fig. 5 (b). The testmeter scaling will normally be in numbers from 0 to 10, whereupon R_1 and R_2 are calibrated from 1 to 20, as shown in the diagram. These calibration numbers correspond to potentiometer resistance in kilohms multiplied by 2, and give the same numerical correlation

with the meter as was given in Fig. 5 (a).

Practical Points

A few words need to be said about the components. D_1 is any silicon diode capable of passing a continual forward current of 10mA. The diode employed by the writer was a Lucas type DD000.

When the 0-100μA meter is included in the unit, R_3 may be a component having a tolerance of 5% or better. In practice, it is not necessary for the meter to indicate 100 when *exactly* 10 volts appears R_1 and R_2 . Instead, it is necessary that it indicates 100 when R_1 and R_2 are both set to 200. Provided that the collector current of TR_1 then remains constant for all other settings of R_1 and R_2 , the required numerical relationship between the potentiometers and the meter will be maintained. R_1 and R_2 should be good quality wirewound components, as with the circuit of Fig. 1.

The computer unit should be initially wired up with the meter and R_3 out of circuit. Insert a milliammeter capable of reading 2mA between the upper ends of R_1

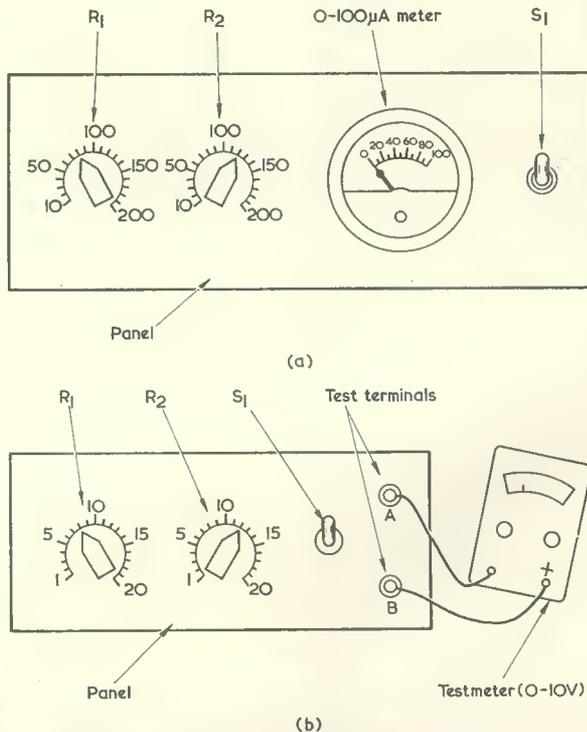


Fig. 5 (a). Suggested panel layout and potentiometer calibration when the microammeter is incorporated in the computer
(b). Alternative layout and calibration for use with an external voltmeter

and R_2 and the negative supply line, at the point marked with a cross in Fig. 4. Next, adjust R_1 , R_2 and R_5 so that these all insert maximum resistance into circuit, connect the 18 volt supply and switch on. Adjust R_5 to give an indication of 2mA in the milliammeter, and ensure that this current is maintained with negligible change at all settings of R_1 and R_2 . Repeat this procedure with R_5 adjusted for 2.5mA in the milliammeter. (This last check merely confirms that the constant current can be maintained over a slightly wider range than will normally be required in use.) It is possible, with some transistors and diodes, that there may not be sufficient range in R_5 to obtain these currents. Should this occur, R_4 may be slightly reduced in value.

Next, return R_5 to the 2mA setting, switch off and take the milliammeter out of circuit. Connect up the meter and R_3 , or apply the external testmeter switched to read 10 volts to terminals A and B, and

switch on. Set R_1 and R_2 to insert maximum resistance and, if necessary, slightly retrim R_5 so that this setting corresponds to full-scale deflection in whichever meter is used. The computer is then ready for use.

A final point concerns calibration. Either R_1 or R_2 may be calibrated in the unit itself for resistance values below $5k\Omega$. The other potentiometer is taken out of circuit during this process. For calibrating values above $5k\Omega$, both potentiometers should be in circuit, one being set to insert full resistance. Several calibration points between 5 and $10k\Omega$ may then be found on the remaining potentiometer working from their calculated value in parallel with $10k\Omega$. Only a few such calibration points should be needed as, if good quality potentiometers are used, the scales should be linear in any case.

With the prototype it was found that reducing the battery voltage to 15 caused the f.s.d. reading in the meter to fall by 2%, although the

circuit otherwise still functioned correctly. This slight drop in meter reading could be readily taken up by a small adjustment in R_5 . Because of this factor, some constructors may prefer to mount R_5 on the front panel as a form of "zero-set" control to take up changes in battery voltage. In this case both R_1 and R_2 are set to insert maximum resistance before the computer is to be used, R_5 then being adjusted at the front panel for full-scale deflection in the meter.

As is to be expected from the constant current of 2mA and the value of R_6 the prototype unit drew approximately 12mA from the 18 volt supply.

To give a concluding note the writer understands that, elsewhere in this issue, Dick and Smithy of "In Your Workshop" make the comment that the constant current offered by a transistor in grounded base should be useful to the designers of "gadgets". The present "gadget-designer" is happy to be able to demonstrate this fact so promptly!



CAN ANYONE HELP ?

Requests for information are inserted in this feature free of charge, subject to space being available. Users of this service undertake to acknowledge all letters, etc., received and to reimburse all reasonable expenses incurred by correspondents. Circuits, manuals, service sheets, etc., lent by readers must be returned in good condition within a reasonable period of time

Circuit Required.—C. Galloway, 41 Eastfields Road, Mitcham, Surrey—circuit required for l.f. transmitter and receiver to operate garage door mechanism, or an arrangement to operate a device buried in the drive-way from a coil fitted under the car.

Jason JTL Tape Unit.—J. T. Tabor, Ridley Hall, Cambridge—circuit and data required, loan or purchase.

Ferguson FR21 TV.—W. James, 19 Heslington Croft, Fulford, York—circuit or manual, purchase or loan.

HMV Radiogram 1618A.—M. J. Levy, 19 Totternhoe Close, Kenton, Middx—service manual or sheets for this equipment.

Jason JTL Tape Link.—J. Kitchener, 25 Beaconsfield Road, Gt. Yarmouth, Norfolk—instruction manual, loan or purchase.

Cossor Double-Beam 'Scope.—A. M. Archer, 99 Freeman Street, Grimsby—this equipment is No. 1 MKII WYO212, serial No. BD/R/54-108, any information, all expenses met.

P58 VHF Receiver.—A. Haigh G8ARJ, 44 Barnhill Road, Hayes, Middx—circuit diagram or any other information, loan or purchase.

E.A.R. Triple Four Amplifier.—J. Edwards, 94 Woodland Road, Leeds 15—loan or purchase of service sheet.

T. R. S. Radio Component Specialist

The price of the 7-Valve A.M./F.M. R G Replacement Chassis, advertised on page 124, September issue, should read £13/19/6 and not as shown.

Miniature Tunnel Diode Oscillator

by A. D. Williams, B.Sc.

After a brief introduction to the tunnel diode, our contributor discusses simple oscillators employing this device, together with practical details of a specific oscillator operating at 10 Mc/s

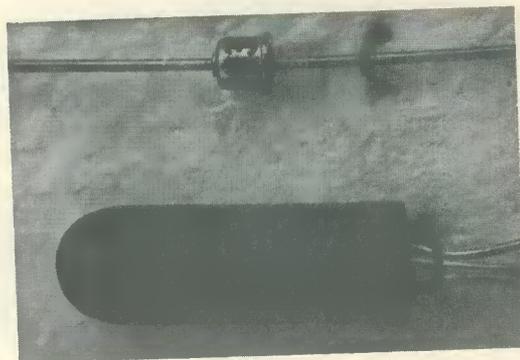
THE TUNNEL DIODE WAS INVENTED BY LEO ESAKI in 1958, and is basically a heavily doped p-n junction. It possesses many of the properties of a conventional semiconductor diode, but its peculiar value lies in its use as an amplifier, oscillator, and switch at frequencies of up to several thousand megacycles per second. The theoretical frequency limit is of the order of 1,000,000 Mc/s.

Tunnel Effect

The device is named from the tunnel effect in Quantum mechanics described by Dr. L. A. MacColl in 1932. (Among its many other uses, this effect permits a theoretical interpretation of the emission of alpha particles by radioactive atomic nuclei.) Classical physical theory states that unless an electron possesses enough energy to overcome a potential barrier it will never cross the barrier. Quantum theory states, on the other hand, that the electron may cross the barrier by "tunnelling" through the potential "hill", and that the probability of this happening can be predicted. The probability is negligible unless the barrier is extremely narrow; and hence tunnelling does not occur unless special precautions are taken in the manufacture of the diode to obtain an abrupt junction with a very

TABLE

R ₂	R ₁ (supply 1.5V)	R ₁ (supply 1.2V)	Top Frequency	Approx. Battery Drain
2.2Ω	12Ω	10Ω	160 Mc/s	100mA
4.7Ω	27Ω	18Ω	90 Mc/s	50mA
10Ω	56Ω	39Ω	50 Mc/s	25mA



The small size of a tunnel diode may be readily observed from this photograph, in which it appears alongside an OC71 transistor

thin barrier between the p and n regions. In practice, this thin barrier is obtained by very heavy doping; the impurities added to the tunnel diode semiconductor materials are approximately 1,000 times greater than those used in semiconductor materials for the rectifying junction diode.

The heavy doping changes the characteristic from that given in Fig. 1 for a conventional diode to that given in Fig. 2.

If the tunnel diode is biased by a potential difference between V_a and V_b it acts as an a.c. negative resistance, and under suitable conditions can function as an oscillator, amplifier, modulator, waveform shaper or switching device.

Apart from its high frequency performance, the tunnel diode has the advantage that it can withstand very much higher temperatures than most other semiconductors (up to 400°C for gallium arsenide tunnel diodes). It cannot be easily damaged by signal overloads, because it is difficult to develop sufficient power to cause damage across the junction.

As can be seen from the accompanying photograph, which shows a tunnel diode alongside an OC71 transistor, the device is very small. The

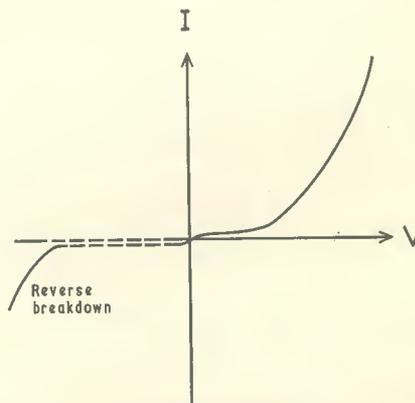
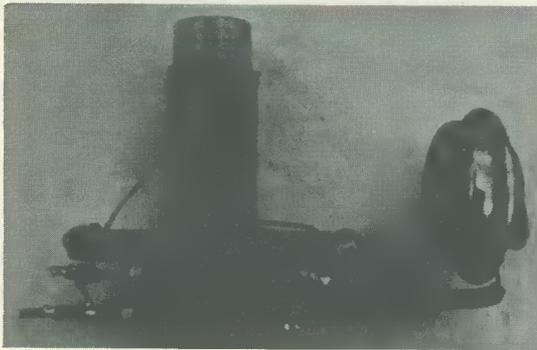


Fig. 1. Current-voltage characteristic of a normal semiconductor diode



This 10 Mc/s oscillator comprises a DEAC cell, two resistors, a coil and a tunnel diode

simplicity of circuits using the tunnel diode represents a further attraction for the experimenter. Against this must be set the cost which, at the time of writing and for a single device, is some 25s. or more retail in the U.K. It is possible that this cost may decrease with time. There are also design difficulties, these being given by difficulties in cascading several stages and by the fact that only a small voltage swing is available.

Practical Oscillator

The oscillator to be described employs a General Electric (U.S.A.) tunnel diode type 1N3720, this being used in the basic circuit arrangement shown in Fig. 3.* The accompanying Table gives top frequencies of oscillation for various values in R_1 and R_2 . These frequencies are calculated from published data and from curves obtained from the author's diode, and they should represent the minimum cut-off frequencies. The values of L and C in Fig. 3 must be such that they resonate at the frequency required. It is quite possible that

*The tunnel diode type 1N3720 is available from M. R. Clifford & Co., 66 Old Oscott Lane, Great Barr, Birmingham 22a.

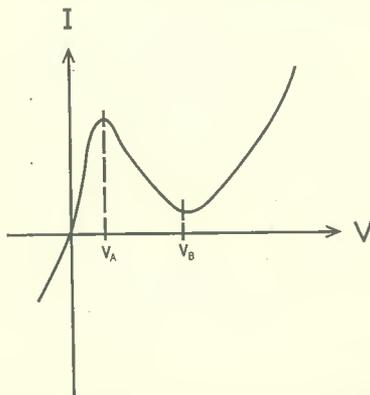


Fig. 2. The characteristic of a tunnel diode. The negative resistance section lies between V_a and V_b

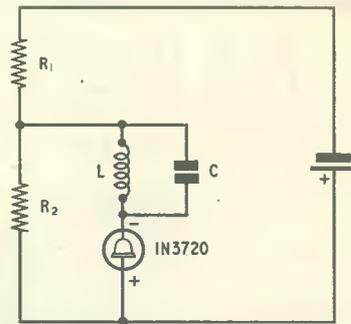


Fig. 3. Basic tunnel diode oscillator circuit. In the oscillator assembled by the writer, no physical capacitor is fitted across the coil, capacitance C being given by the self-capacitance of the coil

practical operation will enable oscillation to occur at higher frequencies than those shown in the Table, this fact offering a useful field for experiment.

R_1 and R_2 provide the required bias for the tunnel diode, different values being given for R_1 according to whether a 1.5 volt dry cell or a 1.2 volt DEAC cell is used for supply. The resistor values are rounded off to the nearest 10% preferred values which will provide correct bias.

It can be seen that by decreasing R_2 , whilst keeping the ratio $R_1:R_2$ constant, the usable upper frequency is increased. However, this increase is obtained at the expense of increased battery drain. The value of R_2 should not be increased so far that the resistance of R_2 and L together exceed about 18Ω , or oscillations may not be sustained at any frequency. This figure is determined by the characteristics of the diode, and may vary slightly between different specimens. The author's diode ceased oscillating when the sum of the resistances was about 19Ω .

The oscillator shown in the photograph represents a typical example of what may be achieved. This was about 19Ω .

The oscillator shown in the photograph represents a typical example of what may be achieved. This is intended for operation at 10 Mc/s, and R_2 has a value of 10Ω . A single DEAC cell is employed for power, causing R_1 to have a value of 39Ω . Contact to the cell is made by way of the connecting wires, the cell being simply removed to "switch off" the oscillator. Oscillation around 10 Mc/s is given when L consists of 20 turns of 27 s.w.g. enamelled wire close-wound on a Radiospares "Core Former". This is a conventional polystyrene former having a height of 0.87in and a diameter of 0.27in. Also used is a Radiospares iron dust core type "A", this being a standard 6mm core 0.5in long, with hexagonal trimming hole. No physical capacitor was fitted in the C position, resonance being obtained with the self-capacitance of the coil. Frequency adjustment is obtained by varying the position of the iron dust core in the former.



Radio Careers

for

Women

Established readers may remember that a year or two ago we wrote about the difficulties women find in making a career in radio and electronics, which is still principally a male preserve.

However, despite difficulties, women can rise to the top in the electronics world.

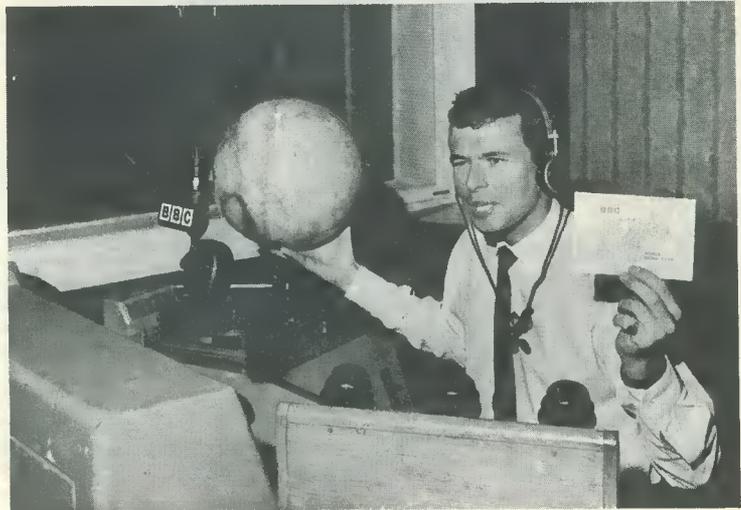
Such a one is Dr. Elizabeth Laverick, Head of the Radar Research Laboratory, Elliott Automation Radar Systems Limited, who has been elected to serve as an Ordinary Member of the IEE Electronics Divisional Board for a period of three years commencing on 1st October 1967. She will be the first woman to hold such a position.

Dr. Laverick, whose field is microwaves and radar, first became interested in an engineering career when she worked for a year at the Radio Research Station before taking her Degree.

In 1953 she joined Elliott Brothers (London) Limited, where, since 1959, she has been Head of the Radar Research Laboratory.

Dr. Laverick, who never had misgivings about pursuing what seemed a predominantly male profession, can foresee a considerable increase in the number of women engineers in this country. As Senior Vice-President of the Women's Engineering Society, she gives careers talks and advice to girls of school-leaving age and is greatly encouraged by the increasing number of enquiries she receives from girls interested in engineering as a career. She emphasises the importance of attracting women into the profession and believes that "with perseverance and keenness in her work a woman will succeed, and in fact, be better than a lot of men". Her view that one can still be feminine and be an engineer is endorsed by Dr. Laverick's own appearance and personality.

BBC WORLD RADIO CLUB



Malcolm Nisbet, compère of the B.B.C. World Service's newest programme WORLD RADIO CLUB, holds aloft the target area of his programme and the Club card. To become a member of this programme for shortwave enthusiasts, listeners simply write to WORLD RADIO CLUB, B.B.C., Bush House, London, W.C.2. Malcolm gives Dx news as well as tips to newcomers on how to improve shortwave reception

In the World Service of the B.B.C. there has recently been started a programme series for shortwave enthusiasts entitled World Radio Club.

The programme is broadcast on Saturday mornings, and repeated in three further broadcasts as shown in the list of transmission times and frequencies set out below.

All aspects of shortwave interest are to be covered and programmes will include technical talks, advance information on listening conditions and Dx news, etc.

A membership card will be sent on request to: World Radio Club, B.B.C., Bush House, London, W.C.2.

Suggestions for topics to be included will be very welcome so that listeners may obtain the maximum benefit and enjoyment from the broadcasts.

Transmission times and frequencies are:

SATURDAYS 0745 GMT:

Africa, Mediterranean

(Central Africa: 498 and 324 m/w) 41, 19, 16, 13 metres (7.295, 15.07, 17.81, 21.71 Mc/s)

Australia and New Zealand

41, 31, 25, 19 metres (7.15, 9.64, 11.955, 15.07 Mc/s)

SUNDAYS 0245 GMT:

Western Hemisphere and Pacific

49, 41, 31, 25, 19 metres (6.11, 7.13, 9.51, 9.58, 11.75, 11.78, 11.865, 15.07, 15.14, 15.26 Mc/s)

COMMENT

HOUSEHOLDERS' "POP" RIVET KIT

A rivetter's skill is brought within everyone's reach with the householders "POP" rivet kit.

So simple that even a child can operate it the kit can be used for all manner of fastening jobs and often more conveniently than a nut and bolt.

The kit contains a rivetting tool, a supply of rivets in three lengths, washers, a 3.3mm drill bit and an instruction leaflet. It is marketed by United Marketing (Leicester) Ltd. and retails at 39s. 11d. from do-it-yourself shops, ironmongers, and general accessories shops such as Messrs. Halfords.

A special feature of the "POP" rivet kit is its use for blind rivetting jobs—where only one side of the work is accessible and a nut and bolt cannot be used.

The "POP" rivet kit is a good example of the adaptation of a process widely used in industry for the benefit of the home handyman.



TUESDAYS 2100 GMT:

Africa, Middle East and Mediterranean

(Middle East: 211 m/w)
31, 25, 19, 13 metres
(1421 kc/s, 9.41, 9.58, 11.82,
11.86, 12.095, 15.07, 15.40,
15.435, 21.71 Mc/s)

Australia and New Zealand

31, 25, 19 metres
(9.41, 11.86, 15.07 Mc/s)

South America

16 metres
(17.79 Mc/s)

West Indies and Central America

13 metres
(21.55 Mc/s)

THURSDAYS 1245 GMT:

Africa, Middle East and Mediterranean

(Middle East: 211 m/w)
19, 16, 13, 11 metres
(1421 kc/s, 15.07, 15.42, 17.705,
17.79, 17.885, 21.47, 21.71,
25.65 Mc/s)

South and South East Asia, and Far East

25, 19, 16, 13, 11 metres
(11.75, 15.07, 15.435, 17.79,
21.55, 21.66, 25.65 Mc/s)

West Indies and Central America

16, 13 metres
(17.79, 21.71 Mc/s)



hispoli

"Too much realism on TV?"

Four-Stage Voice-Operated Switch

By L. J. Moore

A very sensitive sound-operated switch which uses readily available valves.

THIS VOICE-OPERATED SWITCH HAS A VERY HIGH level of sensitivity and has applications other than that for which it was originally intended—that of automatically switching an amateur station to “Transmit” when the operator spoke. The sensitivity is such that the circuit can be set up to operate at the sound of a hand-clap from about 30 feet. It will be appreciated that, with this level of sensitivity, the switch can operate with very low level sounds as well as with speech.

The prototype was made up from parts in the spares box. The valves employed are very common types, and are particularly liable to be encountered in scrap TV sets and the like.

The Circuit

The circuit of the voice-operated switch appears in the accompanying diagram. A crystal microphone connects to the grid of $V_1(a)$, which is one half of an ECC83. The amplified signal at the anode of $V_1(a)$ passes to the grid of $V_1(b)$ where further amplification takes place. The signal appearing at the anode of $V_1(b)$ is then passed to the grid of V_2 , which is an EF91.

A signal at low impedance and having nearly the same amplitude as that at the grid, appears at the cathode of the EF91. The cathode resistor is a $5k\Omega$ potentiometer, and its slider taps off the signal level desired and passes this to the anode of V_3 .



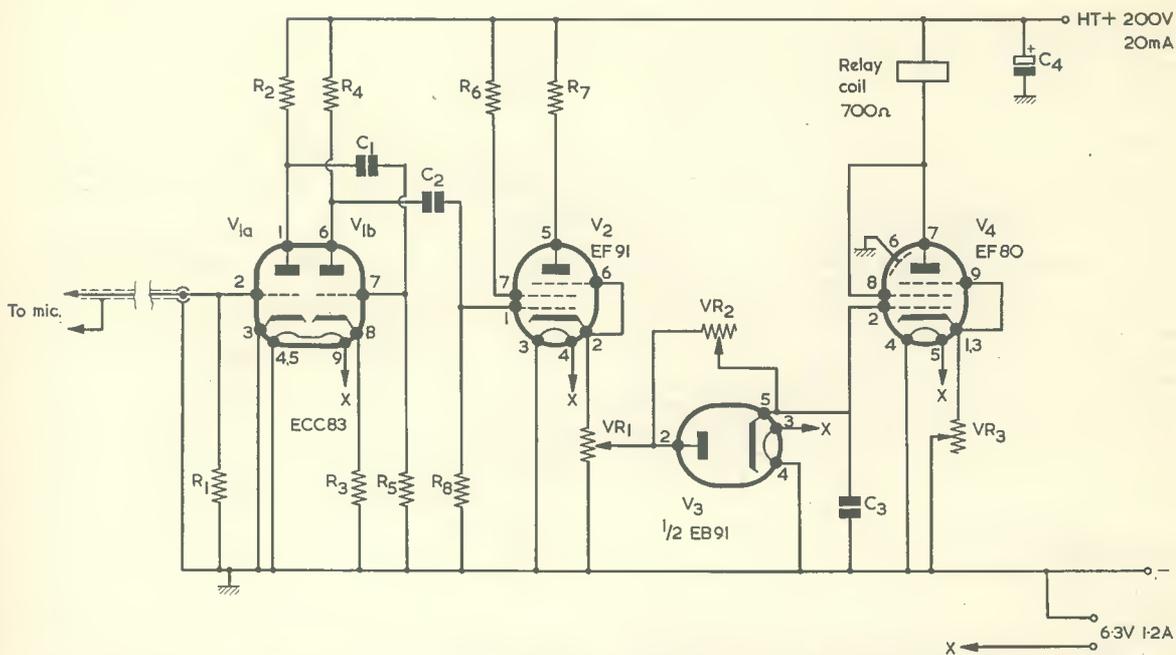
The voice-operated switch constructed by the author

V_3 is one half of a double-diode type EB91, the remaining diode being unused. It functions as a rectifier, causing a positive voltage to appear on the upper plate of C_3 , the positive voltage increasing in proportion to the amplitude of the signal passed to V_3 anode. This positive voltage is applied to the control grid of V_4 .

V_4 is an EF80 with screen-grid and anode strapped to form a triode. As its grid goes positive, an increased anode and screen-grid current flows through the coil of the relay. When this current is sufficiently high the relay energises, and its contacts carry out the external function (in the writer's case, the switching on of a transmitter) required of the sound switch.

It is undesirable for C_3 to remain charged for too long a period after the cessation of the actuating sound, and an adjustable discharge path is provided by VR_2 .

It will be helpful, now, to sum up the circuit operation so far described. A sound signal picked up by the microphone is amplified by $V_1(a)$ and $V_1(b)$ and is then passed to V_2 , from whose cathode the amplified signal is available at low impedance. The amplified signal causes C_3 to charge such that the control grid of V_4 goes positive, whereupon the increased anode and screen-grid current of this valve causes the relay to energise and to turn on the external circuit. If the switch is to be actuated by speech it is necessary for it to operate without delay when the voice is picked up by the microphone. This requirement is satisfied by the low impedance signal available from V_2 , which enables C_3 to charge and the relay to operate, almost instantly after the commencement of speech. At the same time, a short delay before the relay de-energises is needed with speech to cater for the lack of sound input between words, etc. The de-energising delay is made variable by means of VR_2 , which can be set up to give the particular delay desired. It should be noted that, in the absence of signal, V_3 does not conduct since its anode is more negative than its cathode, and the discharge current then flows through VR_2 .



The circuit of the voice-operated switch. The relay employed in the prototype had 4-hole 2-way contacts (not shown here)

Resistors

(All fixed values $\frac{1}{4}$ watt 10% unless otherwise stated)

R ₁	2.2M Ω
R ₂	120k Ω
R ₃	2.2k Ω
R ₄	100k Ω
R ₅	1M Ω
R ₆	22k Ω $\frac{1}{2}$ watt
R ₇	68k Ω $\frac{1}{2}$ watt
R ₈	1M Ω
VR ₁	5k Ω potentiometer, wirewound
VR ₂	2M Ω potentiometer, carbon, linear
VR ₃	5k Ω potentiometer, wirewound

Capacitors

(All capacitors 300V wkg.)

C ₁	0.01 μ F
C ₂	0.01 μ F
C ₃	0.01 μ F
C ₄	8 μ F electrolytic (see text)

COMPONENTS

Valves

V ₁	ECC83
V ₂	EF91
V ₃	EB91 (one diode unused)
V ₄	EF80

Relay

700 Ω relay (see text)

Microphone

Crystal microphone

Sockets

2 B7G valveholders
2 B9A valveholders
Jack socket for microphone

Miscellaneous

Chassis
Suitable power supply (see text)

Sensitivity is controllable by VR₁, whilst VR₃ is used to set up the operating conditions for V₄ which provide reliable energising of the relay. VR₃ will also exert some control on sensitivity. In general, VR₃ should be set up so that, in the absence of signal, the current flowing through the relay coil is considerably lower than that needed to energise the relay, or to hold it on when it is energised. VR₁ may then be set up for the required

sensitivity, and VR₂ for the required delay. In the author's prototype the EF80 cathode current for no signal input was 4mA, this rising to 13mA at maximum signal input. The relay operated at approximately 9mA, whereupon there was an adequate range of current in hand for reliable energising. Under no input conditions did the cathode current exceed the maximum rating of 15mA specified for the EF80.

H.T. and heater supplies may be obtained from any conventional mains power supply offering an h.t. voltage of about 200 volts at a minimum of 20mA and a 6.3 volt heater supply at a minimum of 1.2 amps. Capacitor C_4 is desirable to prevent feedback along the h.t. positive line, but its function will, in practice, normally be carried out by the smoothing capacitor of the h.t. supply circuit. If the power supply connects to the switch via short leads and it has the customary electrolytic smoothing capacitor across the h.t. output lines, there is no need for C_4 and it can be omitted. It should be added that the h.t. voltage required is not critical. The author's version has been used with various supplies ranging from 125 to 200 volts, with little effect on operation after setting up.

The component values and circuitry shown in the diagram are the result of trial and error, and the writer claims no originality in the general design.

Construction

No difficulties should arise in construction, the main necessity being to keep hum level in the grid circuit of $V_{1(a)}$ to a low level. The heater lead to pin 9 of V_1 should be kept well clear of the grid and anode pins, and all wiring in the $V_{1(a)}$ and $V_{1(b)}$ stages should be kept short.

The unused anode and cathode of V_3 (pins 7

and 1 respectively) may be connected direct to chassis. So also may the internal screen (pin 6) of this valve.

The relay was a miniature component with 4-pole 2-way contacts rated at up to 1 amp at 100 volts, and with a 700Ω winding. This relay is available from Henry's Radio, Ltd. As stated earlier, the relay employed by the writer energised at about 9mA.

The prototype was checked with several different crystal microphones, giving equally satisfactory results with all of these.

The accompanying photograph shows the author's version, assembled on a home-built chassis. At the rear (to the left in the illustration) is the relay and the knob for VR_3 . In front of the relay is the EB91, alongside which is the EF80. The two valves nearer the front panel are the EF91 and the ECC83, a knob for VR_2 appearing in front of the EF91. Mounted on the front chassis panel is VR_1 which, in the prototype, was a preset component.

The author's switch has been in use for four months at the time of writing, and no faults have developed in operation. As mentioned at the start of this article, the main purpose of the switch was to turn on an amateur transmitter when the operator spoke, a single microphone being employed which was coupled both to the transmitter and the switch. Results with this application have been found to be most satisfactory.



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RADIO CONSTRUCTOR

The Beta Meter

By Sir Douglas Hall, K.C.M.G., M.A. (Oxon)

This very useful instrument measures the common emitter d.c. gain of p.n.p. and n.p.n. transistors. Leakage currents are fully compensated for, and the design is such that both construction and operation are extremely simple

THE BETA METER WILL GIVE A direct reading of the current amplification factor of a transistor in the common emitter configuration. It shows the d.c. amplification factor, which will be similar to the a.c. amplification at audio frequencies. Amplification at radio frequencies will depend on the characteristics of the transistor. The meter can also be used to test semiconductor diodes.

The current amplification factor of a common emitter amplifier is the ratio between the change of collector current and the change of base current. Provided the collector current is not less than about $500\mu\text{A}$ in the case of most transistors (or about $100\mu\text{A}$ in the case of micro alloy types) and not exceptionally high, a reasonably accurate figure will be obtained by dividing the collector current by the base current at any convenient figure. But a phenomenon which can make a nonsense of this simple calculation is the passage of leakage current—i.e. current which passes between collector and base without the influence of base current. Some transistors which are quite suitable as small signal amplifiers exhibit quite a large leakage current, and if this is ignored the apparent amplification factor may be very different from the true figure. The Beta Meter takes this point into account and provides compensation for leakage current which, at the same time, it measures. The meter is suitable for measuring amplification factor at collector currents from about $100\mu\text{A}$ to 2 or 3mA .

It cannot be used for measuring amplification under the conditions prevailing in output stages which feed loudspeakers. Unless the current to be drawn is very high, a useful indication of the amplification likely to be obtained in an output stage can, nevertheless, be given by measuring at lower current levels.

Basic Circuit

The principles involved are demonstrated in the basic circuit in Fig. 1. Two meters are shown, M_1 and M_2 , the first having a full-scale deflection of $50\mu\text{A}$ and the second a full-scale deflection of 5mA . Two meters are shown for clarity. In the practical version only one is used, with suitable switching.

TR_1 is the transistor under test. Power is provided by B_1 , a single 1.5V cell. Base current is taken from the potentiometer, VR_1 . If TR_1 passes virtually no leakage

current and VR_1 is turned to zero, both meters will register zero. But TR_1 may well pass leakage current. In this event, if VR_1 is turned to zero the needle of M_1 will pass the zero mark and attempt to show a reverse current. The existence of leakage current means that there is, in effect, resistance between collector and base and it will be seen that current which passes through this resistance will find its way to positive battery through M_1 . With VR_1 at zero, M_1 now finds itself reverse connected, as it were, so that the current passing through it will give a reverse indication. Now, if VR_1 is adjusted to allow current to flow, a point will be reached when M_1 will register exactly zero—when the current due to leakage is exactly cancelled out by the current provided by VR_1 . At this setting the current passing through M_2 is equal to the leakage current which would be exhibited if the base were disconnected. That is to say, a reading is given of the leakage current of TR_1 as a common emitter amplifier.

At this stage, there is no base current and TR_1 will not function as an amplifier. It will be necessary to further adjust VR_1 to obtain an indication of amplification but, before this is done, current is passed through M_2 , by B_2 , in a reverse direction to that already flowing. VR_2 controls the current from B_2 and is adjusted so that M_2 reads zero. If VR_1 is now adjusted so that $10\mu\text{A}$ passes through M_1 , the reading given by M_2 will indicate the collector current flowing as the result of the passage of $10\mu\text{A}$ base current, and will show directly the amplification given by TR_1 . For example, a reading of $500\mu\text{A}$ in M_2 will show an amplification of $\frac{500}{10} = 50$.

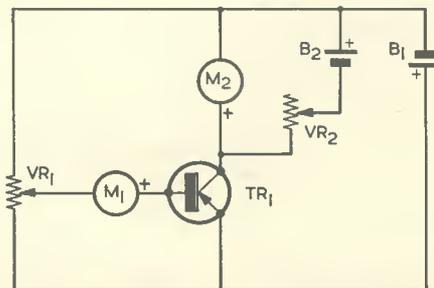


Fig. 1. Simplified circuit demonstrating the basic operation of the Beta Meter

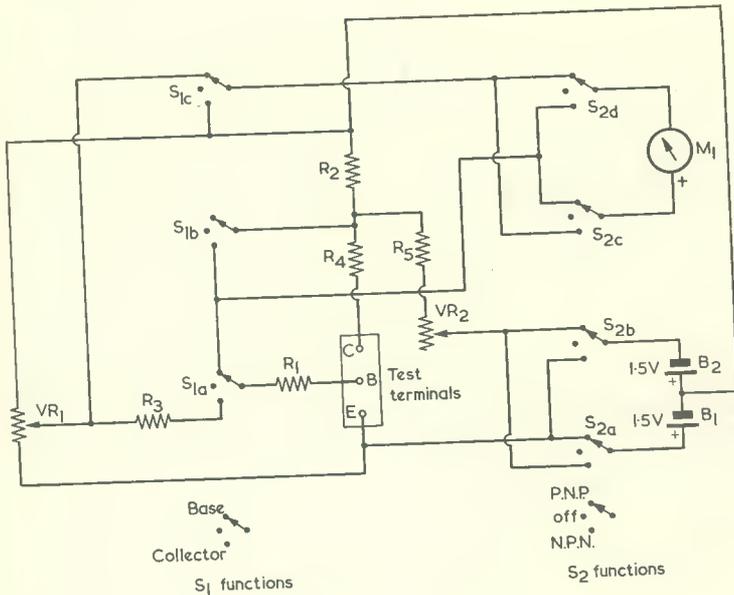


Fig. 2. The complete circuit of the Beta Meter

The Beta Meter

Fig. 2 gives the actual circuit of the Beta Meter. M_1 has an f.s.d. of $50\mu A$. S_1 can remove M_1 from the base circuit and place it in the collector circuit across a resistor R_2 which has a resistance of $\frac{1}{99}$ of the resistance of M_1 , so that M_1 reads with an f.s.d. of 5mA when in the collector circuit. R_3 has a resistance equal to the resistance of M_1 so that, when M_1 is switched to the collector circuit, the bias for the base remains unchanged. R_1 prevents excessive base current from flowing, R_4 limits the maximum collector current to 5mA, and R_5 prevents excessive current from passing through M_1 in a reverse direction, should VR_2 be adjusted carelessly. S_2 reverses the polarity of M_1 and of the two cells, B_1 and B_2 , so that n.p.n. transistors can be tested as well as p.n.p. types. It also provides an off position to prevent current flowing through VR_1 when the meter is not in use.

It will be noted that S_1 is a 3-way switch although only the two outside ways are employed in the circuit. The reason for using a 3-way switch is that, with the small type of wavechange component employed here, it is possible for some contacts to make before the others as the switch is rotated whereupon, without having a central "blank" position, the meter needle could give quite

violent kicks as the switch is adjusted from one position to the other. This effect, which appeared when a 2-way switch was originally tried in this circuit position, is entirely absent with the 3-way component. The actual component used is a

COMPONENTS

- Resistors*
 R_1 30k Ω $\frac{1}{2}$ watt 5%
 R_2 See text
 R_3 See text
 R_4 300 Ω $\frac{1}{2}$ watt 5%
 R_5 820 Ω $\frac{1}{2}$ watt 10%
 VR_1 5k Ω potentiometer, linear
 VR_2 500k Ω potentiometer, log
- Switches*
 $S_{1,2}$ 4-pole 3-way, "Midget" wavechange switch (Radiospares)
- Meter*
 M_1 50 μA Kyoritsu type MR.2P (Henry's Radio Ltd.)
- Batteries*
 $B_{1,2}$ Type U12 (Ever Ready)
- Miscellaneous*
 4 knobs
 Transistor holder or terminals
 Paxolin panel
 Material for case, wire, etc.

(N.B. Radiospares components may only be obtained through retailers.)

standard 4-pole 3-way switch, one pole being left disconnected.

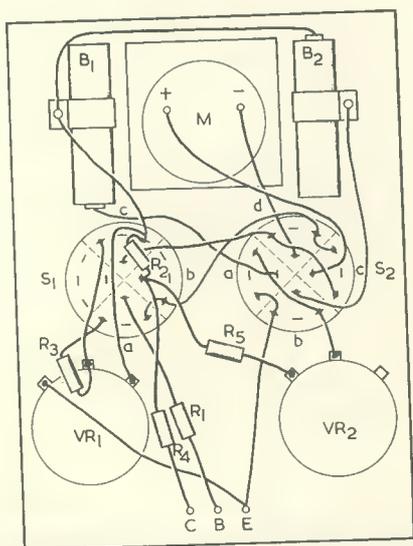


Fig. 3. Wiring behind the panel of the instrument. It should be noted that the switch tags shown correspond to Radiospares components, and that other switches may have different tag positions. If in doubt, check with a continuity tester before wiring

Assembly

The layout is not critical, but that followed in the prototype is shown in Fig. 3, with a front panel as in Fig. 4. A normal transistor holder may be used for the transistor being tested, though the author finds these rather unreliable if they are constantly used, and prefers terminals. If the specified meter is employed it can be taken that its resistance is 820Ω approximately. This is convenient since it gives values of 820Ω for R_3 and 8.2Ω for R_2 . If an 8.2Ω resistor is not available it can be made up with two resistors of 47Ω and 10Ω , respectively, connected in parallel, giving a combined resistance of 8.26Ω . (For an 820Ω meter movement, the calculated value required for R_2 is 8.28Ω .) Should a different meter be used it will be necessary to find out its resistance if this is not shown on the dial.*

The switches shown in Fig. 3 are by Radiospares. If different ones are used their contact positions may vary from those shown. The cells have their paper covers removed and are held in position with two tinplate clips which have leads soldered to them. This means that only the positive leads (the central terminals) need to be soldered into position when battery replacement becomes necessary.

Operation

In the procedure which is to be described for using the meter it is suggested that Fig. 4 be studied at the same time in order to make matters clear. Fig. 4 shows the panel of the meter and, incidentally, shows suggested markings for the controls. Note the blank position between "Collector" and "Base" settings of S_1 .

1. Insert the transistor to be tested into the terminals and turn VR_1 and VR_2 fully clockwise. Turn S_1 to Base and S_2 to P.N.P. or N.P.N. as the case may be. A reading will be shown in M_1 and this should be taken to zero by adjusting VR_1 . If the transistor has very little leakage, the proper position for VR_1 will be very nearly fully anticlockwise. But if leakage is considerable the proper position

*To find the meter resistance, if unknown, connect the meter via a $250k\Omega$ variable resistor to a 6-volt battery. The variable resistor should initially insert its full resistance in series with the meter and it is next adjusted to cause the meter to read f.s.d. Then find the value of resistance which, when connected across the meter under these conditions, causes it to read half-scale. That resistance is equal to the resistance of the meter.—EDITOR.

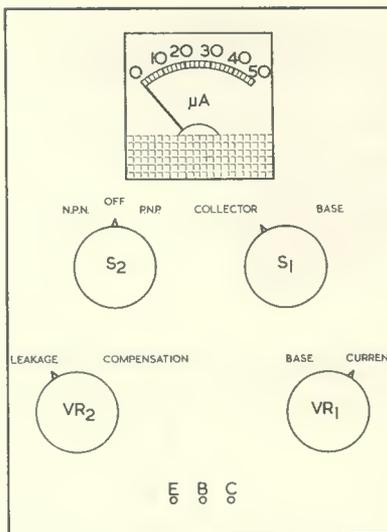


Fig. 4. Front panel layout for the meter

for VR_1 will be well above the fully anticlockwise point.

2. Turn S_1 to Collector. Adjust VR_2 to give a zero reading on the meter, if necessary.

3. Turn S_1 to Base. Adjust VR_1 so that a reading of $10\mu A$ is shown.

4. Turn S_1 to Collector. The meter will now give a direct reading of the amplification factor. If the reading is, for example, $1mA$ (shown as $10\mu A$ on the scale) the amplification factor will be $1mA/10\mu A$, which equals 100.

In the case of low amplification transistors it is as well to take a second reading with VR_1 set to $20\mu A$ (in 3 above) and possibly a third reading with VR_1 set to $30\mu A$. This will show the amplification factor at greater collector currents than flow with a base current of $10\mu A$. With a base current of $20\mu A$ the figure shown for amplification should be halved, and with a base current of $30\mu A$ it should be divided by 3, and so on. It may sometimes be convenient to reverse the processes in 3 and 4, above, in order to find the amplification factor at a given collector current. Let us suppose that we wish to know the Beta for a collector current of $600\mu A$. In this case the procedure will be that already shown for 1 and 2, but 3 and 4 should be as follows:

3. Without moving S_1 or VR_2 , adjust VR_1 so that a reading of $600\mu A$ is shown (remembering that f.s.d. is $5mA$).

4. Turn S_1 to Base, and note the reading. This figure, which is now in μA with an f.s.d. of $50\mu A$, should be divided into 600 to give the amplification factor.

It is clear that the amplification factor can be found for any collector current between about $100\mu A$ (it is difficult to read a lower indication with any accuracy) to about $3mA$. At collector currents higher than $3mA$ there may be a fall in amplification factor due to the voltage drop through R_4 so that a useful indication of the factor at more normal voltage levels will not be given. This applies particularly with silicon transistors, and diffused alloy types, as these need higher voltages between collector and emitter than do most others.

Diodes may be tested in the following manner. The positive end (cathode) is connected to the emitter terminal and the negative end (anode) to the collector terminal. VR_2 should be fully clockwise. VR_1 is inoperative. Turn S_2 to N.P.N. and note the reading. It should be about 2 to $3mA$ (20 to 30 on the scale) for a good general purpose diode of the OA91 type. Turn S_2 to P.N.P. There should be no movement or only a very slight movement of the needle away from zero.

Silicon power rectifiers should give similar readings to those given by general purpose high frequency diodes. *

Water Level Alarm Unit

By W. Kemp

If two metal probes are inserted into tap water it will be found that quite a low resistance exists between them. This basic fact makes possible the very simple level detector described here, which can also be used with any other liquid having similar conductivity

THIS SIMPLE LITTLE UNIT WAS SPECIFICALLY designed to automatically sound an external alarm when the water in a bath reached a certain pre-determined level, but the unit is also suitable for use in any other application in which it is required that an alarm or other external circuit be activated when a liquid having conducted properties reaches a pre-determined level. The unit is perfectly safe to use in such situations, since it operates from a supply of less than 20 volts.

The water level alarm uses a simple 2-transistor circuit that can be built, less the relay and external alarm or buzzer, for about fifteen shillings.

A feature of the unit is that, when switched on but not activated by a liquid, the total current consumption is $2\mu\text{A}$ or less, so that the device can, if required, be left permanently switched on in the knowledge that the battery life will be almost as long as its normal shelf life. The water level alarm is therefore suitable for permanent installation as a battery operated "flood alarm" in cellars or basements, etc.

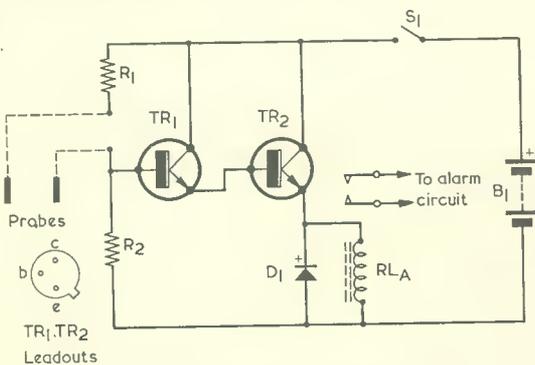


Fig. 1. The circuit of the water level alarm unit

The Circuit

The full circuit diagram of the unit is shown in Fig. 1. Here, TR_1 and TR_2 are wired in the Darlington or "Super-Alpha Pair" emitter follower configuration, and can be regarded as a single-transistor emitter follower with exceptionally high gain. The coil of relay RLA forms the emitter load of the emitter follower circuit. The outstanding features of the configuration are that the input impedance to TR_1 base is of the order of a few hundred thousand ohms, and that the voltage on TR_2 emitter automatically adjusts itself to within about 1.2 volts of the potential on TR_1 base.

Now, in the diagram, TR_1 base is coupled to the negative supply line via R_2 , so that TR_1 base

Resistors

- R_1 $10\text{k}\Omega$ 10% $\frac{1}{2}$ watt
- R_2 $470\text{k}\Omega$ 10% $\frac{1}{2}$ watt

Semiconductors

- TR_1 ST140 (Sinclair)
- TR_2 ST141 (Sinclair)
- D_1 OA200 or similar

Switch

- S_1 s.p.s.t. on-off switch

Relay

- See text

Battery

- Maximum voltage 18V (see text)

Miscellaneous

- Veroboard with 0.15in hole spacing (see Fig. 2)
- Probe assembly
- Connecting wire, sleeving, etc.

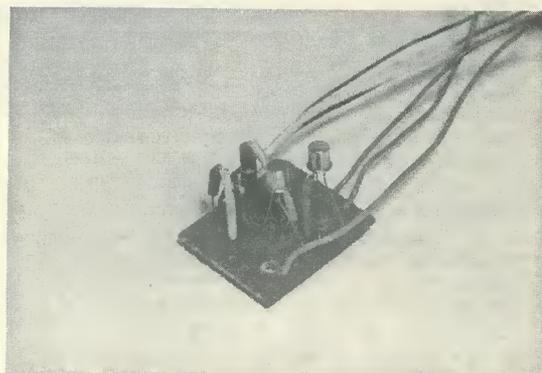
COMPONENTS

is normally at a potential of zero volts with respect to this line. Under this condition TR₂ emitter is also at zero volts, whereupon no current flows in the relay and only a small leakage current of 2 μ A or less is consumed by the circuit. If now the two probes are short-circuited together, either directly or by placing them in tap water, the positive supply line will be connected to TR₁ base via R₁ and, by the potential divider action of R₁ and R₂, almost the full battery voltage will appear at TR₁ base. A corresponding voltage will then appear at TR₂ emitter (across RLA) and the relay will be energised. It should be noted that, due to the high input impedance of TR₁ and the high value of R₂, similar operation will be obtained even if the "short-circuit" across the probes has a resistance of tens of kilohms (although it may be necessary to employ a slightly higher battery voltage to obtain the same result as is given with the direct short-circuit of the probes).

When operated, the relay can be made to switch external devices, such as alarms, buzzers, etc., via its contacts. D₁ is incorporated to prevent the back-e.m.f. damaging the circuit as the relay de-energises. R₁ prevents excessive base currents flowing in TR₁ when the probes are short-circuited together.

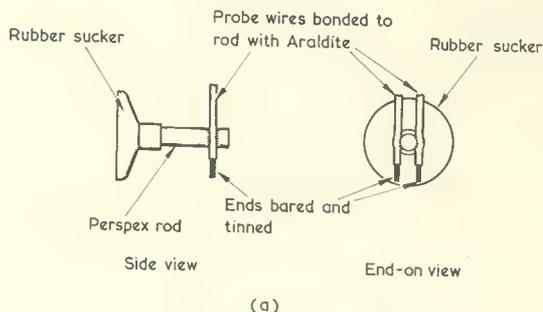
In practice, approximately 1.2 volts is "lost" between the base of TR₁ and the emitter of TR₂ when the relay is operated. The battery supply should therefore be selected to have a potential at least 1.5 volts greater than the operating potential of the relay that is employed. Any supply, up to a maximum value of 18 volts, can be used in the circuit, and any relay with an operating potential of less than approximately 15 or 16 volts may be used, providing that it draws a maximum operating current of less than 70mA. Low current relays are, however, much to be preferred.

A slight complicating effect is that, when the resistance presented to the two probes by the

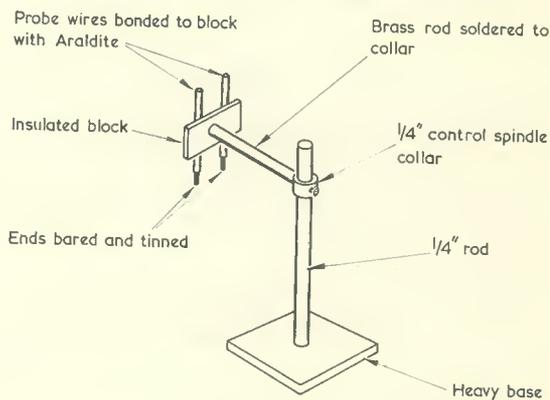


Only a few steps are required in the assembly of the components, as is well demonstrated here

water has a value in the order of tens of kilohms, the conducting path provided by the water can cause the base of TR₁ to attain a potential a volt or so less than that on the positive supply line. The battery voltage will in consequence need to be slightly higher to counteract this effect than is required merely to overcome the voltage "lost"

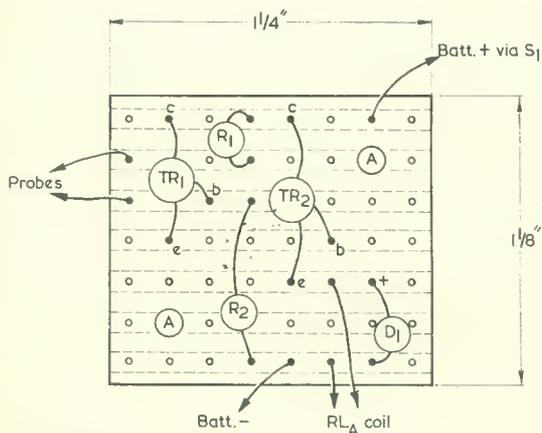


(a)



(b)

Fig. 3 (a). A simple probe assembly
(b). A more complex probe assembly which allows for the checking of surface level water



A-drill 6BA clear

Fig. 2. How the components are assembled on the Veroboard panel

in TR₁ and TR₂. Nevertheless, it should still not exceed 18 volts.*

Construction

The major part of the circuit is wired up on a small piece of Veroboard panel with 0.15in hole spacing, as shown in Fig. 2. Start construction by cutting this panel to size and then drill the two small mounting holes to clear 6BA screws. Clean the copper away from the inside edge of the upper hole in Fig. 2, to prevent possible short-circuits when the mounting screws are later inserted.

Mount the two transistors, two resistors and the diode on the board, the resistors and diode being vertical. Use insulated sleeving where necessary and finish off the assembly by wiring the battery, probe and relay leads in position as indicated. The unit can now be given a simple functional test in the following manner.

Connect a suitable relay coil to the relay leads, and connect a battery with the requisite voltage to the battery leads, taking care to observe the polarity indicated in the diagram. Next, with the probe leads insulated from one another, check that the unit draws a total current of less than several microamps. If satisfactory, remove the current meter from the circuit or switch it to a high current range, and short the two probe leads together, checking that the relay operates correctly. If satisfactory, bare the ends of the probe leads and ensure that the relay also operates when these leads are placed in normal tap water without being in actual contact with one another.

The basic circuit is now complete and ready for use.

*The maximum power rating for the ST141 in free air is 360mW, and maximum dissipation will occur in TR₂ when half the supply voltage appears across it, the remaining half appearing across the relay coil. The power resulting from half the supply voltage across the relay coil resistance should not therefore exceed 360mW. A light-weight relay which would enable TR₂ to work well within its maximum dissipation figure is the Cat. No. Z70B from Home Radio (Mitcham) Ltd., with a resistance of 670Ω and a nominal operating voltage of 7-9 volts. This could be used with a supply of 10.5 volts or, to overcome the effect of water resistance, any supply up to 18 volts.—EDITOR.

Using The Unit

The Veroboard panel should now be mounted in a small box or container, complete with the relay, battery, on-off switch, and terminals for connecting to a suitable buzzer or alarm circuit. The actual probe can be either permanently wired to this container or coupled via a plug and socket.

The probe itself can take any one of a number of forms, and two typical examples are illustrated in Figs. 3 (a) and (b).

A very simple probe is shown in Fig. 3 (a). Here, a short length of Perspex rod is attached to a rubber sucker, the two probe leads, with their ends bared and tinned, being secured to the rod with Araldite or a similar adhesive. This type of probe has the advantage of simplicity, and is ideally suited for quick attachment to the side of a bath or to some other smooth surface.

A more complex probe, intended for use where a smooth surface is not available, is shown in Fig. 3 (b). Here, a long rod $\frac{1}{4}$ in diameter is fixed vertically in a heavy base, and the probe leads are attached to a movable arm on this rod. The movable arm comprises a brass rod soldered at one end to a $\frac{1}{4}$ in control spindle collar, which fits on the vertical rod. At the other end of the rod is an insulated block to which the probe leads, with ends bared and tinned, are secured with adhesive. This type of probe has the advantage that, provided the length of the movable arm causes it to extend beyond the base, the probe leads can be placed right down at floor level if required, making the unit suitable for the detection of surface water, etc.

It should be noted that any liquid used to activate the alarm unit must have good conductive qualities, and in this context it should be appreciated that although many liquids, such as water and some types of oil, have excellent insulating properties in their pure states, they form very good conductors when slightly contaminated. Thus, tap water and even rain water in some industrial areas, are sufficiently good conductors to activate the alarm system. *

Low Voltage and Isolating Transformers

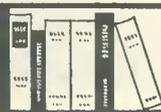
As a result of the increasing demand for low voltage and isolating transformers for use with radio and electrical appliances, coupled with the realisation of the greater safety given with low voltage equipment, Gardners Transformers Ltd. have released a new publication illustrating their full range of low voltage and isolating transformers, and autotransformers intended for operation from the mains. A very wide range of transformers for applications extending from heavy industrial to light domestic use is listed.

The publication is Brochure No. GT.17, and is available from Gardners Transformers Ltd., Somerford, Christchurch, Hampshire.

New Calibration Resistance Standards

A series of six Transfer or Secondary Resistance Standards for calibrating test instruments for measuring very low currents between 10⁻⁸ and 10⁻¹⁶ amperes is now available from Morganite Resistors Limited of Jarrow. These "MORGANITE" Standards are made with resistance values of every decade from 10⁸ to 10¹³ ohms. They are based on the "Megistor" glass-enclosed resistor which over the past fifteen years has proved its exceptional reliability and stability. Each Standard is enclosed in a case 4.25in (10.8cm) long on which the B.N.C. coaxial socket connectors are mounted. The complete set of six Standards is supplied in a presentation and storage case.

RECENT PUBLICATIONS



COMPUTERS FOR THE AMATEUR CONSTRUCTOR. By R. H. Warring. 104 pages, $8\frac{1}{2} \times 5\frac{1}{2}$ in. Published by Museum Press Limited. Price 20s.

Intended for any constructor who can follow simple circuit diagrams, this book provides a useful introduction to computer practice and principles, and illustrates how simple computing devices may be built at home.

Computers For The Amateur Constructor commences by defining computers and stating what they are capable of doing; and then proceeds to the binary numbering system, showing also the advantage of working with binary and octal. Next dealt with are binary counters, with practical circuit advice; to be followed by decade counters, again with practical circuits. Chapters on logic, logic gates, logic circuits, and diode and valve circuits follow, the remainder of the book dealing with the arithmetic unit, memory devices, input and output devices, programming, and practical details for binary computer construction. There is a good index and the book will be of especial interest to those who wish to try their hand at constructing working computers of a simple nature.

ABC'S OF MICROWAVES. By H. Charles Woodruff. 102 pages, $8\frac{1}{2} \times 5\frac{1}{2}$ in. Published by W. Foulsham & Co. Ltd. Price 16s.

Appearing in the Foulsham-Sams Technical Books series, *ABC's Of Microwaves* has an American text with an added introductory chapter for English readers. The book does not go into detailed mathematics or circuit design, but treats its subject in a manner which enables the basic operation of microwave equipment to be understood.

The first chapter deals with the history of microwaves, and includes some interesting details of British wartime radar equipment. This is followed by chapters on microwave propagation, transmission systems (including waveguides), cavity resonators, and microwave oscillators. This last chapter discusses magnetrons and klystrons. A chapter on the microwave transmitter/receiver appears next and the seventh chapter, dealing with antennas, covers horns, parabolic antennas and the metal lens. The eighth and final chapter is devoted to multiplexing techniques.

The book provides a useful introduction to microwaves for those who are conversant with radio transmission and reception at v.h.f. and lower frequencies.

FURTHER TITLES. The following are further titles in the Foulsham-Sams Technical Books series. These also have the $8\frac{1}{2} \times 5\frac{1}{2}$ in page size, and each consist of an American text with an introductory chapter for English readers. All are published by W. Foulsham & Co. Ltd.

101 WAYS TO USE YOUR COLOUR-TV TEST EQUIPMENT. By Robert G. Middleton. 150 pages. Price 24s.

This gives 101 examples of the use of American test equipment for performance checking and fault-finding with N.T.S.C. receivers.

2-WAY MOBILE RADIO HANDBOOK. By Jack Helmi. 229 pages. Price 30s.

A very detailed account of 2-way mobile systems, including a large number of working circuit diagrams with component values. Although intended for the American technician working under F.C.C. regulations there is much of interest to English readers, amateur and professional, who are interested in mobile working.

CAR RADIO SERVICING MADE EASY. By Wayne Lemons. 134 pages. Price 24s.

Down-to-earth practical advice on car radio faults and their repairs. The radios and cars referred to are American, but quite a lot of the information is equally applicable to British vehicles and equipment.

ELECTRONIC CIRCUIT ACTION SERIES: TV SYNC AND DEFLECTION CIRCUITS. By Thomas M. Adams. 166 pages. Price 25s.

The approach in this book is to explain circuit "actions". A circuit is given and all the currents which flow in it are identified, by function and direction, after which the circuit operation is explained. Currents are depicted by coloured arrowed lines printed alongside the circuit diagram lines. The text is carefully and painstakingly written, and there are no mathematics. There are many excellent waveform diagrams. Although the book deals primarily with 525-line receivers much of the basics are common to British practice, and there is some interesting material on flywheel sync.

ELECTRONIC CIRCUIT ACTION SERIES: TV VIDEO AND SOUND CIRCUITS. By Thomas M. Adams. 164 pages. Price 25s.

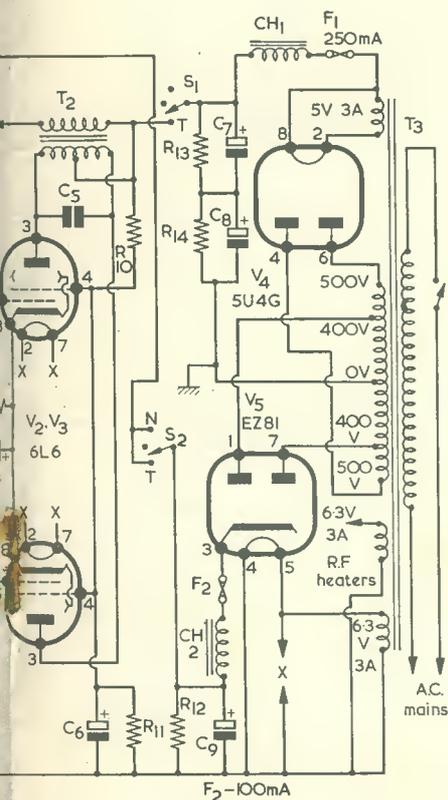
Using the same techniques as are employed in *TV Sync And Deflection Circuits*, this book covers the passage of the signal from the aerial to the c.r.t. and to the loudspeaker. Again, reference is to 525-line receivers. The intercarrier f.m. discriminators dealt with include ratio and phase types, together with the gated-beam and locked-oscillator discriminators.

Phone Transmitter



er, G3OGR

operates v.f.o., power supply and high level readily adapted for multi-band working. Transmitter must not, of course, be operated at high voltages at relatively high current be taken to avoid the consequent risk of damage and operating the transmitter



supply section. S₁ and S₂ are part of a 5-pole rotary switch used for power control, and is not included in the diagram for those in the r.f. section of the transmitter

COMPONENTS

(Fig. 1)

Resistors

(All resistors 10% unless otherwise stated)

- R₁ 2.2MΩ ¼ watt
- R₂ 33kΩ ¼ watt
- R₃ 220kΩ ½ watt
- R₄ 1MΩ ¼ watt
- R₅ 1.5kΩ ¼ watt
- R₆ 22kΩ ½ watt
- R₇ 220kΩ ½ watt 5%
- R₈ 220kΩ ½ watt 5%
- R₉ 250Ω wirewound 3 watt, or 240Ω carbon 3 watt
- R₁₀ 15kΩ 2 watt
- R₁₁ 47kΩ 1 watt
- R₁₂ 68kΩ 3 watt
- R₁₃ 20kΩ 5 watt
- R₁₄ 20kΩ 5 watt

Capacitors

(All electrolytic capacitors wire-ended unless otherwise stated)

- C₁ 0.005μF silver-mica 350V wkg.
- C₂ 8μF electrolytic 350V wkg.
- C₃ 50μF electrolytic 6V wkg.
- C₄ 50μF electrolytic 50V wkg.
- C₅ 0.002μF silver-mica or paper 800V wkg.
- C₆ 4μF electrolytic 350V wkg.
- C₇ 32μF electrolytic 350V wkg.
- C₈ 32μF electrolytic 350V wkg.
- C₉ 16μF electrolytic 450V wkg, can type with clamp (see Fig. 3)

Inductors

- T₁ Intervalve transformer 1:3 ratio, Radiospares "Midget"
- T₂ Modulation transformer, Woden type UMI
- T₃ Mains transformer, Gardners type R147
- CH₁ Swinging choke, 5-25H 250mA
- CH₂ Smoothing choke, 25H 60mA

Valves

- V₁ 12AX7
- V₂ 6L6
- V₃ 6L6
- V₄ 5U4G
- V₅ EZ81

Fuses

- F₁ 250mA, with chassis-mounting holder
- F₂ 100mA, with chassis-mounting holder

Switch

- S₁₋₅ 5-pole 3-way rotary (see text)

Sockets

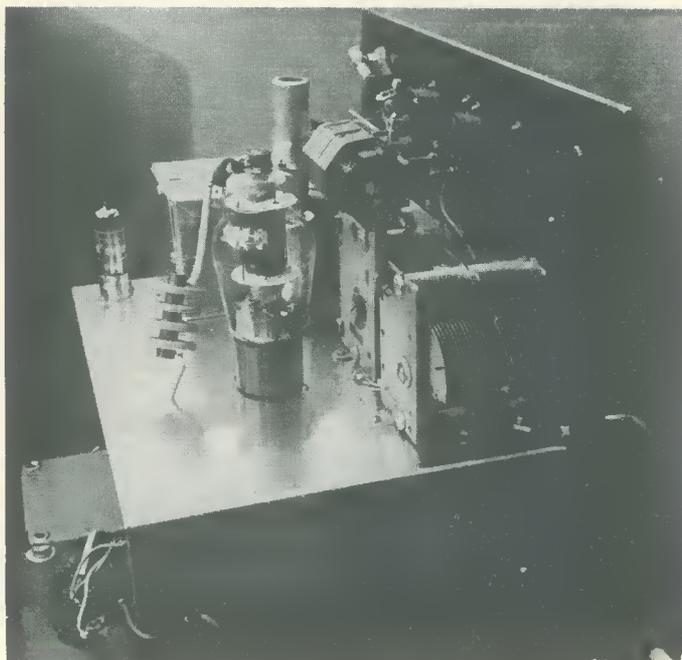
- 1 Coaxial socket
- 1 B9A valveholder
- 1 B9A valveholder with skirt and screening can
- 3 Octal valveholders

Microphone

- Crystal microphone

Miscellaneous

- Chassis, 10 x 11 x 2in
- Knob for S₁₋₅
- Screened wire
- Connecting wire
- Grommets, tagstrips, etc.



The rear of the transmitter, illustrating how the r.f. section is fitted above the modulator and power supply section

leads run from R_6 and T_2 through a grommet near the panel, these being connected later to S_1 and S_2 .

A long tagstrip was bolted to the side runner, as illustrated, to support C_7 , C_8 , R_{13} and R_{14} . An earthed tag and two separate insulated tags would do equally well. The 100mA fuse holder was fixed with the aid of a long bolt, a spacer being fitted between the fuse holder and the chassis.

A soundly insulated lead passes, from tag 2 on T_2 , through the grommet near R_{13} , and is later connected to the r.f. section anode meter circuit.

The inter-connecting circuits between the modulator and power supply and the r.f. section are as follows:

Low voltage h.t. supply, via S_2 .

High voltage modulated supply from T_2 , tag 2.

6.3V heater supply.

Common chassis-to-chassis return.

The input is intended for a crystal microphone, and a screening can is needed for V_1 . The modulator valves can be 6L6 metal, large glass, or glass tubular. A microphone should not be connected and used until the modulator is loaded by the p.a. stage.

The following voltages relative to chassis were given in the author's

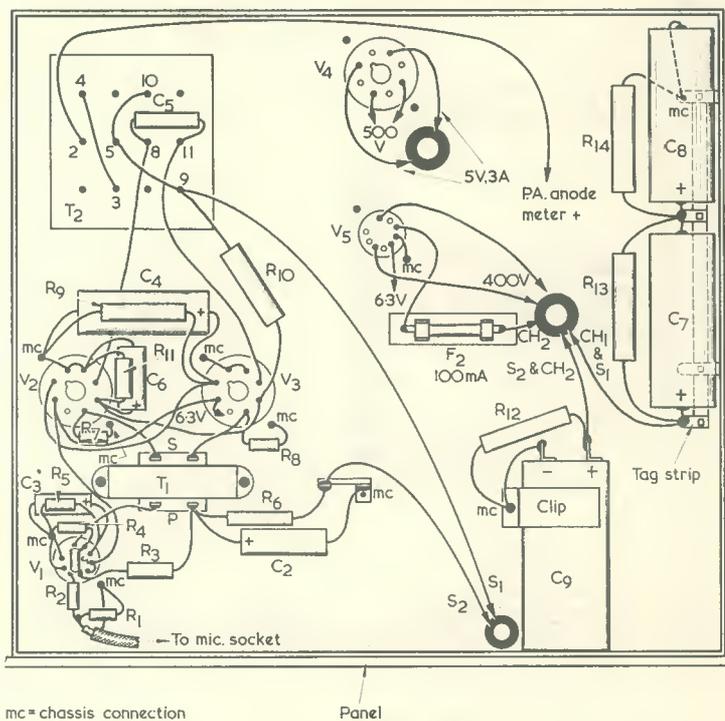
transmitter and are an approximate indication of correct working conditions: V_1 h.t. line, 270V. V_1 pin 3, 2V. V_2 and V_3 , pin 8, 22V. V_2 and V_3 , pin 4, 250V. V_2 and V_3 pin 3, 400V. Should the h.t. line voltage be much over 275V on load at C_9 , connect a resistor between pin 3 of the EZ81 and fuse F_2 . The h.t. voltage given depends somewhat on the d.c. resistance of the small choke, CH_2 .

RF Section Circuit

The circuit of the r.f. section is shown in Fig. 4. V_1 is the VFO, and tunes from 1.75 to 1.9 Mc/s. It is mounted in a separate screened box. The OB2 regulates the h.t. supply to both anode and screen-grid. L_2 is resonant at about 3.6 Mc/s so the tuning range of 1.75-1.9 Mc/s of L_1 gives 3.5-3.8 Mc/s coverage.

V_2 is a buffer-amplifier, with L_3 tuned to about 3.7 Mc/s. VR_1 adjusts the screen-grid voltage and, thus, the drive applied to V_3 . By staggering L_2 and L_3 slightly, almost equal drive is obtained over most of the band, and VR_1 seldom needs adjusting.

V_3 is the power amplifier, with grid and anode current shown on individual meters. Best results were



mc = chassis connection

Panel

Fig. 3. The underchassis wiring of the modulator and power supply section

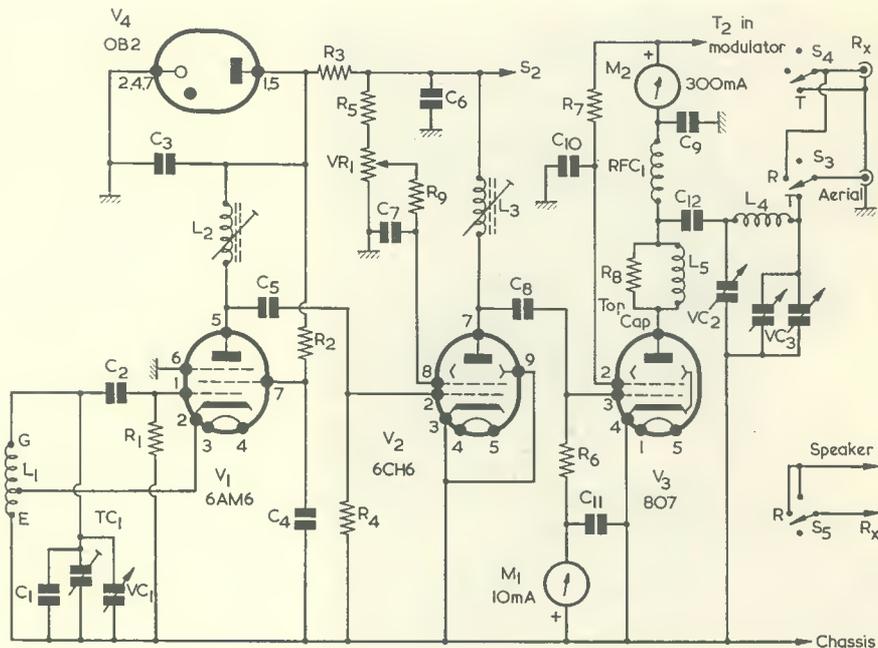


Fig. 4. The circuit of the r.f. section of the transmitter. Switches S₃, S₄ and S₅, in company with S₁ and S₂ of Fig. 1, make up the 5-pole rotary switch

given with about 3 to 4mA grid current, or about 100V bias developed across R₆. L₅ and R₈ form a parasitic stopper. L₄ is the pi output tank, with p.a. tuning capacitor VC₂, and output capacitor

VC₃ (2-gang). This allows the p.a. to be loaded by a dipole, and by many of the usual end-fed aerials.

Switch section S₃ transfers the aerial from the tank to the receiver. S₄ short-circuits the receiver aerial

input circuit on transmit, to avoid too much r.f. being passed to the receiver, while S₅ is open on transmit to mute the receiver speaker.

Though there are only three stages, the circuit of Fig. 4 has

(Fig. 4)

Resistors

(All fixed resistors 10%)

- R₁ 100kΩ ½ watt
- R₂ 100kΩ ½ watt
- R₃ 20kΩ 3 watt
- R₄ 100kΩ ½ watt
- R₅ 47kΩ 1 watt
- R₆ 27kΩ 1 watt
- R₇ 10kΩ 3 watt
- R₈ 47Ω 1 watt
- R₉ 2.2kΩ ½ watt
- VR₁ 50kΩ potentiometer, linear track

Capacitors

- C₁ 250pF 5% silver-mica
- C₂ 47pF silver-mica
- C₃ 0.02μF silver-mica or disc ceramic 500V wkg.
- C₄ 0.01μF silver-mica or disc ceramic 500V wkg.
- C₅ 47pF silver-mica or disc ceramic 500V wkg.
- C₆ 0.01μF disc ceramic 500V wkg.

COMPONENTS

- C₇ 0.01μF disc ceramic 500V wkg.
- C₈ 47pF silver-mica or disc ceramic 500V wkg.
- C₉ 1,000pF silver-mica or ceramic 1kV wkg.
- C₁₀ 1,000pF silver-mica or ceramic 1kV wkg.
- C₁₁ 0.01μF disc ceramic 500V wkg.
- C₁₂ 5,000pF silver-mica or ceramic 1kV wkg.
- TC₁ 30 or 50pF air-spaced trimmer
- VC₁ 100pF variable
- VC₂ 250pF double spaced variable
- VC₃ 2-gang 500pF variable (both sections in parallel) —receiver type

(Avoid using small or "miniature" components for VC₂ and VC₃)

Inductors

- L₁—L₅ See text
- RFC₁ 2.6mH 250mA, type RFC9A (Denco)

Valves

- V₁ 6AM6
- V₂ 6CH6
- V₃ 807
- V₄ OB2

Meters

- M₁ Grid meter, f.s.d. 10mA (see text)
- M₂ Anode meter, f.s.d. 300mA (see text)

Sockets

- 2 Coaxial sockets
- 1 B7G valveholder
- 1 B7G valveholder with skirt and screening can
- 1 B9A valveholder with skirt and screening can
- 1 UX5 valveholder

Miscellaneous

- Ball drive with circular scale and cursor
- Knobs for VR₁, VC₂ and VC₃
- Chassis, 8 x 11 x 2in
- Metalwork for v.f.o. box
- Connecting wire
- Grommets, tagstrips, etc.

been found to be very free from pulling of frequency and similar defects. The grid drive available, with VR₁ set to apply maximum screen-grid voltage, is very much greater than required. It is also quite easy to change the transmitter to another band, as is described later.

R.F. Section Construction

Fig. 5 shows the chassis layout for the r.f. section. No side brackets were used because panel and chassis were braced by stand-off spacers between the v.f.o. box and the panel, and the chassis is light in weight. The r.f. section can be built and tested without the chassis being fixed to the panel.

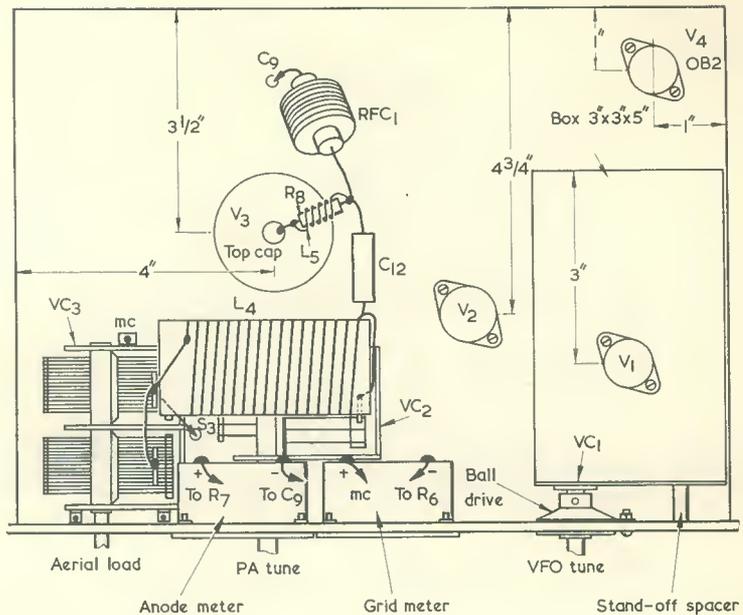
Valveholder and other positions can be taken from Fig. 5. V₁ and V₄ valveholders need a 3/8 in hole, V₂ a 1/2 in hole, and V₃ a 1 1/4 in hole. If to hand, an OA2, VR105, or VR150 voltage regulator will do instead of the OB2 specified for V₄. The VR105 and VR150 require octal holders with pin 2 to chassis and pin 5 to R₃.

Connect the two sections of VC₃ together and take a lead down for S₃. (This lead can go to a co-axial socket if aerial switching is not wanted). Join the rotor tags of VC₂ and VC₃ to each other and to the chassis with 16 s.w.g. wire.

L₅ is self-supporting, and consists of 5 turns of enamelled 18 s.w.g. wire, about 3/8 in in diameter, with R₈ placed inside. The turns are spaced by slightly more than wire diameter. Use very short stout leads from the valve cap clip to R₈ and L₅, and to the r.f. choke, C₁₂, and VC₂.

The ball drive for VC₁ was fitted in a hole in the panel, so that it lined up with the spindle of VC₁, when the v.f.o. box was in place. This requires accurate fitting, or a clearance hole so that the ball drive can be moved slightly, if necessary. Alternatively, the drive could be permanently fixed to VC₁, and its lug held by a pillar or bracket bolted to the front of the v.f.o. box. The drive would then simply come into a clearance hole in the panel, but would not be fixed to it. The ball drive should have a flange capable of taking a circular scale.

Fig. 6 shows the underside of the chassis. Disc ceramic capacitors are most suitable for C₆, C₇ and C₁₁, but C₁₀ should be rated at more than twice the screen grid voltage, while C₉ must be suitable for over twice the h.t. voltage. Appropriate mica capacitors were used in the author's version.

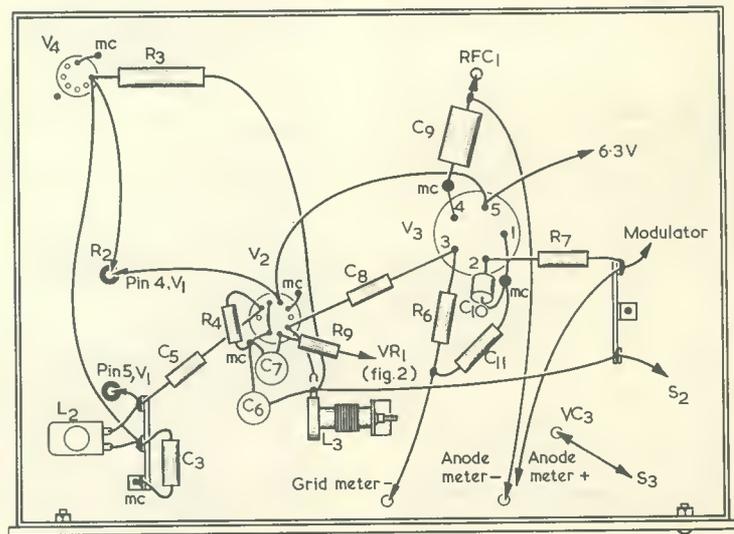


mc - chassis connection

Fig. 5. Layout and wiring above the chassis. See Fig. 6 for valveholder orientation and solder tags mounted under valveholder securing nuts. V₁ and V₂ have screening cans

Tagstrips anchor some of the leads. External connections consist of low voltage h.t. from S₂, modul-

ated h.t. from T₂, 6.3V from the mains transformer, and a chassis-to-chassis return. These points were



mc - chassis connection

Fig. 6. The wiring and components below the r.f. chassis

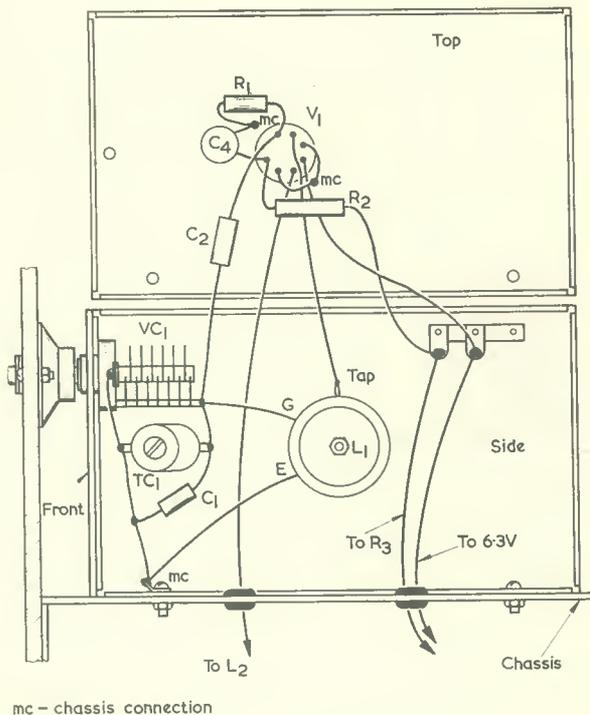


Fig. 7. Wiring in the v.f.o. box. This is shown "opened out" for clarity

referred to earlier, when discussing the modulator and power supply chassis.

Flexible leads pass up through the chassis for the grid and anode meters. For grid current, an indication around 3 to 5mA is needed, and so a 5mA, 10mA or similar instrument may be fitted. Normal p.a. anode current is 100mA, so a 150mA, 200mA, 250mA or 300mA meter may be used. More sensitive instruments can of course be shunted, to obtain suitable ranges for grid or anode currents.

V.F.O. Box

The v.f.o. box measures 5 x 3 x 3in and is made up easily from Home Radio (Mitcham) Universal Chassis members. Fig. 7 gives an "opened-out" view. The v.f.o. is most conveniently built and wired by assembling the top, side and front sections shown in Fig. 7. When construction is finished, bolt the v.f.o. to the chassis, passing the three leads down through grommets. When all is found to be in order, fix the remaining side and back by self-tapping screws. The Universal Chassis members have flanges all round so they only need drilling.

Use stout connections. TC₁ was soldered across VC₁ and was not secured in any other way. A 50pF or similar variable capacitor with its spindle slotted, and mounted in a hole in the box top, could also be used for TC₁. So would the type of trimmer which is secured by bolts and has a slotted spindle reached through a hole.

Components in the v.f.o. box are well removed from heat, and results proved quite satisfactory in practice. V₁ must be fitted with a screening can.

Switching

Switching connections are shown in detail in Fig. 8. Section S₁ completes the high voltage h.t. circuit at "Transmit" only. S₂ applies low voltage h.t. in both "Net" and "Transmit" positions. S₃ transfers the aerial from VC₃ to the receiver, and S₄ short-circuits the receiver circuit on "Transmit." S₅ completes the speaker circuit on "Net" and "Receive." The switch used should have insulation and contacts adequate for the voltages and currents involved.

The switch is fixed to the panel immediately under VC₃. This allows

short r.f. connections. The "Net" position is for tuning up, or netting on the frequency of a station heard.

VR₁ is at the other side of the panel, matching up with the switch. In the photograph of the transmitter front panel, the v.f.o. dial is top right. Under this is the drive control VR₁, with the microphone socket below, and a twin socket strip for speaker muting at the bottom right.

The two knobs central and left are p.a. tuning and aerial loading. Below is the aerial socket, then the transmit-receive-net switch, and receiver aerial socket. Below is the mains lead. This is 3-core, with green earthing to chassis. No mains switch is present in the actual transmitter because a switch was included in an external supply panel used for various equipment. If a switch is wanted, insert it in the red (L) lead to the transformer primary.

Coils

L₁ is wound with 24 s.w.g. enamelled wire, the turns being side-by-side on a smooth Paxolin former 1in in diameter. Anchor the wire at each end through two small holes. First, smear the former thinly with clear Bostik or similar cement. Wind 30 turns, make a small loop for the tap, and wind 10 further turns, finally fixing the wire in place. The beginning is at G and the end at E, so the tap is 10 turns from E. The former was cemented to a disc of wood pushed inside, and bolted to the v.f.o. box side.

When wiring is complete, this coil is checked in the following manner. Set VC₁ half open and rotate TC₁ until the v.f.o. harmonic is heard at 3.65 Mc/s on a receiver. VC₁ has some unused rotation at each end of the band, and this can be reduced if desired by removing some of its plates. Exact calibration of the v.f.o. is left until the box is closed and construction finished. The easiest method is to calibrate at 3.5, 3.6, 3.7 and 3.8 Mc/s by beating the v.f.o. against the harmonics of a 100 kc/s crystal marker, using the station receiver.

Coils L₂ and L₃ have 65 turns of 32 s.w.g. enamelled wire, on ½in diameter formers with adjustable iron-dust cores. L₂ is mounted vertically, and L₃ horizontally on a small bracket. Set VR₁ to show 2 to 3mA grid current, put the v.f.o. at 3.6 Mc/s, and rotate the core of L₂ for maximum grid current. Move the v.f.o. to 3.7 Mc/s, and rotate the core of L₃ for maximum grid current.

L₄ has 34 turns of 18 s.w.g. enamelled wire, spaced to occupy

2½in winding length on a 1½in diameter former. This will allow tuning over the 80m band with most aerials.

Other coils should also be satisfactory. Small medium wave coils with adjustable cores can be used after modification, for L₂ and L₃. Take off unwanted coupling or other windings, and remove turns from the remaining winding (grid coil) until the core can be peaked for maximum grid current, or as necessary when checked in circuit with a grid dip oscillator. With Osmor QA5 coils, 31 turns needed to be removed. Another type of 80 metre or multi-band tank could also be fitted instead of L₄.

Tuning And Operating

The receiver is tuned to the channel to be used, the switch put at "Net" and the v.f.o. adjusted until the carrier is matched in frequency with the receiver. This will be shown by the receiver tuning meter, or by a heterodyne with a station to be answered, or as a result of putting on the receiver b.f.o.

First tests are best made with a 40 or 60 watt 200 to 250V household lamp connected to the aerial socket, or across VC₃. Set VC₃ for maximum capacitance, turn the switch to "Transmit" and rotate VC₂ for minimum anode current. To load the p.a. more fully, open VC₃, meanwhile closing VC₂ for minimum

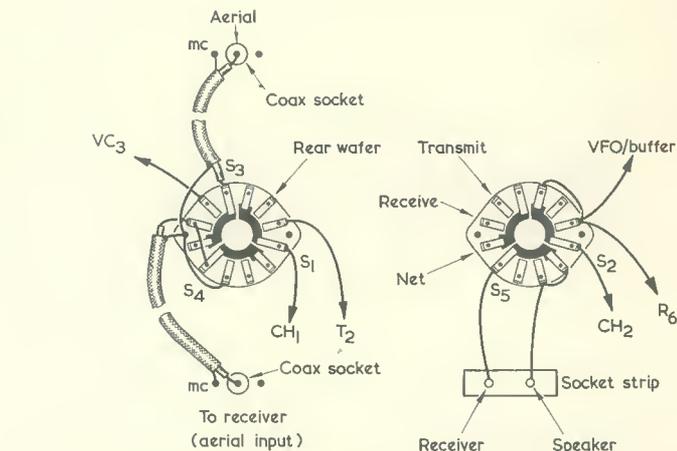


Fig. 8. Connections to the 5-pole rotary switch. This should have insulation and contacts suitable for the voltages and currents handled

current. If this is continued until the anode meter shows 100mA, the lamp should light brightly. Grid current is set at about 3-4mA by VR₁. VC₂ is always "dipped" for minimum current.

If headphones, with a crystal diode in series, are connected to a loop of about 2 to 4 turns, and this is brought towards L₄ (not too near!) speech in the microphone should sound crisp and clear. Alternatively, listen with the station

receiver, but avoid feedback to the microphone.

Loading up with an aerial follows the same method. Begin with VC₃ set to maximum capacitance. Should it prove impossible to load the p.a. to full input, this shows that the impedance of the aerial falls outside the range of adjustment. The cure is to use some form of aerial tuner, change the type of aerial, or change its length. If space permits, a ½-wave dipole will avoid difficulties of this kind, though end-fed wires can be perfectly satisfactory.

If no other means are available to test modulation depth, then reports from stations contacted can be used as a guide.

4-Band Coverage

With a little modification, the transmitter will cover 80, 40, 20 and 15m bands. The changes necessary are best seen from Fig. 9 and this circuit is particularly straightforward for 4-band coverage.

In Fig. 9 V₁ is a 5763 to increase output, and the v.f.o. is set for 3.5 Mc/s. L₁ consists of 24 turns of 24 s.w.g. enamelled wire on a ¾in diameter former and spaced to occupy 1in winding length. The cathode tap is 3½ turns from the chassis end. Trim the circuit to obtain a range of 3.5-3.8 Mc/s. The OA2 provides 150V, stabilised, for the anode and screen-grid.

L₂ consists of 33 turns of 32 s.w.g. enamelled wire, wound side-by-side on a ¾in diameter former with an adjustable core. This tunes to 7 Mc/s, and provides 7 Mc/s drive for V₂ on the 7, 14 and 21 Mc/s bands. On 3.5 Mc/s L₂ acts as an r.f. choke.



A further view of the r.f. section of the transmitter. The panel light is an optional extra which can be run from the 6.3 volt heater line, if desired.

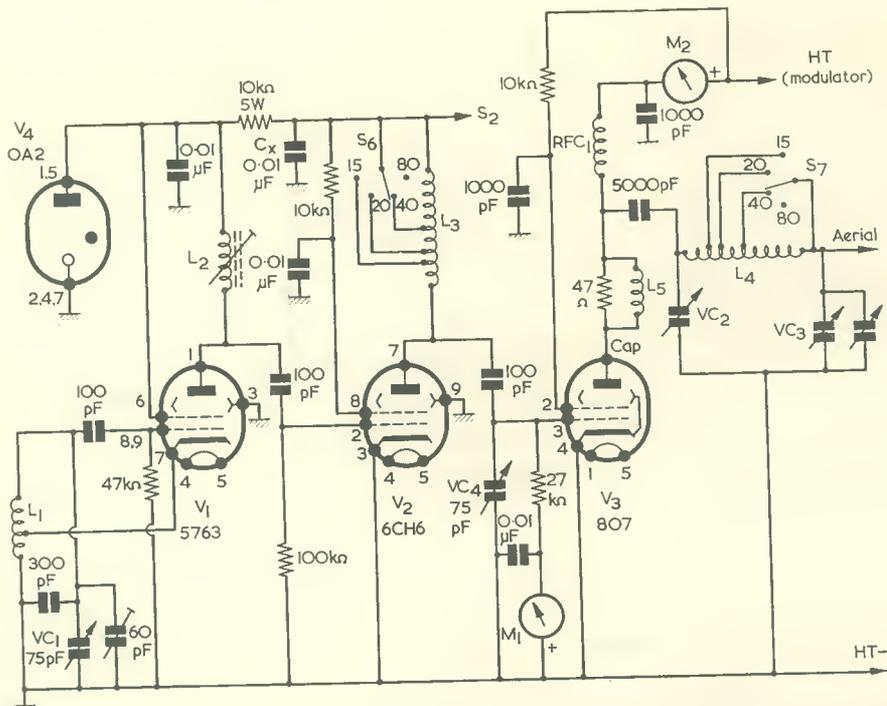


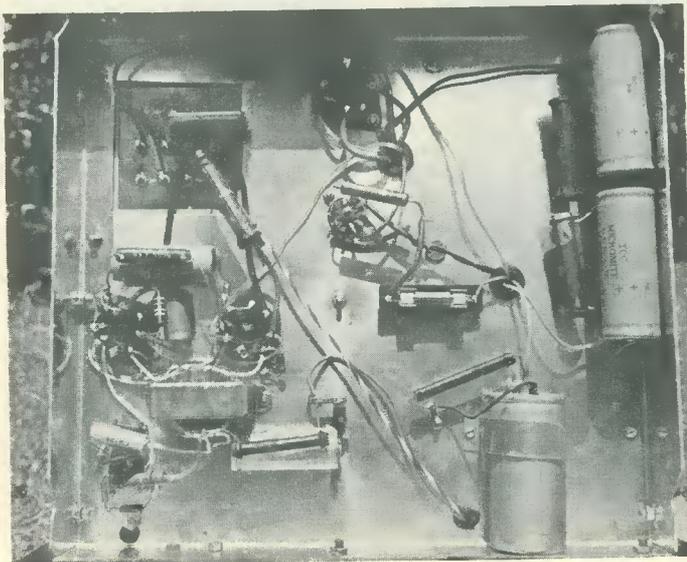
Fig. 9. Modifications required to the r.f. section for multi-band operation. Note that RFC₁, L₅, M₁, M₂, VC₂ and VC₃ are the same as in Fig. 4. VC₁ now has an altered value and VC₄ is introduced. V₄ is now an OA2. The output may be applied to S₃, as in Fig. 4

Subsequently, adjust the core of L₂ for maximum 807 grid current at 7.1 Mc/s (or 14.2 Mc/s, or 21.3 Mc/s).

V₂ acts as buffer-amplifier, doubler or tripler, according to the band. The screen grid potentiometer is omitted, because 807 grid current

can now be adjusted by the tuning capacitor VC₄. L₃ is wound on a 1in diameter former without core, S₆ being the bandswitch. Beginning at the anode end of L₃, wind 7½ turns and make the 15 metre tap, then a further 6 turns and tap for 20 metres. These 13½ turns are of 20 s.w.g. wire and are spaced to occupy ¾in. Leave ¼in space, then continue with 15 turns of 26 s.w.g. wire side by side, and tap for 40 metres. Leave another ¼in space, and wind 25 turns, also 26 s.w.g. enamelled wire side-by-side to complete the coil.

S₆ is set for the band on which output is wanted. VC₄ is near maximum capacitance for 3.5 Mc/s, but its vanes are almost fully open for 14 and 21 Mc/s. The grid drive actually found was 7.5mA for 80 and 40, 6.5mA for 20, and 4.75mA for the 15 metre band. VC₄ is adjusted to the position giving the required grid current. With the values shown, L₃ could not be tuned to wrong harmonics of 7 Mc/s. But when first testing this stage it would be wise to check with a simple wavemeter, especially on the h.f. bands.



A view of the underside of the r.f. chassis

V_3 could be used with a commercially made multi-band tank coil and switch assembly in the tank circuit. Alternatively, L_4 can be home-wound on a $1\frac{1}{2}$ in diameter former. Beginning at VC_2 , wind on 6 turns of 16 s.w.g. wire, and make the 15 metre tapping. Wind on 4 turns more, join on 20 s.w.g. wire, and make the 20 metre tap. The 10 turns of 16 s.w.g. wire are spaced to occupy $1\frac{1}{4}$ in winding length. Leave $\frac{1}{4}$ in clear, wind on 7 turns of the 20 s.w.g. wire, and make the 40 metre tap. Continue for a further 17 turns to complete the coil. The 24 turns of 20 s.w.g. wire occupy $1\frac{1}{4}$ in. S_7 should be immediately over the variable capacitors, connected to L_4 with stout, short leads. Coverage of L_4 can be checked by setting VC_3 to maximum capacitance, switching to "Net",

and noting the slight dip in grid current when VC_2 is tuned through resonance. VC_2 is almost fully open for 21 and 14 Mc/s bands.

Layout and wiring will be almost exactly the same as with the 80 metre—or by transmitter r.f. section. L_3 is under the chassis, near V_2 anode and VC_4 , the latter being near V_3 grid. Capacitor C_x is wired from L_3 to the moving vanes tag of VC_4 (chassis). A second 5763 was tried for V_2 , with equally satisfactory results. Make an initial test on each band by loading up into a lamp or other artificial aerial.

When operating into a suitable aerial, it was found possible to work 80, 40 and 20 metre bands with no interference to TV. On the 15 metre band, TV interference arose in the author's locality, but this was also the case with a well known com-

mercially manufactured transmitter.

Case Dimensions

As a guide to the possible use of cabinets to hand, the modulator and power supply chassis is 11in wide and 10in deep, and this unit required a clearance height of $8\frac{1}{2}$ in. The r.f. section is on a chassis 11in wide and 8in deep, and also requires $8\frac{1}{2}$ in height. The single panel illustrated is $12\frac{1}{2}$ in x $17\frac{1}{2}$ in. The case was $12\frac{1}{2}$ x $17\frac{1}{2}$ x 11in.

H. L. Smith & Co. Ltd., can supply various cases, and prepared members to assemble cases. The dimensions given above for the power supply unit and r.f. section are those of the actual assemblies, so a little must of course be added for clearance, or to allow for internal flanges on cabinets. *

Step Recovery Diodes

by J. B. Dance, M.Sc.

If any semiconductor diode is made to conduct in the forward direction and the polarity of the applied voltage is reversed very suddenly, conduction in the reverse direction will take place for a very short time.

This effect is the result of residual minority carriers being stored in the semiconductor material and causing conduction for a short time after the polarity has been reversed.

Fast Recovery Diodes

The charge storage and the consequent reverse conduction is detrimental in many applications of diodes in logic circuits and in computers, and the period of conduction must be reduced to the minimum possible time. The resulting diodes are known as "fast recovery diodes".

Step Recovery Diodes

In step recovery diodes there is a very abrupt transition from the state of reverse conduction to that of non-conduction. If the reverse current flowing is plotted against time, the resulting graph approximates closely to a step function. Such a

function can be shown (according to Fourier Analysis) to contain many harmonics. One of the main uses of step recovery diodes is therefore the efficient generation of harmonics in the microwave region.

Device Design

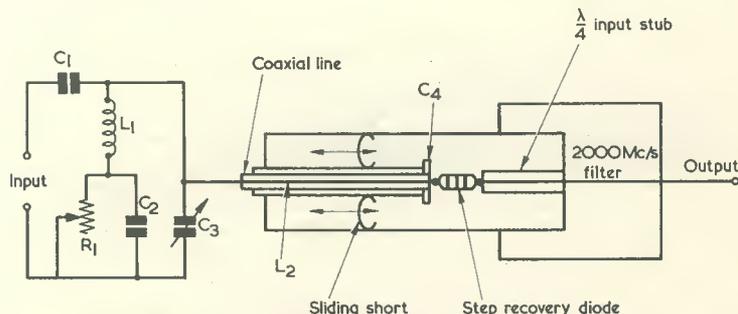
Step recovery diodes are designed so that a high field is present across the p-n junction, since this will confine the charge to the junction region. High fields are obtained on

both sides of the junction by employing epitaxial silicon devices with very abrupt junctions. Process control of the very abrupt gradient of the semiconductor material at the junction allows the lifetime and transition times to be determined in the devices.

The delay between the change of polarity of the applied potential and the end of the period of reverse conduction may be varied from about 1 to 500 nanoseconds by variation of the forward or reverse currents¹ (1 nanosecond = 1/1000 of a microsecond).

Pulse shaping

Step recovery diodes may be used as pulse sharpening devices for providing pulses with rise and fall times of less than two nanoseconds at pulse amplitudes exceeding 10 volts and impedances of about 50Ω .¹ Some types will provide pulses with rise and fall times as small as 0.25 nanoseconds when extremely simple circuits are employed.



This diagram (due to Hewlett Packard) illustrates a step recovery diode frequency multiplier

Tens of volts or hundreds of milliamps can be switched in less than a nanosecond. No other known device can switch such currents at this speed.²

Step recovery diodes can be used as impulse generators to drive tunnel diodes and sampling bridges.

Frequency Multiplication

The most important use of step recovery diodes is almost certainly the generation of high order harmonic power using a simple single stage circuit. For example, 100 milliwatts of power at 100 Mc/s may be multiplied in frequency by a factor of twenty to provide about 10 milliwatts of power at 2 Gc/s. (1 Gc/s is 1,000 Mc/s.) Over 20 milliwatts of power can be obtained at X band frequencies (5,200 to 10,900 Mc/s) from an input of 500 or 1,000 Mc/s. In some applications the input frequency can be multiplied by a factor of up to one hundred.

Comparison with varactor diodes

In most solid state equipment used for frequency multiplication varactor diodes are employed, these devices acting as variable capacitors. High order harmonic power is not easily generated by varactors, since there is a smooth (or steady) variation of capacitance with the applied voltage. The efficiency of conversion with a varactor diode falls off at a rate of $1/n^2$ where n is the number of the harmonic. Therefore a number of cascaded frequency multiplying stages are often needed

when varactor diodes are used. The conversion efficiency of a step recovery diode generating the n th harmonic falls off as $1/n$ where n exceeds 5.³ Therefore step recovery diodes can be used to make much more efficient multipliers for obtaining a high harmonic in a single stage. Although they behave to some extent like the varactor, this is a second order effect.⁴

Step recovery diodes used as frequency multipliers also have the advantage over varactors that they give a more even response over the band of frequencies which is undergoing frequency multiplication. They also have a better noise performance and the simpler circuitry which can be employed enables the alignment procedure to be carried out much more quickly.

A typical single stage twenty-times frequency multiplier circuit is shown in the diagram.³ Efficiencies exceeding $2/n$ where n is the number of the harmonic can be obtained. The input power is fed through the capacitor C_1 (about $0.1\mu\text{F}$) which, in conjunction with the $5\mu\text{H}$ choke L_1 , is used to separate the input power from the bias voltage developed across R_1 ($50\text{k}\Omega$). The input impedance is matched by a network consisting of the variable capacitor C_3 , L_2 ($0.07\mu\text{H}$) and the bypass capacitor C_4 (70pF). The step recovery diode is placed in series with the input resonant circuit. The sliding short is adjusted for optimum output. The 2,000 Mc/s output filter has a bandwidth of 20 Mc/s and 2dB insertion loss.

The total circuit losses are 2.5 to 3dB.

An exceptionally stable source of microwave power can be obtained by using a crystal oscillator and amplifier to drive a step recovery diode used as a frequency multiplier.

It should be noted that there is no such thing as an ideal step recovery diode. The most suitable device must be chosen according to the application in hand, paying attention to the circuit impedances and power levels. Various theoretical papers on the diodes have been published.^{5,6}

Acknowledgement

The writer is indebted to Messrs. Hewlett Packard Ltd. of 620 Page Mill Road, Palo Alto, California, U.S.A., for the information they have kindly sent him about their step recovery diodes. Similar types of diode are available from the Sylvania Company.

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Yorkshire Colour TV

Yorkshire Television Ltd., one of the new independent television programme contractors, has ordered Marconi colour television cameras, telecine equipment and outside broadcast units worth nearly £650,000. This is probably the largest single order for television studio equipment ever placed in this country, and it will provide Yorkshire with their main programme origination equipment for their initial development.

This is the first equipment to be ordered by one of the new programme contractors created in the re-shuffle of independent television earlier this year, and it will give Yorkshire the first studio centre in the country to be designed for full colour capability from the outset.

A total of 16 of the latest Marconi Mark VII colour cameras have been ordered. These will be used in a new studio centre at Kirkstall Road, in Leeds, and in two four-camera, colour outside broadcast units to be built by Marconi. The studio centre will contain a four-camera studio, a three-camera studio and a remotely-controlled presentation studio, with a single Mark VII camera. The very high stability of the camera, which can be operated for long periods without adjustment, will be of particular importance in this last application.

Three colour television channels will also be supplied to Yorkshire Television. These new units, which will be introduced by Marconi later this year, employ a modified version of the Mark VII camera, and provide similar advantages in terms of stability, and high quality performance.

Deliveries of the equipment will start in February of next year, and the majority will be supplied by the summer when this new contractor is due to go on the air.

IN LAST MONTH'S ISSUE WE EXAMINED OUTPUT pentodes and beam tetrodes; and we saw how, in the latter, the optical alignment between control grid and screen-grid wires causes the electrons emitted by the cathode to form horizontal beams which converge to give maximum electron density per beam at a plane between the screen-grid and the anode. This plane of maximum electron density is equivalent to a virtual cathode, and its existence prevents the passage of secondary electrons from the anode to the screen-grid which is characteristic of a normal tetrode. Hence, the beam tetrode has a "kinkless" $I_a V_a$ characteristic similar to that of a pentode, and it may be similarly employed as an a.f. output valve.

We now turn our attention to other features of the output stage, and will also commence, this month, to deal with phase splitters.

Valve Performance

As was stated last month, pentodes and beam tetrodes offer a higher output for a given h.t.

amount of second harmonic distortion, and it could be described as representing a higher degree of "shrillness".

Because the beam tetrode provides predominantly second harmonic distortion the use of this valve in simple push-pull output stages, where second harmonics cancel out, becomes attractive. Two 6BW6 beam tetrodes (the output valve type we employed in the receiver which formed our last constructional project) are, for instance, quoted as offering 1% harmonic distortion at 12 watts output in a push-pull output circuit. This is quite a reasonable performance for a simple output stage in which no additional distortion-reducing circuit device (i.e. negative feedback—to be discussed later) is employed. The third harmonic distortion introduced by pentodes does not cancel out in a push-pull output stage, but it is possible, by lowering the anode load impedance, to reduce the third harmonic distortion at the expense of an increased second harmonic distortion, which is then cancelled out whereupon pentode output operation in push-pull can also become attractive.

It must be emphasised that the points concerning

UNDERSTANDING RADIO

Output Stages and Phase Splitters

$$f = \frac{1}{2\pi\sqrt{LC}}$$



by W. G. Morley

consumption than do comparable triodes, and they are also more sensitive. In consequence, pentodes or beam tetrodes are almost always employed in the output stages of valve a.f. amplifiers. Triode a.f. output valves are not, indeed, normally listed in valve manufacturers' current lists, although the technical details given for most output pentodes and beam tetrodes specify operating conditions for such valves when triode-operated, as is given when the screen-grid and anode are "strapped" (i.e. connected) together.

An important feature of the performance of an a.f. output valve is the amount of distortion it introduces, and this can be expressed in terms of the additional harmonics of the input grid signal which are generated due to the distortion. Speaking in very general terms, triode and beam tetrode output valves operated in Class A_1 (the normal mode for radio receiver output stages) cause distortion in which the second harmonic predominates. Pentodes in Class A_1 produce distortion in which the third harmonic predominates. The subjective effect of third harmonic distortion is more unpleasant than an equivalent

distortion which have been given in the preceding two paragraphs are of a general nature, and apply to simple a.f. output circuits only. It has also to be remembered that the distortion increases with output, with the result that distortion may be small at low output settings, reaching a high figure only when the output approaches the maximum for which the valve is rated. In practice, the output stages of commercially manufactured valve radio receivers tend to employ pentode valves more frequently than beam tetrodes. So far as home constructor designs are concerned either type of valve may be used, and it is always very desirable to employ an output transformer having a ratio which offers an anode load impedance equal to, or close to, the anode load impedance specified by the manufacturer of the valve. A widely incorrect anode load impedance may not result in a very large apparent reduction in output volume, but it can cause a significant increase in distortion.

With a.f. output stages employing a single valve, the normal method of connection for the beam tetrode and the output pentode consists of returning

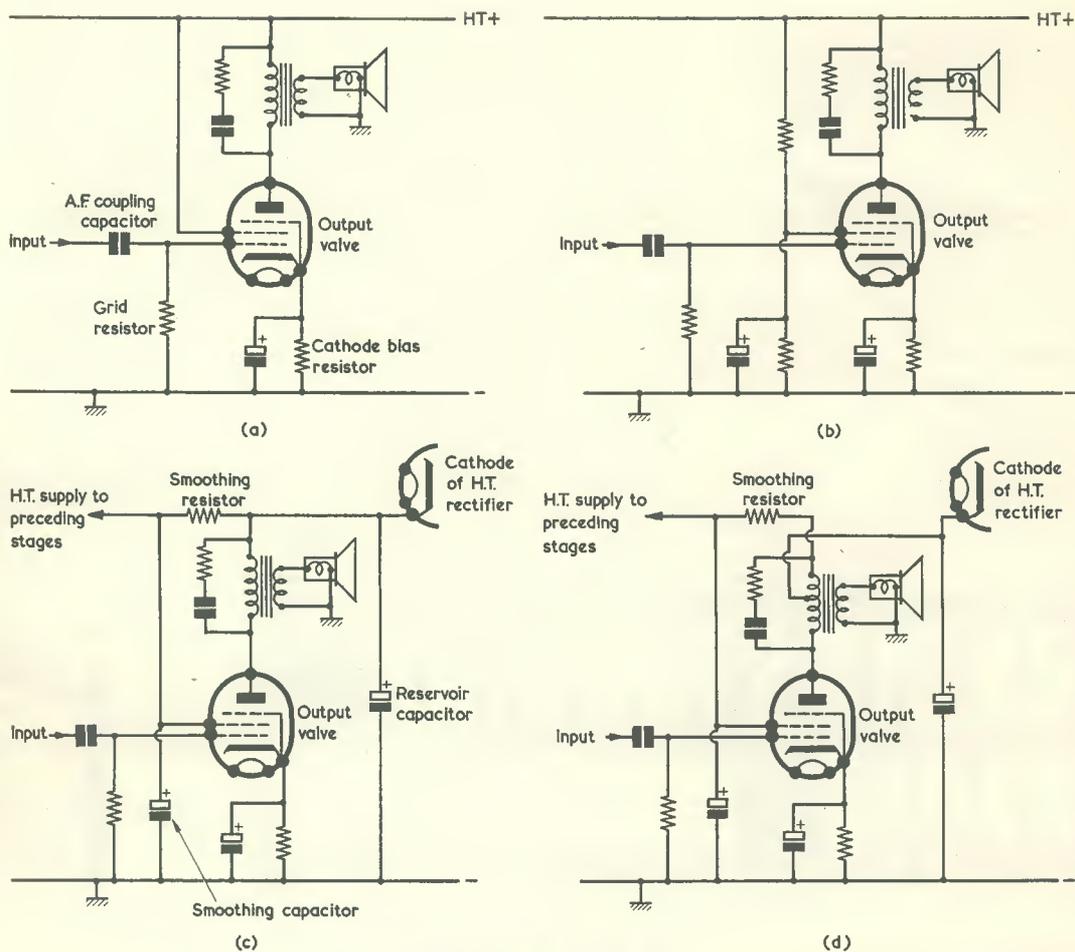


Fig. 1 (a). In a simple a.f. output stage, the screen-grid may be returned to the same h.t. positive point as the primary of the output transformer. A pentode is shown here, and in (b), (c) and (d), but a beam tetrode with its beam forming plates connected to cathode can be similarly employed in all cases
 (b). In some output circuits the screen-grid is fed by way of a fixed potentiometer given by two resistors
 (c). A typical circuit technique in which the high r_a of a pentode or beam tetrode allows only a low ripple current to flow in the output transformer primary. A valve h.t. rectifier is assumed
 (d). An improvement in the circuit of (c) which further reduces the ripple level in the output transformer secondary

the screen-grid direct to the h.t. positive rail, as shown in Fig. 1 (a). Either type of valve may be connected up in this manner. If it is desired to operate the screen-grid at a lower potential than the anode it may be fed via a fixed potentiometer given by two resistors, as shown in Fig. 1 (b). In general, the resistors should have values which cause about four times as much current to flow in them, on their own, as is drawn by the screen-grid, and the screen-grid should be bypassed to chassis via a capacitor of some $4\mu\text{F}$ or more. Due to the fact that the r_a of an output pentode or beam tetrode has a high value (of the order of 30 to 80k Ω for either type of valve) it is possible for the output transformer primary to

be returned to an unsmoothed point along the h.t. positive line, as in the example shown in Fig. 1 (c). Even if there is a relatively large ripple at the point where the output transformer primary connects, the high r_a presented by the valve keeps the ripple current flowing in the primary of the output transformer at a sufficiently low level to be acceptable for normal domestic applications. The circuit of Fig. 1 (c) has the advantage that the high anode current does not flow through the smoothing resistor, whereupon this can have a high value without incurring an excessive voltage drop, and h.t. smoothing requirements become eased. An improved version of this arrangement is shown in Fig. 1 (d), in which the tap

in the output transformer primary is close to its upper end. The small ripple current flowing in the lower section of the primary is approximately cancelled out, in the transformer, by the ripple current flowing in the opposite direction in the upper section, thereby ensuring an even lower ripple in the secondary.

In all the output circuits shown in Figs. 1 (a) to 1 (d), the output transformer primary has a resistor and a capacitor in series connected across it. This is standard practice in low-cost a.f. output stages employing a single valve, the function of the capacitor and resistor being to attenuate the higher audio frequencies and thereby reduce the subjective effect of the harmonics introduced by the output valve. Typical values of resistance and capacitance for an output pentode are $10k\Omega$ and $0.05\mu F$ respectively, and it would be possible to use components offering less attenuation with a beam tetrode output valve. Circuit devices of this nature do not affect the cause of the distortion, they merely alleviate its audible effect. Alternative approaches are employed in a.f. amplifiers which are intended to offer a high fidelity output.

Ultra-Linear Output Stage

An interesting push-pull a.f. output stage is illustrated in Fig. 2. This employs two pentodes but, whereas it is normal practice for the pentode screen-grids of a push-pull output stage to be bypassed to chassis by way of a large-value capacitor, in Fig. 2 the screen-grids are connected to taps in the primary of the push-pull output transformer, these taps being situated between the anode connections and the h.t. positive centre-tap. The cathode, control grid and screen-grid of each valve constitute a triode, whereupon the circuit takes up the attributes of a triode push-pull output stage as well as those of a pentode push-pull output stage. As a result, the performance of the circuit tends to fall between that of a triode output stage and that of a pentode output stage.

The distortion introduced by a pentode output stage is predominantly third harmonic whilst that introduced by a triode is predominantly second harmonic. When pentodes are employed in the circuit of Fig. 2 the odd harmonic distortion decreases, whereupon the remaining even harmonic distortion can be readily cancelled out in the primary of the push-pull output transformer. Thus, the circuit offers less distortion than is given with pentodes whose screen-grids are bypassed to chassis. At the same time, the available output power is somewhat lower than with two pentodes operated in the normal manner.

The circuit of Fig. 2 is frequently used in the output stages of high quality and high fidelity a.f. amplifiers because the advantage of lower distortion outweighs the disadvantages of reduced power in such applications. The pentodes may be operated in Class A or AB₁. Beam tetrodes may also be employed in an output circuit of this type.

The screen-grid taps in the output transformer

primary are, according to individual output stage design, positioned some 20% to 45% of each half of the winding away from the anode end. Speaking in general terms, both distortion and power output reduce as the screen-grid taps approach the centre-tap within this range.

Valve manufacturers (notably Mullard) quote output stage operating conditions for specific screen-grid tap positions in their literature covering valves suitable for use in this type of circuit. The circuit shown in Fig. 2 is generally known as an *ultra-linear* output stage. In Mullard literature, however, it is referred to as an output stage operating under *distributed load* conditions.

Phase Splitters

When, in the July issue, we introduced the push-pull output stage, we employed an a.f. transformer with a centre-tapped secondary to provide the two out-of-phase signals needed for the output control grids. The centre-tap was connected to chassis and the two outside ends of the secondary to the control grids, whereupon the input a.f. signal caused one grid to go positive when the other went negative and vice versa, thus providing the desired 180° phase difference between signals which is required for push-pull working.

In practical high quality a.f. amplifiers having push-pull output valves which operate in Class A or Class AB₁, the use of a transformer to provide out-of-phase signals is not attractive because, if the transformer is not to introduce a relatively large

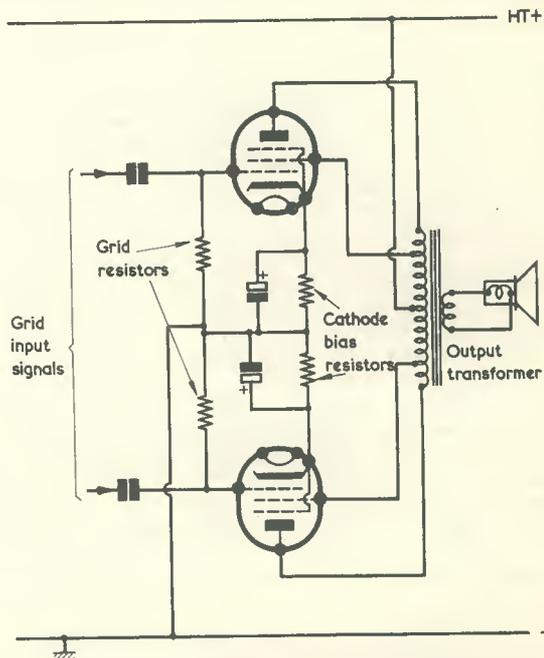


Fig. 2. Two pentodes in an ultra-linear push-pull output circuit. This differs from a conventional push-pull pentode output circuit because the screen-grids are connected to taps in the output transformer primary

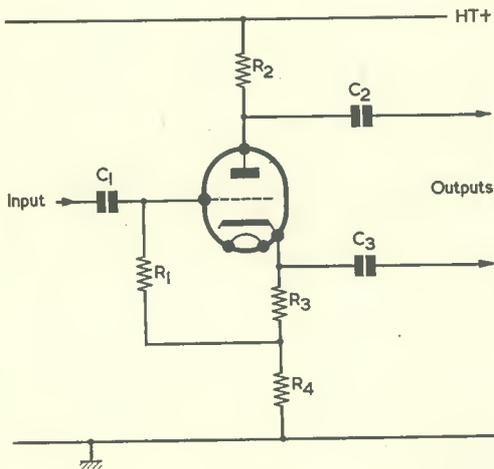


Fig. 3. A simple phase-splitter. C_1 , C_2 and C_3 are a.f. coupling capacitors. R_1 is the grid resistor, having a value of the order of $470K\Omega$ to $1M\Omega$

amount of distortion, it has to be a carefully designed and expensive component. It is much simpler and cheaper to provide the out-of-phase signals with a valve or valves, and the circuits employed for this purpose are known as *phase splitters*. We shall next commence to consider some of the phase splitter circuits which are most commonly encountered in valve amplifiers.

Fig. 3 shows a very simple and effective phase splitter. In this diagram a single voltage amplifier triode is used, and equal values of resistance are connected between its anode and the h.t. positive line and between its cathode and chassis. The anode resistance is given by R_2 and the cathode resistance by R_3 and R_4 in series, R_3 plus R_4 being equal to R_2 . R_3 is a cathode bias resistor having a value suitable for the triode employed, grid resistor R_1 being returned to its lower end. Outputs are taken, via coupling capacitors C_2 and C_3 , from the anode and cathode. C_1 is an a.f. coupling capacitor in series with the input signal.

Let us consider the action of the circuit when the input a.f. signal causes the triode grid to go positive. The consequent increase in anode current causes a higher voltage to be dropped across R_2 , whereupon the anode goes negative. The increased anode current has to flow through R_3 and R_4 , whereupon the voltage dropped across these two resistors increases also. Thus, the cathode goes positive.

If the input a.f. signal causes the grid to go negative, anode current decreases. Less voltage is

dropped across R_2 and the anode goes positive. At the same time, less voltage is dropped across R_3 and R_4 , and the cathode goes negative.

We can now see that, if an a.f. signal is applied to the grid of the triode of Fig. 3, a signal which is 180° out of phase with the input appears at the anode and a signal which is in phase with the input appears at the cathode. The signals at the anode and cathode are, therefore, suitable for passing on to the control grids of a push-pull output stage.

Because there is no bypass capacitor across the resistance in the cathode circuit (R_3 and R_4) there is a very high degree of degeneration in the circuit, and the a.f. output voltages at the anode and cathode are slightly lower than the a.f. input voltage. With conventional component values, the output voltages will be about 0.9 times the input voltage. Typically, the value of R_2 (and, in consequence, of R_3 plus R_4) may be about half the value of anode load resistor which would normally be used by the triode when employed as a straightforward voltage amplifier. Sometimes, somewhat lower values are used. The impedances at anode and cathode are different, that at the cathode being lower. Because of this, it is necessary for subsequent stray capacitances to chassis to be kept low or there will be unbalance (i.e. dissimilar output voltages) at the higher audio frequencies.

For good balance, R_2 should be equal to $R_3 + R_4$ within $\pm 5\%$ or better. Similarly to maintain balance, the following output stage grid resistors should also be closely matched in value. R_3 provides cathode bias and, in a normal voltage amplifier, would have a large-value bypass capacitor connected across it to prevent degeneration. No advantage would accrue from adding such a capacitor across R_3 in the present circuit, because R_4 is normally considerably higher in value than R_3 and it is R_4 which provides most of the degeneration. A disadvantage with the circuit is that, since the cathode is unbypassed and connects to chassis via a relatively high value of resistance, it is capable of picking up hum from the heater supply due to stray heater-cathode capacitance and leakage. This hum could be particularly troublesome if there were voltage amplification between the phase-splitter and the output stage. Normal practice, however, is to apply the phase-splitter output direct to the push-pull output control grids, whereupon there is usually insufficient subsequent amplification for any hum at the cathode to be reproduced at excessive level.

The circuit of Fig. 3 is sometimes referred to as a *split-load phase splitter*.

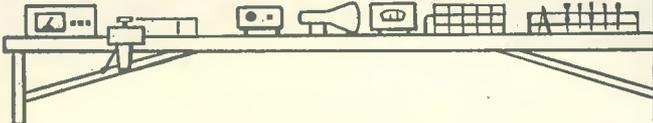
Next Month

In next month's issue we shall continue our discussion on phase splitters. *

Correction

In the Components List of the SCT/RS1 Superhet Receiver—see page 36 August issue—the value of R_{29} should read 330Ω and not $330k\Omega$.

In your workshop



In this month's episode Smithy the Serviceman, aided as always by his able assistant, Dick, locates a component with an intermittent fault in a transistor record player. In the process, Dick learns a few facts about transistor output in mains operated equipment

"I MUST SAY," REMARKED DICK chattily, "that I do like to have a go at a bit of transistor gear which runs from the mains. All during this last Summer I seem to have been doing nothing else except fix transistor portables with fiddling little batteries hidden away inside them. It's a real change to have something you can plug into the mains."

Smithy, standing at his side, nodded gravely in assent.

Dick picked up the mains plug of the transistor mono record player he had just placed in front of him and surveyed the row of assorted mains sockets fitted to the back of his bench. With a grunt of satisfaction he fitted the plug into the particular socket which corresponded to it, and leaned back again.

He switched on the record player. Obliging, the gram motor whirred, just audibly, into life.

Dick placed one of his 45 r.p.m. test records on the turntable spindle, selected the correct speed and actuated the changer mechanism. The record fell cleanly, the pick-up arm rose, and it descended on the rotating disc at exactly the correct point. The tinny sound of a pygmy pop group became audible from the pick-up head.

Intermittent Fault

"Turn the wick up a bit," commanded Smithy.

Dick put his hand on the knob in question, to find that it was at its minimum setting. He turned it up, whereupon the speaker offered a weak sound which had very nearly the same high-pitched quality as had been given at the stylus. The pop record spinning on the turntable reached a heavy and unexpected crashing guitar chord. This chord obviously had a beneficial effect on the internal workings of the record player because the sound from the speaker abruptly changed for the better. It suddenly covered the full compass of audio frequencies at the maximum volume of which the record player was capable, and the Workshop reverberated to the sound of the pop group as it caterwauled its way (borrowed drummer, *et al*) through its rendering. Hastily, Smithy leaned forward and turned the volume down.

"Well, blow me," remarked Dick, as the record player continued at reduced volume level but without the loss of the lower frequencies which had previously afflicted its output. "All of a sudden it started going all right! Just after that guitar chord."

"That record player," commented

Smithy, "has got an obvious intermittent in it. If we're lucky the fault may show up again soon."

"We've got plenty of time to wait for it anyway," remarked Dick. "There's nothing else in the Workshop that needs servicing."

And such, in fact, was the case. The "For Repair" racks were completely empty. Indeed, Smithy had decided to devote the last hour or so of the afternoon to giving Dick a hand with the record player, which was the only unserviceable item outstanding.

"Hallo," exclaimed Dick. "That fault's on again!"

Without warning, the sound from the record player had reverted to its previous weak and high-pitched character. Dick leaned forward to adjust the volume control, but Smithy motioned him back.

"Hang on a minute," he said. "Let's see if it clears up when the volume is at this reduced level."

Quietly, the pair watched the record as it rotated to its end. There was a click, the pick-up arm rose, traversed the surface of the record and then descended neatly on its rest. The turntable began to slow down whilst, in the silence, the little motor under the gram deck could just be heard as it whirred busily away.

"I wonder," queried Dick absently, "why the motor doesn't switch off."

"There's a good reason for that," replied Smithy, "but don't let's bother about it now. Play the record again."

Obediently, Dick switched the changer to "Manual" and placed the pick-up on the disc. Once more, the weak, high-pitched reproduction became audible from the speaker. Smithy listened attentively.

"I think that's enough at low volume," he announced eventually. "Turn the gain up again."

Once more, Dick turned the volume to full and the high-pitched reproduction increased in level. Again, the pop recording reached a crescendo, whereupon the fault suddenly cleared and the Workshop was once more filled with the deafening racket from the speaker. This time, however, Smithy made no immediate attempt to reduce the volume control. Wincing visibly as the record abraded on, he allowed some thirty seconds to elapse before he finally adjusted the gain control. The record player continued to offer an undistorted output at its reduced volume level, then it abruptly returned to its former condition.

With a satisfied expression on his

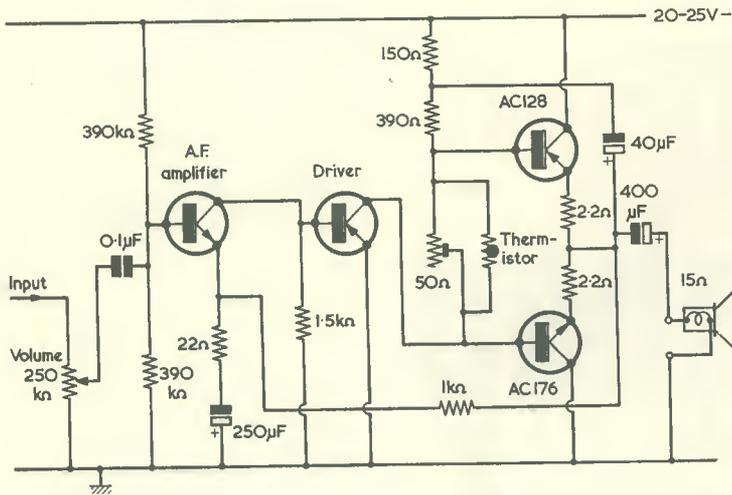


Fig. 1. The AC128 and AC176 complementary output stage, with a typical preceding a.f. amplifier and driver. The driver may be another AC128 and the a.f. amplifier a silicon a.f. type. The circuitry shown here preceding the output stage proper is based on Ekco design, but it must be emphasised that these stages are merely included for illustration, and that references in the text are only intended to apply to AC128/AC176 output stages in general and not to the product of any specific manufacturer. A.F. amplifier and driver circuitry by other manufacturers is, basically, similar to that shown here

face, Smyth selected "Reject", waited until the pick-up arm had returned to its rest, then switched off the record player.

Complementary Output Stage

"Dick, my boy," he remarked cheerfully, "we're in luck! We've got an intermittent here all right, but it's one that we should be able to locate quite quickly."

"Don't tell me," queried Dick, "that you know what it is already."

"I don't," grinned Smyth, "but I've got a darned good idea where to start looking for it, nevertheless. Whilst you're getting the works out, I'll find the service sheet."

Smyth soon returned from the filing cabinet with the service sheet. He opened it and looked carefully at the circuit diagram.

"Here we are," broke in Dick. "I've got the chassis out, although I've had to unplug the speaker leads to do it."

"Fair enough," said Smyth. "Can you see any obvious snags in it?"

"Nothing at all," replied Dick. "All the components look nice and new, and the printed circuit board is as clean as a whistle. Just a minute, though!"

"What's up?"

"What output is this record player supposed to give?"

"Oh, about four watts or so," replied Smyth. "Why do you ask?"

"There don't," said Dick, puzzled, "seem to be any large transistors in it at all. All the transistors are the standard small types in little cans. Don't tell me that these can handle four watts!"

"They can, you know," said Smyth. "Come and have a look at the circuit of the output stage, and I'll show you what I mean."

Smyth indicated to his assistant the appropriate part of the circuit diagram in the service manual. (Fig. 1).

"If you look at this," he continued, "you'll see that the output stage is given by a complementary pair consisting of an AC128 p.n.p. transistor and an AC176 n.p.n. transistor. Both these transistors are in small cans but they can offer up to 4 watts speech and music in the present circuit, provided that they're very adequately coupled to a good large heat sink. In some amplifiers they're inserted into apertures in the sink, with a liberal amount of silicone grease around them to ensure good thermal contact. In others, they're secured to the sink with clips which make good thermal contact all the way round the can. Several different manufacturers are using the AC128 and AC176 in the output stages of mains-

driven transistor record players and radiograms, and these two transistors give a jolly good account of themselves provided that care is taken with their cooling. The drive circuitry up to the two transistors tends to vary a wee bit according to the manufacturer, but the actual output stage proper, with the two transistors and their 2.2Ω emitter stabilising resistors in a complementary circuit, seems to represent a standard approach."

"It certainly," remarked Dick, "looks like a very simple output circuit."

"It is," confirmed Smyth. "Each of the transistors functions as an emitter follower. On one half-cycle the base of the AC128 is driven negative, whereupon this transistor drives the speaker. On the next half-cycle the base of the AC176 is driven positive, and it's then this transistor which drives the speaker. In other words you've got a standard transistor Class B output stage. Also, you have the usual circuit technique to prevent crossover distortion. There's resistance between the two bases which causes the base of the AC128 to go a little negative and the base of the AC176 to go a little positive under quiescent conditions, so that both transistors pass a small current even when no signal is fed to them. In the circuit we have here that resistance is provided by a preset pot in shunt with a thermistor. The pot is set to give the correct quiescent current, and the thermistor then looks after changes in temperature."

"You meet that sort of thing in battery output stages, too," volunteered Dick. "I suppose the idea is that, when temperature goes up, the resistance of the thermistor goes down."

"You've got it," confirmed Smyth. "The consequence is that an increase in temperature results in a decrease in base bias, thereby counteracting the tendency of the output transistors to pass increased current themselves. An alternative idea of providing the base-to-base resistance is to use the base-emitter junction of a third transistor. (Fig. 2). This base-emitter junction is forward-biased and you once again get a decrease in resistance as the temperature increases. It's usual practice to couple this third transistor to the same heat sink as is employed by the two output transistors, with the result that it is affected by the temperature of the actual output transistors themselves."

Smyth pushed the service manual away from him.

"That's it then," he remarked. "As you can see, all that we've got here is pretty much the same that we find in battery output stages."

"Not entirely it isn't," said Dick, quickly pulling the service sheet back again. "For a start, there's a lot more power available for the output transistors than you find in battery equipment."

"Well, that's true enough," admitted Smithy. "The fact that you've got stacks of cheap power available from the mains *can* influence the output stage design, though manufacturers still tend to follow the Class B output stage techniques which have grown up with battery sets. Incidentally, the power supply circuits you get in mains-driven transistor equipment are pretty well the same for all types of domestic gear, whether these be radios, record players or radiograms. There are two very similar approaches, one of which is to have a simple double-wound mains transformer whose secondary applies some 17 to 20 volts a.c. to a bridge rectifier. (Fig. 3 (a)). Occasionally the mains transformer has primary taps to suit different input voltages between 200 and 250 volts, but it's much more usual to have a primary without taps. Any voltage between 200 and 250 is applied to the complete primary in this case. The bridge rectifier following the mains transformer secondary feeds into a dirty great reservoir electrolytic having a value of some 2,000 to 4,500 μ F. The output stage and driver supplies are normally taken direct from this capacitor, resistance capacitance smoothing being employed for the supply to the earlier stages of the equipment."

"What's the other approach?"

"It's almost identical," said Smithy, "except that instead of a mains transformer a secondary winding is fitted to the gram motor instead. (Fig. 3 (b)). This idea is only used with record players, of course. The secondary winding applies about 17 to 20 volts a.c. to the bridge rectifier in the same way as does the secondary of a mains transformer, and the cost of the latter component is saved."

Dick was visited by sudden illumination.

"That explains," he said brightly, "why the gram motor in that record player is running all the time, even when the pick-up is at rest. It's got to run all the time in order to provide a continual a.c. supply for the rectifier."

"Exactly," agreed Smithy. "A secondary winding on the gram motor is, in fact, just the job for a record player, whose only function in life is to play records. On the other hand, you'd have to use a mains transformer in a radiogram, because you wouldn't want the gram motor running all the time whilst you were listening to radio programmes. Incidentally, I'm rather surprised that you found it necessary to comment on the fact that the motor in this record player runs continually. You've handled quite a lot of valve record players in the past in which the heater supply is taken from a tap in the gram motor windings. The motor runs continually in those, too."

But a quite different query had now arisen in Dick's mind.

"If," he remarked suddenly, "the driver and output stages take their supply directly after the rectifiers, won't there be a pretty hefty ripple introduced into the a.f. output?"

"Not really," replied Smithy. "What you have to remember is that transistors have a high output resistance, in the same way that an a.f. output pentode has a high r_a . You can run an output pentode anode straight from the h.t. reservoir capacitor without introducing too much hum, as you know from your own experience with valve equipment."

Smithy took a pen from his pocket and scribbled in the margin of the service manual.

"The collector voltage-collector current curves of a transistor in grounded emitter," he continued, "are rather like this. (Fig. 4 (a)). As you can see, after you've gone to the right of the knee, increases in

collector voltage cause only a small increase in collector current. This indicates a high output resistance. At the same time you still get amplification because, as these curves show, changes in *base* current cause large changes in collector current. The same sort of thing happens with an output pentode where, despite the high r_a , changes in grid voltage cause large changes in pentode anode current. A transistor in grounded emitter is very much like an output pentode in this respect. In grounded base, incidentally, a transistor becomes virtually a constant current device, giving you curves like this. (Fig. 4 (b)). To the right of the knee of the curves, collector current remains virtually unaltered, despite very large changes in collector voltage."

"Blimey," said Dick impressed. "I hadn't realised you could get a transistor to give *quite* as steady a current as that! There must be all sorts of gadgets you could make up which take advantage of that constant current."

"There are," chuckled Smithy. "The fact that a transistor in grounded base can give a constant current hasn't been entirely forgotten by the gadget designers! In the record player circuit we've got here, the transistors are more likely to exhibit a collector voltage-collector current characteristic similar to that of the grounded emitter transistor, but the output resistance will still be high enough to ensure that negligible hum gets into the output. Incidentally, please note that the rectified voltage applied to the output stage is about 20 to 25 volts, together with quite a high current availability. Voltage and current are a lot greater

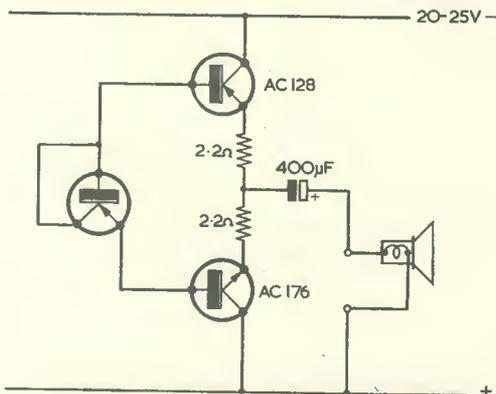


Fig. 2. The preset potentiometer and parallel thermistor of Fig. 1 are replaced, in some models, by the forward-biased base-emitter junction of a third transistor. In the H.M.V. 2024 record player, which uses this circuit device, the third transistor is an AC169

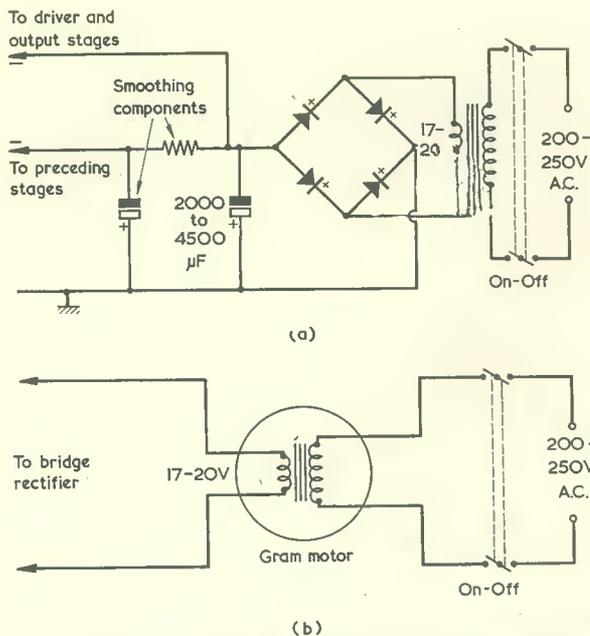


Fig. 3 (a). A typical power supply for mains-driven transistor equipment. The driver and output stages are fed directly from the reservoir capacitor, which normally has a value between 2,000 and 4,500 μ F. The subsequent smoothing resistor may be of the order of 1k Ω , and the smoothing capacitor around 200 μ F

(b). An alternative approach, which is encountered in record players. This is the same as (a) with the exception that, by adding a secondary winding to the gram motor, the latter replaces the mains transformer

than could be provided economically with batteries."

Speaker Impedance

"Fair enough," said Dick. "Well, I suppose I'd better get this record player amplifier going and see if we can find that intermittent."

He reached up to the shelf over his bench and brought down a pair of test leads which he clipped to the speaker leads from the record player chassis.

"Ye gods," snorted Smithy, shocked. "What the dickens do you think you've doing?"

"Coupling up my bench speaker to the output of the record player amplifier," replied Dick innocently. "You'll remember that when I took out the chassis I had to unplug the output leads to its own internal speaker."

"What's the impedance of your bench speaker?"

"Oh," replied Dick vaguely, "it's the usual 3 Ω , I suppose."

"Then," retorted Smithy, "jolly

well disconnect it again! That transistor output stage is intended to operate into a 15 Ω speaker, and you'd wreck it if you coupled it to an impedance as low as 3 Ω ."

"Pull the other leg, Smithy," replied Dick indignantly. "This one's got bells on it! How on earth can the output stage be wrecked when it's isolated from the speaker by a 400 μ F electrolytic?"

"That 400 μ F electrolytic," pronounced Smithy, "is nothing less than a dead short so far as a.f. is concerned. You've got two emitter followers in the output stage and the only thing that limits emitter and, hence, collector current flow when a high level of a.f. is applied to their bases is the impedance of the speaker. If the speaker impedance is lower than the figure intended by the designer, those output transistors are going to pass excessive collector currents and they're quite liable to break down in the process. Don't forget also that this is a mains-driven job, and its power

supply is quite capable of providing such excessive currents."

"Well, stap me," remarked Dick elegantly. "I must say that this speaker impedance business is a new one on me."

"Then you'll have to start remembering it from now on," stated Smithy, sternly. "I'd better say right now that the best approach, when working with mains-driven transistor amplifiers, is to always ensure that the speaker impedance presented to the output terminals is never lower than the figure intended by the manufacturers of the amplifier. It's a good idea to apply this rule to *all* the mains-driven transistor amplifiers you handle, even though many of these may be very much less susceptible to damage in this respect than others. And, of course, there is a similar risk of damage if you should happen to accidentally short-circuit the speaker leads together whilst the amplifier is handling an a.f. signal."

Armed with this information, Dick disconnected the output of the amplifier from his bench speaker and, using a spare pair of leads fitted with crocodile clips at each end and which he kept on hand for contingencies of this nature, coupled the output instead to the speaker inside the record player cabinet. He carefully checked that there was no risk of the crocodile clips short-circuiting together, then looked up enquiringly at the Serviceman.

"That's better," commented that worthy approvingly. "Well, we can now, at long last, get down to that intermittent fault of ours! Intermittent faults being what they are, it's always unwise to make any firm prediction as to their position in a circuit, but in this instance I think I can volunteer a fairly safe guess. To start off with, it's an intermittent which clears temporarily when a high-level a.f. signal appears in the circuit. This is a fairly common intermittent fault condition and it's very probable that the heavy a.f. signal is causing the intermittent connection to become good for a while. A sudden surge of a.f. current can break down the oxidation which has presumably built up between the two conductors of the faulty connection, thereby making it good again. Following from this, we can make the assumption that the fault is in a component or connection to which a.f. is applied. I must admit, by the way, that those horrible pop records you use for testing purposes do at least have the advantage of feeding some good sudden bursts of noise into the works!"

Smithy paused for a moment. "Now a second pointer to the fault," he continued, "is given by the fact that we had to turn the volume up high to get it to clear. There was no evidence of the fault clearing when the volume control was at a low level. So the fault is almost certain to be *after* the volume control. Thirdly, the fault, when it comes on, causes the output to be weak and high-pitched. What does that suggest?"

"Off-hand," replied Dick promptly, "I'd say it sounds like an a.f. coupling capacitor going low in value."

"Exactly," confirmed Smithy. "And, finally, which is the first class of components you normally suspect whenever you get an intermittent fault?"

"Electrolytic capacitors," said Dick, equally promptly.

"Good," said Smithy. "Then it looks as though our beady eyes of suspicion must be at once directed at one single component in that circuit of ours."

"Would that be," enquired Dick, "the 400 μ F electrolytic which couples to the speaker?"

"None other," confirmed Smithy. "So let us now get this machine into operation."

Dick plugged the record player into the mains once more, switched on and set the pick-up on the turntable. Smithy turned the volume control to mid-travel. The weak high-pitched sound was once more audible from the speaker.

Smithy located the 400 μ F electrolytic capacitor in question, and gently tapped it with his pen. At once, the sound from the speaker changed to full and correct reproduction. Several seconds later the fault returned, to clear once more as Smithy gently tapped the capacitor again.

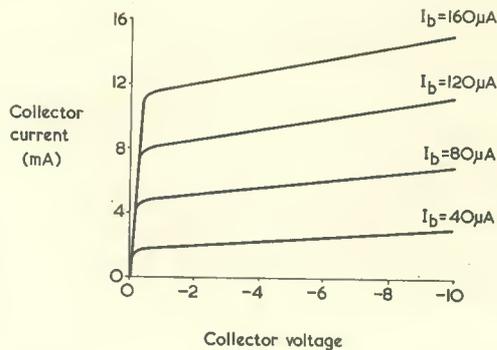
"That's it, then," remarked Dick. "All we now need to do is to tell the customer that his record player will go like a bomb provided he keeps tapping that electrolytic every few seconds!"

Smithy chuckled.

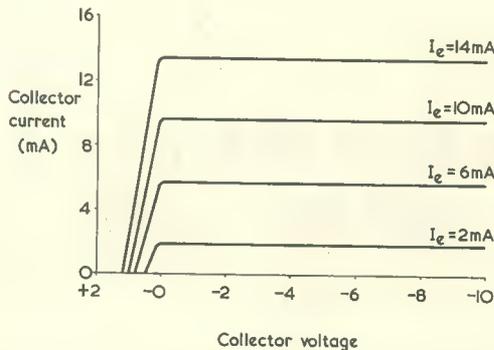
"That's one way out," he laughed, "but we'll do the next best thing, which is to fit a new electrolytic instead."

No Meters

Dick soon found a new capacitor in the spares cupboard, and fitted it in place of the suspect component. On checking the record player, the pair found that it now worked correctly and that no amount of tapping of components or gentle



(a)



(b)

Fig. 4. Typical collector voltage-collector current curves for a germanium p.n.p. transistor in (a) grounded emitter and (b) grounded base

flexing of the board could cause the fault to reappear. The record player continued to operate just as reliably after the chassis had been returned to its cabinet, and even the cautious Smithy eventually pronounced that it was now well and truly repaired.

"Have you noticed," said Dick, as he triumphantly carried the record player to the "Repaired" rack, "that there was something rather unusual about this last job?"

"What was that?"

"We cleared it," replied Dick, "with nothing more technical than a screwdriver to get the works out, or a pen to tap the capacitor with. We didn't even have to use a test-meter."

"That's not entirely true," said Smithy. "We had one *highly* technical device to help us."

"Did we?"

"We did," stated Smithy. "And the highly technical device was the service manual. I think it's safe

to say that the service manual can sometimes be more useful than all the rest of the test gear put together. I know that a lot of servicing is done without a service sheet, because many snags are pretty easy to spot visually and because a service engineer gains experience with particular makes and types of set. But if you ever have a fault which promises to be at all sticky you should always get the manual out without delay. A couple of minutes' quiet study of the circuit and the gen that goes with it can often save you hours of fruitless prodding around in the dark."

There was an unwonted silence for a moment and Smithy looked up enquiringly.

"Oh no," he sighed to himself, as he saw the furrowed look on Dick's brow which indicated that his assistant was about to produce a further sample of his occasional instant doggerel.

Suddenly, Dick's face cleared.

"Here, listen to this, Smithy," he said excitedly. "This must be one of the greatest I've done up to date!"

*"Now, why is Robert nervous,
Whilst Pete is confident?
They're both in radio service;
They're each as diligent.
Yet, two days' work for Robert
Takes half-an-hour with Pete.
And what makes Pete so expert?
He reads the service sheet!"*

An embarrassed expression spread over Smithy's face as Dick brought his creation to an end.

"Now, what," asked Dick eagerly, "do you think of *that*?"

Smithy hesitated as he searched for the correct word.

"I would say," he remarked, after what was obviously considerable thought, "that it expresses an admirable sentiment."

"Do you," said Dick, pleased, "really think so?"

"Oh, definitely," replied Smithy,

grateful at having found a safe avenue for comment. "It's a sentiment, indeed, with which I am in full accord."

"That's fine," commented Dick, beaming at the Serviceman. "I'll try and dream up some more later on."

Smithy stole a glance at the Workshop clock whose hands, he was relieved to note, were now pointing to finishing time.

"Tomorrow," he said firmly.



When Beta doesn't matter

By G. Short

With careful circuit design it is possible to obtain a fixed stage gain figure despite wide variations in transistor beta

IN THE EARLY DAYS OF THE JUNCTION TRANSISTOR, great emphasis was placed on the small-signal current amplification factor, then known as "beta", and now as h_{fe} . The reason was pretty obvious. Any transistor with h_{fe} greater than about 10 was a saleable commodity, and one with h_{fe} over 50 was a rather good one. The first British junction transistors to be mass-produced were the OC70 and OC71, with h_{fe} ranges of 20 to 40 and 30 to 75, respectively. These were, of course, basically the same transistor, produced by the same process, and afterwards sorted into gain groups with a higher price tag on the higher gain group.

Transistors are still priced according to h_{fe} , but for some purposes h_{fe} doesn't matter so long as it exceeds a certain figure, and you may as well buy a lower-gain transistor and save money.

Microphone Amplifier

Look at Fig. 1, which shows a simple microphone

amplifier. The only difference between the transistors in (a) and (b) is in their h_{fe} , which is 50 and 500 respectively. The bias resistances are selected to produce identical operating conditions. Despite the enormous difference in h_{fe} , the voltage gain of the high-gain transistor is only slightly higher.

Why? Well, the reason lies in the fact that we are using a low-impedance microphone. The consequence of this is that the input impedance of either transistor is much higher than the impedance of the signal source. In the case of Fig. 1 (a) the input impedance is $2,500\Omega$. In the case of Fig. 1 (b) it is $25,000\Omega$ —ten times larger, because the input impedance of a transistor is approximately proportional to h_{te} .

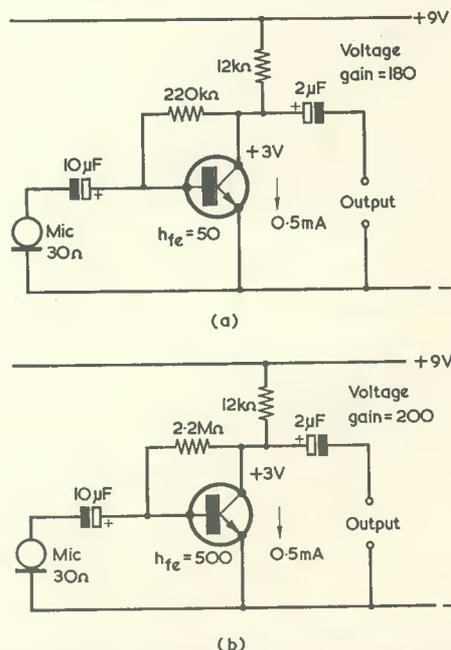


Fig. 1. The transistors in (a) and (b) have greatly differing current amplification factors, but the stage gain is virtually the same in each case

If the microphone produces 1mV, then in case (a) the input current to the transistor is 1,000/2,530 μ A. In case (b) it is 1,000/25,030 μ A. The ratio of these input currents is 25,030:2,530, and without working it out exactly it is obviously going to be very nearly 10. The low-gain transistor takes nearly ten times as much input current as the high-gain transistor, and this almost exactly compensates for its lower h_{fe} . If the transistor parameters other than h_{fe} were identical the voltage gains would be within 1% of each other. However, other parameters tend to be correlated with h_{fe} , and this has a slight effect on the voltage gain. But the improvement (if any) is not large. If the transistor in case (a) had a really low h_{fe} , say 10, the difference would be slightly larger, because its input impedance would then be only 500 Ω , but to reduce the gain by half (6dB) it would be necessary to reduce h_{fe} to less than 1.

I have taken an extreme (though quite practical) case. But the principle which emerges can be applied universally. *If the signal-source impedance is much lower than the input impedance of the transistor, then the stage gain is virtually independent of h_{fe} .*

I.F. Amplifier

At first sight this may seem to be a pity, but there are circumstances in which it is an advantage. A typical case is given by an i.f. amplifier, as shown in Fig. 2. Suppose the transistors which are to be used have a spread of h_{fe} of 30 to 120, that is, a 4:1 variation. If a receiver had two such i.f. stages, and if the operating conditions were such that the stage gain depended on h_{fe} , then the overall gain using low-limit transistors would be one-sixteenth of the gain with high-limit transistors.

The sensitivity of some sets could in consequence

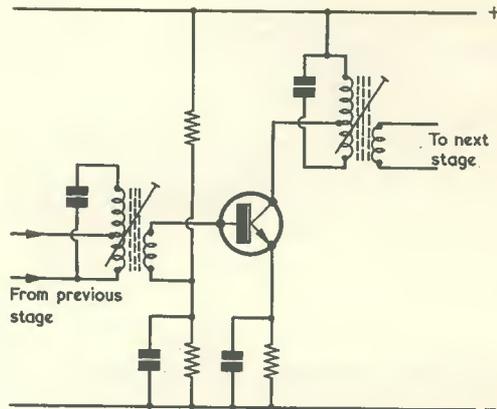


Fig. 2. Typical i.f. amplifier stage. Gain variations due to variation in current amplification factor can be largely "ironed out" by correct design

be 24dB worse than that of others. There would also be a problem in keeping the high-gain sets stable.

What the intelligent designer does in a case like this is to adjust the transformer turns ratios so that they are optimum for a low-limit transistor. The effect of using a high-gain transistor is then to increase the stage gain very slightly, and improve selectivity a little. Even if the better transistor had infinite h_{fe} the stage gain could then only increase by 6dB. In practice, it is possible, with typical transistor spreads, to restrict the overall gain spread to some 2 or 3dB. In exchange for a slight sacrifice in gain, there is a big improvement in consistency.



TRADE NEWS

● Arbiter Echo Units Use Mastertape Drums

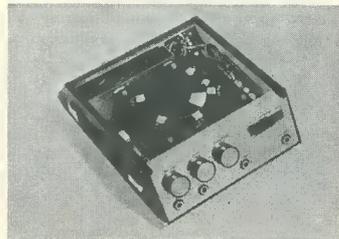
Magnetic drums coated by Mastertape (Magnetic) Limited form the heart of the popular Arbiter range of echo and reverberation units, which are selling widely in both home and overseas markets.

Breaking away from the troublesome tape-loop principle, Arbiter specified drums with a dimensional accuracy approaching that needed for computer drum stores. This enables recording and pick-up heads to work out of contact with the magnetic coating, so eliminating wear of either. On to the edges of these drums Mastertape coat magnetic paint to a thickness of half a thousandth of an inch, with a uniformity better than $\pm 5\%$ within drums.

The drums themselves are of aluminium $\frac{1}{4}$ in thick and $3\frac{1}{2}$ in diameter, the edges being machined concentric to within ± 0.2 thou' and bevelled slightly to give an effective width of 0.2in. After etch-priming, the edges

are coated with Mastertape magnetic oxide paint and then stoved. This produces an exceptionally tough coating which is impervious to damage during any subsequent normal handling or assembly. Finished drums are individually inspected for coating flaws and batch-tested for electromagnetic sensitivity and uniformity.

In use, the drum is surrounded by a number of magnetic heads (including an erasing head, a recording head and one or more playback heads) whose working gaps are spaced from the coating surface by controlled amounts—of the order of one thou' according to the function of the head and the type of unit.



Mastertape edge-coated drum mounted in Arbiter Echo Unit

The delayed signals picked up by the playback heads can be used individually, or mixed and controlled to produce a variety of reverberation flutter and echo effects. The delay time of each echo is set by the peripheral speed of the drum and the spacing of each playback head from the recording head. The track width permits the use of either single $\frac{1}{2}$ -track heads for mono working or twin $\frac{1}{4}$ track heads for stereo (as in one of the Arbiter units). At a peripheral speed of 20 in/sec, the units provide delays between 80 and 240 milliseconds and have a useful frequency range up to 5 kc/s.

Drums of this kind obviously have applications in other fields; in delayed speech reinforcement systems and in temporary stores for small amounts of analogue or low-density coded data, for example. Since Mastertape magnetic paints can be formulated for a wide range of rigid materials, manufacturers have considerable latitude in the design of drives and mountings.

Further details from Mastertape (Magnetic) Ltd., Poyle Trading Estate, Colnbrook, Bucks.

● BIB Home Electrician's Kit

Multicore Solders Ltd. recently announced the introduction of the new Bib Home Electrician's Kit, which will be an invaluable aid for every householder. It contains, in handy, compact form, virtually every item the handyman (or woman) requires to carry out electrical work in the home, workshop or garage.

The kit is contained in an attractive plastic wallet, as illustrated, which folds down to a size of 4in x 5½in. It will slip easily into the pocket or the glove compartment of a car.



The kit contains the following items:

Bib Model 8 Wirestripper and Cutter: this has an eight-gauge selector for different wire thicknesses. It has easy-grip plastic-cushioned handles. Apart from stripping insulation from flex and cables it will cut wire and split twin flex.

Three Bib Flex Shorteners: used for keeping flex, cables and leads neat and tidy. The Flex Shortener shortens without cutting and helps to prevent accidents.

Ersin Multicore Tape Solder: contained on a card, this solder melts with a match. No soldering iron or extra flux is required. There is sufficient for 80 average joints.

Insulating tape: on a reel. Made of high-quality plastics.

Screwdriver: designed specially with a blade to suit all types of plugs in normal use.

Fuse Wire: wound on a card; for 5 and 15 amp fuses.

The wallet is accompanied by a card bearing full instructions for use.

● Nombrex Audio Generator 30

This new instrument has been styled to the latest standard of presentation and incorporates new features and improvements in circuitry, performance and accuracy.

The model is housed in a new-design case, with modern recessed panel styling in three colours—blue, black and satin-silver. Spin-disc styled control knobs are fitted as shown in the accompanying illustration. Provision is made for simple rear access to battery compartment and a jack socket is included for alternative operation by an a.c. mains unit.

Specification is as follows:

RANGE:
10 c/s to 100,000 c/s in four ranges.

OUTPUT:
1 volt peak, sine or square wave.
Impedance, maximum 1,000Ω.

STABILITY:
Output constant over entire ranges, thermistor controlled.

DISTORTION:
Sine wave: better than 1% throughout.
Square wave: Rise time less than 0.3μsecs.

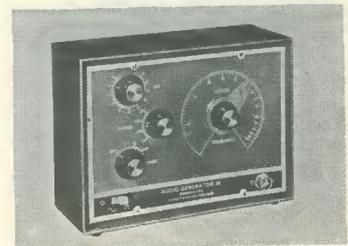
ACCURACY:

Frequency: Within 5% all ranges (average 3%)

Output: Within 3% of indicated voltage.

CALIBRATIONS:

Direct dial and attenuator calibrations, discrimination average 2½%.

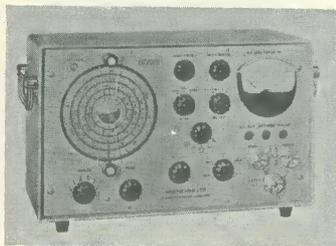


ATTENUATORS:

1. Three-decade switched multiplier.
2. Continuously variable, calibrated millivolts.

● Transistorised Standard A.M. Signal Generator

Developed by Westechno Ltd., Exmouth, Devon, this Laboratory Standard R.F. Signal Generator is the achievement by patient design work to produce, by modern transistorised applications, a high quality custom-built instrument incorporating not only the essential design features



of high accuracy, stability and robust construction but with many other facilities which previously have been available only at exclusive prices. The Model 28 is an ideal instrument for the research laboratory, for technological training and for trade or industrial purposes where only the best specification is acceptable.

Such features as the unusually wide frequency range from 30 kc/s upwards, small size and light weight of only 10½lb, with instant changeover to external power supply recommend it for services or shipping applications and for other general purposes in the field.

The circuitry is fully transistorised with stabilisation applied to ensure consistent long-term accuracy and stability. Printed circuitry is employed throughout, using pluggable type components with conservative ratings to provide long trouble-free service. The mercury cell batteries employed contribute to the high stability and replacements are readily available world-wide. Useful additional features are the provisions for the crystal calibrator and a.f. oscillator outputs to be available for use externally with other equipment.

Special features include—30 kc/s to 30 Mc/s range, crystal calibration checks throughout, fully transistorised—20 semiconductors and monitoring of r.f. level and modulation percentage on two scales by switch selection of function.

Full technical specification may be obtained from the manufacturer.

Radio Topics

By Recorder

HOW OFTEN, WHILST CARRYING out radio and TV repairs, is one entitled to *modify* the receiver being serviced?

This is quite an important question for those who take servicing seriously, because it raises a basic ethical point. If we lived in a perfect world the function of the service engineer would be that of restoring a faulty receiver to exactly the

condition it was in when it left the factory. Whereupon, accompanied by the bitter laughter of professional service engineers, I must hasten to add that the world we inhabit is in fact very far from being perfect, and that minor modifications are inevitable with *some* receivers. That changes are occasionally required is made evident by the fact that manufacturers introduce new sched-

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ules when some of their receivers are half-way through their production runs, the later schedule models incorporating improvements and component value changes deemed necessary by the manufacturers themselves.

Service Modifications

To give an example of the sort of modification which, to my mind, represents an honest approach, let me relate the following servicing story.

A small radio and TV shop sold quite a number of a certain make and model of television receiver in which a fixed capacitor was connected across the primary of the vertical output transformer. After a while these sets started coming back to the shop with no vertical scan, and in each case it was found that the capacitor had broken down. The shop's engineer fitted the first set returned to him with a replacement capacitor of the same working voltage. But, when the vertical fault appeared on a second set several days afterwards he decided to fit a replacement capacitor having a higher working voltage than that installed by the manufacturer. The wisdom of this cautious approach was confirmed when, later, more sets turned up on his bench with short-circuited capacitors. He similarly replaced these with components having a higher working voltage, and the fault never reappeared in the sets with these capacitors.

Now, whenever he handles a TV set of this make and type which is fitted with its original capacitor, the engineer automatically changes it for a higher voltage component *even if the set comes in with an entirely different fault.* This is, surely, a sensible policy, since he is clearing a possible future snag before it occurs. With a small radio and TV business the first essential is to maintain customer goodwill, and owners of television sets are notorious for refusing to accept that a receiver which has just been repaired for one snag can become faulty with a completely different snag at any instant afterwards. Our service engineer made certain that this particular snag wasn't going to occur later with the sets he handled.

It could well be that the reason why the engineer initially encountered the run of faulty receivers was due to fortuitous circumstances at the factory. What might have happened was that a batch of dicey capacitors slipped through on to the line. The first sets encountered by the service engineer had these capacitors

whereupon he then made the incorrect assumption that all the later capacitors were of the same unreliable type, with the result that he was just wasting his time in automatically replacing them. But I'm certain that anybody employed in practical servicing would agree that the engineer's action was a rational one. Provided that the higher voltage capacitors were of the same type and value, the modification could, in any event, cause no foreseeable harm to the receiver.

Another common fault in servicing work is the resistor in a radio or TV set which has shifted value because of overheating. All currents and voltages around the resistor appear to be exactly as they should be, and the only assumptions which can be made are that the resistor was initially faulty in itself, that an intermittent fault which cannot be made to reappear on the bench caused it to overheat, or that the set-maker chose a wattage which was just a little too low for reliable operation in all the receivers in which the resistor was fitted. On first encountering a fault of this nature an engineer would probably replace with a resistor of the same wattage, or he might play safe and replace with one having a higher wattage. If he later encountered the same fault on another receiver of the same make and model he would almost definitely replace with a higher wattage. Again, this is a reasonable modification and the only eventuality of the three just mentioned which may not be covered by using the larger resistor is that the overheating was due to an intermittent fault. But it would be doubtful if a similar intermittent fault would occur on two different sets.

Bad Practice

These two examples are typical of what happens in normal servicing work and are, to my mind, ethically sound. In both cases they protect the customer because the service engineer is giving the product he handles a higher reliability factor than that provided by the manufacturer, without basically changing the manufacturer's performance specification.

Now for two examples of bad practice in making modifications.

One of the worst instances of "servicing" which is morally wrong occurred in a rather ancient mains valve radio I bumped into some years ago. The set had a faulty smoothing capacitor and, when I fitted a new one, gave quite good results with local stations; although it didn't have the overall sensitivity

it should have done. A visual examination soon revealed that a stranger had been added to the set, this consisting of a 10kΩ resistor connected between the screen-grid of the i.f. amplifier and chassis. On removing the resistor the screen-grid took up its correct potential and the i.f. amplifier burst into oscillation. The fault causing the oscillation was an open-circuit bypass capacitor at the upper end of the first i.f. transformer primary. Replacing this cleared the oscillation and enabled the set to work as it was intended to do. But *somebody* in the past had deliberately added that 10kΩ resistor to hold down the i.f. gain and thereby stop the oscillation instead of looking for the actual fault.

When the high g_m frame-grid EF183 and EF184 pentodes made their debut in television receivers, the vision i.f. strips in which they were fitted had a lot more gain per stage than occurred in previous models and were more inclined to become unstable. The consequent "cure" carried out by some people handling these sets was to fit an EF80 (which has the same pinning) in place of the newly introduced valve. The EF80, with its lower gain, caused the instability to disappear, but the receiver was not then working as it should have done either in terms of sensitivity or of vision i.f. response. The correct attack here would have been to find what was causing the instability instead of merely getting rid of it by deliberately degrading the performance of the receiver.

These four examples are all cases of modification to the manufacturer's product. Two are obviously good and two are obviously bad; and any service engineer with the slightest pride in his work would avoid carrying out "repairs" similar to the bad examples.

But there are borderline cases. What happens, for instance, when you get a picture on a monochrome TV set which suffers from slight pincushion distortion on one side only, the distortion being outside the capabilities of the correcting magnet fitted to the yoke? At the same time, it can be cleared by positioning an *additional* magnet inside the cabinet near the surface of the tube. Provided that the deflection yoke is obviously in good order and that the new magnet can be safely secured in place, I would suggest that the addition of such a magnet is ethically a good thing to do. Quite a few modern TV receivers suffer from very slight

picture shape distortion when they leave the factory and most domestic viewers either accept this or, even, do not realise that the distortion is there. At the same time, if a set-owner who wants an exactly rectangular picture shape can be satisfied with the additional magnet modification, then it would be a reasonable thing to incorporate. Don't, incidentally, start hanging magnets round the tube of a colour receiver!

Or, again, what happens when one finds that a vertical hold control in a multivibrator grid leak circuit only stops the picture from rolling when it is right at the end of its track and is inserting full resistance into circuit? This trouble is probably occurring because the associated valve in the multivibrator happens to have a longer grid base than usual. The valve will be perfectly satisfactory otherwise, so does one insert an extra fixed resistor in series with the control to bring the hold position more central, or does one find a new valve whose grid base enables the hold control to operate normally with the circuit values installed by the manufacturer? Common-sense dictates that the new valve be fitted, even though the old one would give a completely satisfactory performance in another application and only differs from the norm due to a characteristic which is somewhat unpredictable.

Complete Answer

I can see that I haven't been able to give a complete answer to the question with which I started my column this month. Perhaps it is *impossible* to give a hard and fast answer to a question of this nature when it applies to so problematic a subject as the servicing of domestic electronic equipment, with its different manufacturers and their different standards, and with its considerable technical complexity.

It is, then, evident that each case where a modification may be required has to be judged on its own merits. Only a small proportion of receivers require modification along the acceptable lines I've mentioned and it is then up to the service engineer himself to determine whether such a change is justified.

One thing is certain. The man who can make the correct decision in every instance where a modification is required to domestic equipment will be a very competent service engineer indeed.



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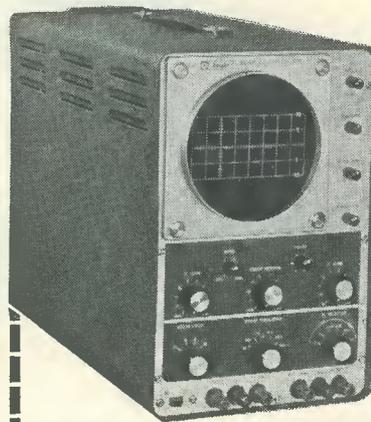
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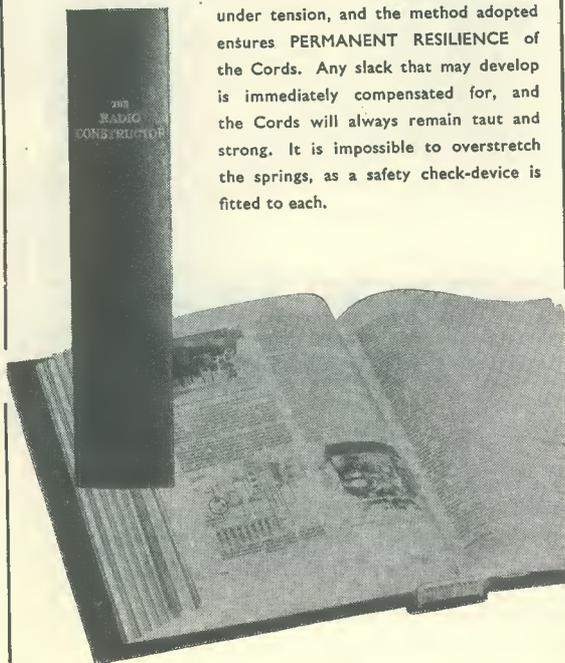
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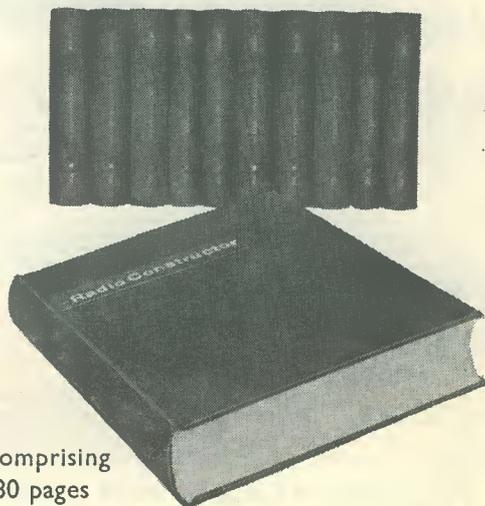
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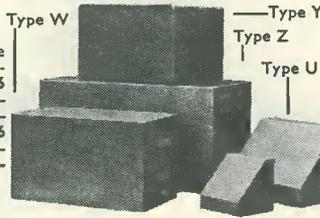
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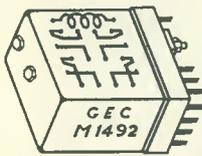
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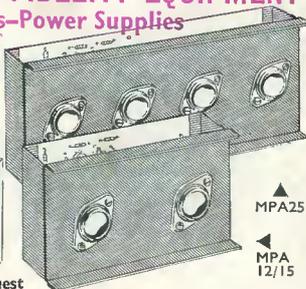
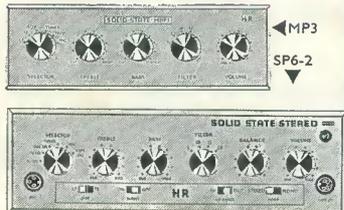
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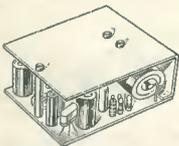
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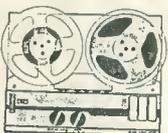
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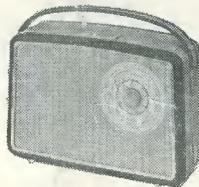
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