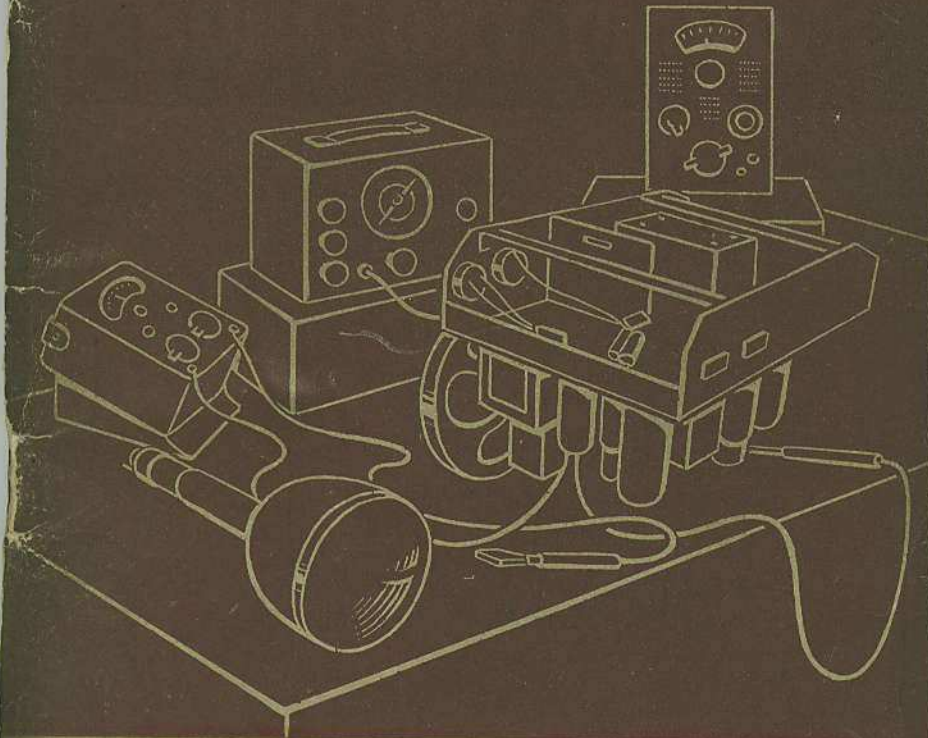


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RADIO & TELEVISION LABORATORY MANUAL

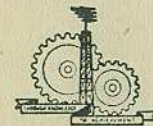


by EDWIN N. BRADLEY

RADIO & TELEVISION
LABORATORY MANUAL

by

EDWIN N. BRADLEY, A.I.P.R.E.



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LABORATORY MANUAL

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RADIO & TELEVISION LABORATORY MANUAL

CHAPTER 1. THE LABORATORY.

The hobby and practice of radio, which has held the attention of so many adherents ever since the inception of broadcasting, has diverged and branched along so many different lines of work and application that it is now practically essential for the home experimenter to specialise. In the broadest possible classification three distinct types of work are outlined; radio service and the repair of receivers, amateur transmission and, finally, development and experimental work. The latter classification is that with which this manual is concerned, though it is hoped that it may prove of interest and value to those engaged in other fields.

The home laboratory has distinct differences from the home repair shop and from the transmitting man's "shack," for the repair shop must of necessity be strictly utilitarian and the shack must be given over to the housing (with possibly the building) and operation of communications equipment. The laboratory, on the other hand, can, and indeed, should be a mixture of both the practical and the imaginative, reflecting as it does the tastes and ideas of its owner, for here are developed and tested the circuits and plans which might arise from no more than a stray thought or a fact observed when carrying out some other type of work.

The laboratory itself must, of course, depend upon the means and circumstances of the owner, but it is to all intents and purposes essential that a room should be set apart for the work and used for nothing else. A boxroom or an attic offer many possibilities whilst failing anything better a cellar might be used; the writer does not favour such a room, however, for the laboratory must be light, airy and dry. It is worth while remembering, too, that radio as a hobby is seasonal, and that the laboratory will be visited in winter much more than in summer. The chosen room should, therefore, be warm and comfortable.

Probably the ideal laboratory is a separate building made of concrete slab, designed from the outset with the one purpose in view, but under present-day conditions the erection of such a structure is an undertaking fraught with difficulties. A good shed may be used, however, in which case every attention must be paid to the weather-proofing of both the roof and the walls, for it need hardly be stressed that dampness is the prime enemy of all types of radio and measuring gear; failing this an empty garage can be pressed into service provided that the end doors are well fitting and draught proof.

With the laboratory space provided, the next point of consideration is the bench accommodation. Bench layout and bench design may depend on the builder's previous experience and the exact type of work in which he is engaged, but the writer finds at least two separate benches essential. Each bench should be at least 2 ft. deep and some-

thing between 2 ft. 3 ins. and 2 ft. 8 ins. in height, to suit the owner, whilst each bench top should be covered with a plain coloured linoleum, if this material is available. Hard plywood may be used as a substitute, and given a double coat of good varnish.

One bench is used as the workbench proper, on which sets and circuits may be constructed, whilst the other bench is the testbench where all measurements and test readings are made. A strict rule should be observed that no constructional work of any sort is carried out on the testbench which is reserved for such operations as alignments, oscillograph observations and the like. Naturally, various units will have to be connected together and different pieces of apparatus assembled into a complete circuit on this bench, but only completed gear should be found on its surface.

If space allows, a third bench is extremely useful for test equipment storage. In a large laboratory this third bench might well be a trolley bearing the signal generator, audio generator, etc., but in a small laboratory the trolley is not necessary, and indeed, takes up too much space required by the worker. If the third bench is ruled out on account of lack of room the test equipment should be stored on a stout shelf above the testbench, or the bench may itself have a "super-structure" designed to hold both the test gear and, possibly, books of reference for which some space should certainly be provided.

Below each bench should be at least one shelf for the storage of tools or apparatus, and the bench ends may be fitted with a set of shelves or sliding drawers. The working area of the bench, however, should have adequate knee room below the top surface, for, sitting "clear" of a bench which has no knee room is very fatiguing.

For seating, a laboratory stool should be used, or a "commercial" type chair with thin steel legs and back support with a fibre seat and backrest. Whatever type of seat is used it will inevitably be in the way and will be moved a great deal. A wooden chair is both too large and too heavy for convenience.

The tools used on the workbench require some sort of housing or mounting and a rack, as used by a carpenter, is in the writer's opinion far from ideal for the smaller and lighter tools used in radio construction. A bench drawer, divided into sections by cross pieces, has been found convenient, one section holding pliers, another screwdrivers, and so on. Larger tools such as a wheel brace might be rackmounted, but in the writer's laboratory all tools are stored in drawers and some effort is made to drill all holes, tap all threads, etc., at one time, so that tools are replaced immediately they are finished with.

Tools, like reference books, are best collected over a period of time, gaps in the collection being filled in as they are discovered. Indeed, it is presumed here that the laboratory builder or owner has already a good variety of both tools and books—the need or desire for the laboratory would probably not otherwise have arisen—so that no list of tools is given here.

Lighting and power supplies are of great importance in the smooth

running of the laboratory. Daylight cannot be relied upon since the room will be used at all times and throughout the winter especially, and whilst a good window should overlook the testbench at least both benches should be fitted with the best possible lighting. Here again the question of expense arises, but a proprietary bench light, such as a Terry Anglepoise, pays for itself in terms of saved time, saved temper and the convenience of a lamp which can be directed to light up any nook and cranny. An Anglepoise light on each bench would be ideal, but a single lamp which can be readily transferred from one bench to the other is easier on the pocket.

Besides the bench light a good general room light is also a necessity. After working for some time in the concentrated light of a bench lamp it will be found that the rest of the laboratory appears very gloomy and poorly illuminated unless a good top or ceiling light can be switched on. Here again "commercial" equipment is recommended, the ceiling light being fitted with a factory type of shade enamelled green on the outside and white within. Such a shade gives good light distribution without glare, whilst all the light is directed downwards.

For general bench illumination some workers may consider fitting a fluorescent tube, but this must be a matter of opinion. The writer finds such a light trying to the eyes and inadequate for fine work but there is no doubt that other workers find such a lamp ideal. After the initial cost the running expenses are, of course, very low, but no lower than those of a 60 watt bulb in an Anglepoise lamp, the arrangement used by the author for all work. Incidentally the degree of concentration which can be attained by working in a pool of light surrounded by shadow is quite remarkable.

Each bench should be fitted with a number of mains supply points. The points may be mounted either at the rear of the bench or just below the front edge; possibly points at both positions will be found most convenient. The soldering iron on the workbench should have a front edge supply point, and the iron itself should have a substantial rest which conducts heat away from the tip when the iron is not in use. A very convenient rest can be fashioned from a deep loop of perforated iron or copper sheet or from copper mesh, the loop being screwed to the underside of the bench to the right-hand side of the working position thus forming a cradle for the iron, removing it and its lead from the bench surface and preventing its overheating.

Such a cradle is shown in Fig. 2. In Fig. 1 is shown a design for the testbench, with test equipment and reference book space.

No matter how many points are supplied on each bench, it is a sensible plan to have each one controlled by its own switch, with the bench as a whole isolated from the mains supply by an iron-clad switch and fuse box. This box will contain a double pole switch; if the smaller switches on the distribution points are single pole switches care must be taken to ensure that the switch is in the "live" line and not in the neutral lead, assuming an A.C. supply. On D.C. supply, the switch must also be in the "live" line and not in the earthed line.

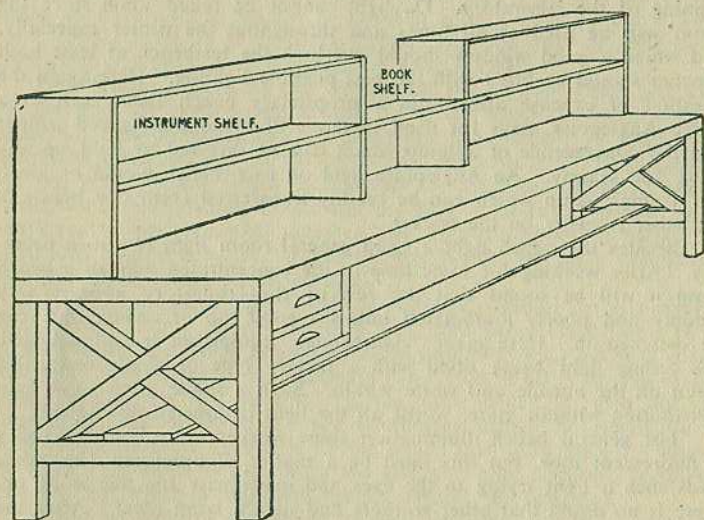


Fig. 1. The Workbench.

All bench wiring must be shielded and run through an earthed conduit. The use of lead-covered cable is satisfactory if the cable is run below and to the rear of the bench, so that the covering cannot be damaged in any way, and if all the cable runs have their lead sheaths well bonded together and directly earthed, but a proper steel conduit is better if the materials can be found.

Besides an array of mains supply points on each bench it is very desirable to bring out a smoothed power supply of, say, 350 volts at 100 mAs. or more, together with heater supplies of 2-0-2 and 3-0-3 volts for 4 and 6-volt heater valves. The writer has found such an arrangement indispensable. With power directly to hand the construction and testing of temporary experimental equipment becomes a matter of minutes—chassis space is saved and the weight of the transformer and choke is avoided—whilst, if different pieces of gear are supplied at one time from the main bench supply only the simplest decoupling is needed, generally, to prevent interaction.

The main supply should be robustly constructed using the best materials, and the transformer should be chosen to give generous output at both heater voltages. The provision of both 4 and 6-volts heater lines is no problem since universal transformers are now widely available. All the wiring to the bench outlet points from the power pack must be well insulated and of heavy cable so that voltage drop is avoided—this is of especial importance so far as the low voltage lines

are concerned—and two complete points on each bench are not too many. By a complete point is meant a socket or other connecting device from which may be drawn either heater voltage and the H.T. supply. Octal sockets with octal plug connectors on the gear are suitable, or Jones' plugs may be used, with Jones' sockets on the bench.

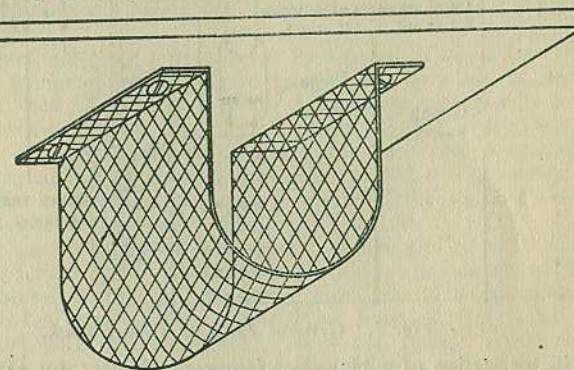


Fig. 2. The Soldering Iron Cradle.

The most suitable position for the power supplies is found to be at the rear of the bench. The power supply itself may be placed beneath the testbench, and is best shielded completely in a metal case with good ventilation. The main on-off switch may be on the front edge of the testbench but a main on-off switch on each bench, the switches being connected in parallel or as a three-wire two-way switch combination, is ideal. In this case a main power supply switch is immediately to hand at either bench in the event of accident or a false connection.

The power supply itself should be fused, the fuse being connected between the centre tap of the mains transformer H.T. secondary and the chassis or earth connection of the pack. The fuse then carries all the H.T. current and protects both the transformer and the rectifier valve from short circuits both in the external circuits and in the pack itself such as might occur if a smoothing or reservoir capacitor were to fail.

A suggested power pack circuit is shown in Fig. 3, and it will be seen that a heavy bleeder resistance is connected directly across the H.T. terminals. This assists the pack regulation and provides a load when apparatus under test is switched off or disconnected without the main power switch being thrown.

Voltage regulation on the power supply would be an added improvement, but since the pack must be capable of working at all loads from full to zero load (apart from the bleeder), the fitting of automatic regulation is difficult and has not been attempted. It is, perhaps, more satisfactory to build regulation into gear where it is needed—in the

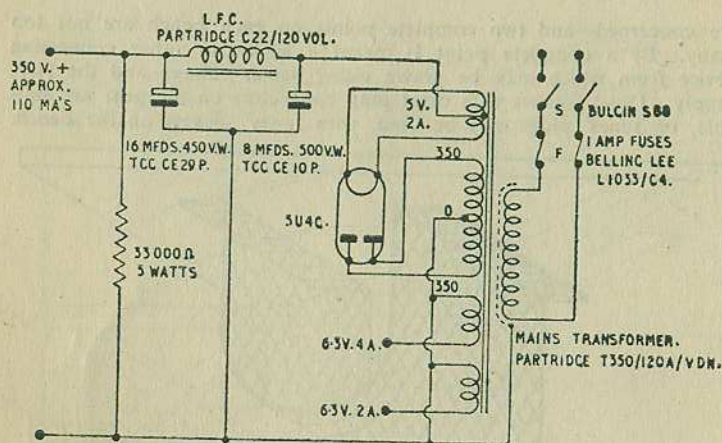


Fig. 3. General Purpose Power Pack.

oscillator section of a high-class frequency changer, for example—using neon regulators.

Each bench, besides the mains power and smoothed and heater power supplies, will need a separate earth point or points, taken to a buried earth plate, and aerial points. The aerial or aeriels will depend entirely on the type of work to be carried out—broadcast, short wave or very high frequency operation, for example—and the space available for their erection. In general a good broadcast type aerial and a television aerial with reflector are very useful and the television aerial will also serve for work on the 5 and 10 metres band although a properly cut and erected short aerial for general coverage is to be preferred.

The aerial down-leads should all be screened and noise eliminating systems are an advantage, whilst the leads within the laboratory should be as short and direct as possible.

No laboratory can have too much storage space, for no matter how empty the shelves are when the room is first put into use there will inevitably be an accumulation of gear and component stocks which all too easily can fall into disarray. At least one large store cupboard should be provided, and shelves earmarked for valves, components, finished assemblies, etc., the smaller components such as resistors and fixed capacitors having sectionalised cases with components grouped according to their values. If a periodic stocktaking is held shortages of the more widely used components can be made up with only a small outlay. No matter how small and unpretentious the laboratory may be, neat and tidy component storage assists the work immensely, whilst no work at all can be accomplished without a reasonably good stock of the basic resistors and capacitors, and a study of the small advertisements in the monthly radio press is always worth while. New

stock only should be purchased, used surplus components are always unsatisfactory in the long run.

The shelves above the benches, also providing storage space, should be reserved for larger finished articles, and it is a wise plan to cover each shelf and also to fit hinged or sliding doors so that the shelves are in effect also small cupboards. This will exclude dust and give a neat appearance.

The shelves above the testbench can be adapted, if desired, to hold standard test equipment which can be coupled into gear on the bench by leads. A shelf mounted bridge for resistance measurements is of great value, whilst the laboratory amplifier can also be shelf-mounted. The standard receiver, which should preferably be of the communications type, may also be mounted above bench level but a good deal of convenience is sacrificed thereby and a space on the testbench or a special receiver table is a better site for this article.

At least one really good loudspeaker should be mounted on a baffle and mounted above bench level, and if a permanent magnet speaker is chosen, so that no energising power has to be supplied to the field, speaker input sockets can also be mounted at the rear of both the workbench and testbench. A single output transformer mounted beside the speaker can have leads from a tapped primary brought to small sockets so that a number of ratios and provision for push-pull inputs are provided, but it must not be forgotten that there is a possibility of feedback between these cables and the grid circuits of associated gear so that shielded cable must be used. Long cable runs will have an effect on tone, also, and it is, therefore, suggested that this type of speaker installation is first investigated as a temporary arrangement.

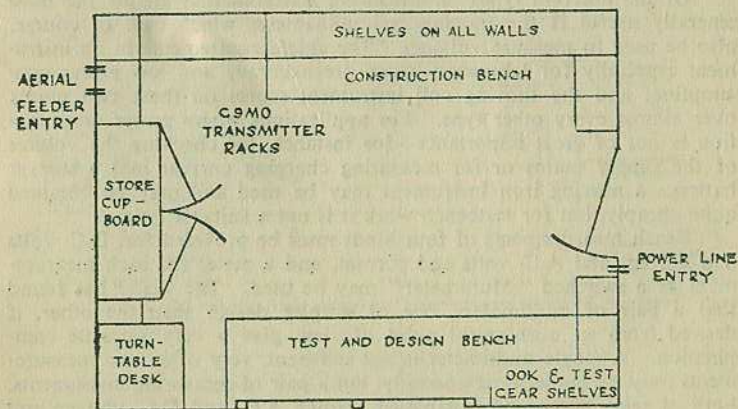


Fig. 4. The Author's Laboratory Layout.

The loudspeaker response in the laboratory will appear different from that obtained in a living room because of the very considerable difference in furnishings, so that for best results a good deal of experimental work in speaker positioning will be needed. A corner baffle is often found to be as good a mounting as any, and has the added advantage that the loudspeaker is taking up as little useful space as possible.

In Fig. 4 the author's laboratory layout is shown. The structure is of concrete block with a wall board lining to prevent condensation. Power and aerial lead-in conduits were planned with the structure and built in.

CHAPTER 2. TEST EQUIPMENT, Part I. GENERAL RADIO TEST GEAR.

As important as the laboratory itself is the test equipment and apparatus which it is to contain, and with which the experimental gear will be aligned and checked. Probably few home laboratories are as well equipped as their owners would desire, but given some basic articles of test gear, further equipment can be built in the workshop section of the laboratory itself.

The exact types of test gear required depend to some extent on the interests of the individual worker—the quality reproduction enthusiast will have little use for a very high frequency oscillator, for example—so that test equipment is considered under three headings: general radio test gear, television test gear and v.h.f. test gear. The second and third types of gear may be regarded as in some respects complementary, and the first heading, general radio test gear, may be further divided into sub-headings, the first of which is:

ELECTRICAL MEASUREMENTS.

Of the different types of measuring instruments available the most generally useful is the moving coil milliammeter which can, of course, also be used to measure voltages. The chief requirements in an instrument especially for laboratory work are accuracy and low power consumption, and the moving coil instrument scores on these two points over almost every other type. For applications where power consumption is not of great importance—for instance, for checking the voltage of the supply mains or for measuring charging current into a storage battery—a moving iron instrument may be used and may be obtained quite cheaply, but for testbench work it is not a suitable type.

Bench measurements of four kinds must be provided for, D.C. volts and current and A.C. volts and current, and a meter for each measurement or a switched "Multimeter" may be used. The writer has found that a pair of multimeters, one of simpler design than the other, if desired from an economical point of view, give a very versatile combination. A single multimeter is not sufficient, very often two measurements must be made simultaneously, but a pair of measuring instruments, both of wide range and capable of reading A.C. and D.C. voltage and current, should handle every requirement that arises. A multimeter and a valve voltmeter are also a good combination.

It is sometimes thought that a multimeter, by reason of its design, is less accurate than a single range instrument. This is not the case: some commercial multimeters are perhaps less accurate than might be desirable in order to assist their mass production, but a reputable or a carefully constructed home-made multimeter can have an accuracy of 1 per cent. and better, depending on the basic moving coil meter used and the accuracy of the resistors incorporated in the circuit.

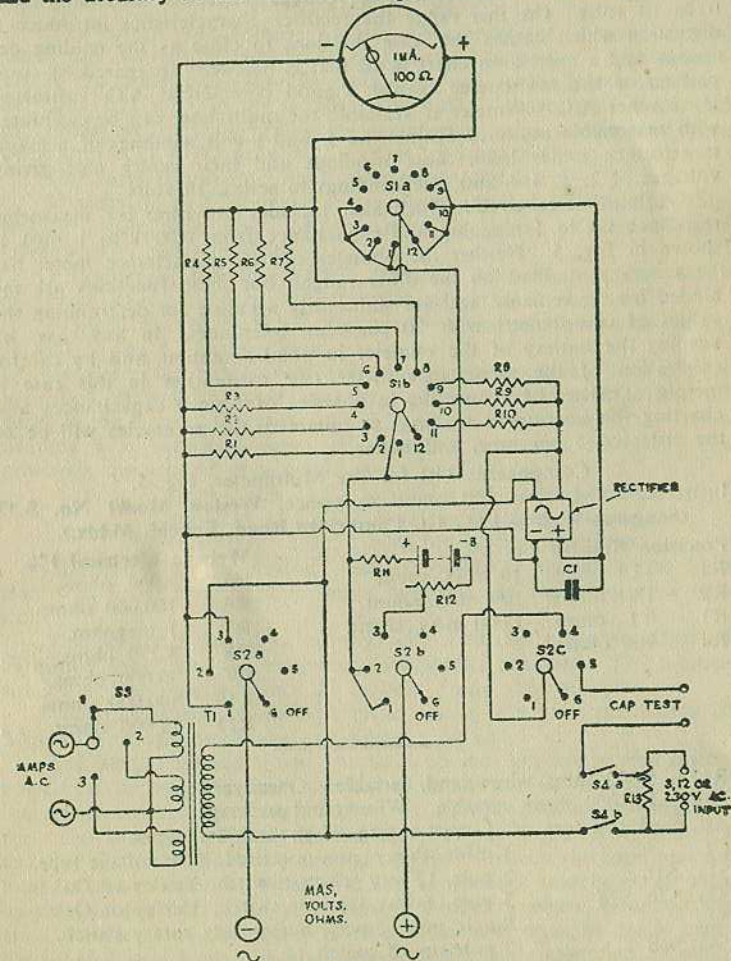


Fig. 5. The Multimeter.

A.C. instruments can never be as accurate as D.C. gear, but an accuracy of 2 per cent. on voltage measurements and better than 2 per cent. on current measurements is attainable. Again, the construction of a multimeter is often not undertaken by the amateur because of the mistaken idea that a considerable amount of range calibration is necessary. The only calibration which has to be made on practically any multimeter is that of the lowest A.C. voltage range, conventionally from 0 to 10 volts. On this range the rectifier characteristics introduce a distortion which causes the scale divisions to close as the reading decreases and a correction chart is all that is necessary, prepared by comparison of the multimeter against a good commercial A.C. voltmeter. If no other A.C. voltmeter is available the multimeter can be calibrated with reasonable accuracy against the 4- and 6-volt windings of a mains transformer under load, these windings and their centre taps giving voltages of 2, 3, 4, 6 and, the windings in series, 10 volts.

A multimeter circuit which also includes provision for measuring resistance up to 1 megohm and capacitance from 0.0001 to 1 mfd. is shown in Fig. 5. Neither the ohmeter nor the capacitance meter has the accuracy attained on the other ranges, but these functions are included for convenience and are sufficiently accurate for determining the values of components with 20 per cent. tolerances. In any case, by keeping the battery of the ohmeter in good condition, and by careful calibration of the capacitance meter (the calibration in this case is merely a matter of connecting in a series of known capacitances and charting the instrument readings so obtained) the accuracies will be of the order of 5 per cent. and better.

Components List for the Multimeter, Fig. 5.
Instrument, 0.1 mA, 100 ohms resistance, **Weston Model No. S.37**
(Sangamo-Weston Ltd., Gt. Cambridge Road, Enfield, Mddx.)

Precision Resistor Co. 1%.		Welwyn Electrical 1%.	
R1	11.1 ohms. 10 mAs. shunt.	R5	9,900 ohms.
R2	1.01 ohms. 100 mAs. shunt.	R6	100,000 ohms.
R3	0.1 ohms. 1,000 mAs. shunt.	R7	1 megohm.
R4	900 ohms.	R8	8,250 ohms.
		R9	90,000 ohms.
		R10	900,000 ohms.
		R11	12,000 ohms.

R12 5,000 ohms. wirewound, variable. Ohms zero set.

R13 100,000 ohms. variable. Wirewound preferred.

All fixed resistors of 1 watt rating, High Stability types.

C1 4 mfd. Paper, non-polarised. Low voltage type.

S1a, S1b 2 pole, 12-way selector switch, Yaxley or Oak.

S2a, S2b, S2c 3 pole, 6-way selector switch, Yaxley or Oak.

S3 Single pole, 3-way, heavy duty rotary switch.

S4a, S4b 2 pole on-off switch.

Rectifier Westinghouse 1mA. Instrument Rectifier.

B 13.5 volt battery. (3 flat batteries in series).

T1 A.C. Transformer. See below.

4 Heavy duty input terminals.

4 Light duty input terminals.

5 control knobs for S1, S2, S3, R12, R13.

Test prods or clips.

Wire, sleeving, battery clips, etc.

DETAILS OF T1.

The current transformer T1 has three primaries, through one of which the alternating current to be measured is passed. The secondary of the transformer supplies up to 1.11 mA to the instrument rectifier (with 1.11 mAs. in the rectifier gives a D.C. output of 1 mA.), and the ratios are so chosen that the transformer suits currents of from 0.0.1 amp A.C., 0.0.5 amp A.C. and 0.2.5 amps A.C.

The parts required to build the transformer are:—

33 pairs of 70-T Mumetal laminations, obtainable from The Telegraph Construction and Maintenance Co., Ltd., Telcon Works, Greenwich, London, S.E.10.

1 Former or bobbin, 70-FSC., from W. Bryan Savage, Ltd., Westmoreland Road, London, N.W.9. (Centre partition removed.)

About 2 ozs. of 36 D.S.C. Copper Wire and small amounts of 28, 18 and 12 D.C.C. Copper Wire.

Reinforce the bobbin with temporary wooden cheeks secured by a long bolt through the core aperture and wind on in neat layers, 100 turns to the layer, 2,190 turns of the 36 D.S.C. wire, covering the whole winding with varnished paper or a similar protective material. The primaries are wound in a single layer, side by side.

25 turns of 28 D.C.C. wire for 0.1 amp. primary.

5 turns of 18 D.C.C. wire for 0.5 amp. primary.

1 turn of 12 D.C.C. wire for 2.5 amps. primary.

The single turn to be exact must be wound as shown in Fig. 6, its start and finish being tied or taped together and led away as a twin lead.

The primaries should be covered with a further protective layer of varnished paper, and the temporary end cheeks removed. The laminations are then inserted into the bobbin from alternate ends.

The transformer details here given are by the kind permission of Messrs. Westinghouse Brake and Signal Co., Ltd.

The whole multimeter may be built up into any convenient instrument case or box and since the layout details can be adjusted to suit individual circumstances no diagram is shown. During construction the chief care needed is in the soldering of the 1 per cent. resistors, and the wire ends should be gripped by pliers between the joint and the body of the resistor in order that the component undergoes as little heating as possible. The same care is necessary when mounting the 1mA. rectifier, and the joints to this component must be made using the braided wire leads already attached. The leads identified by white spots are the A.C. input leads, the positive and negative D.C. output

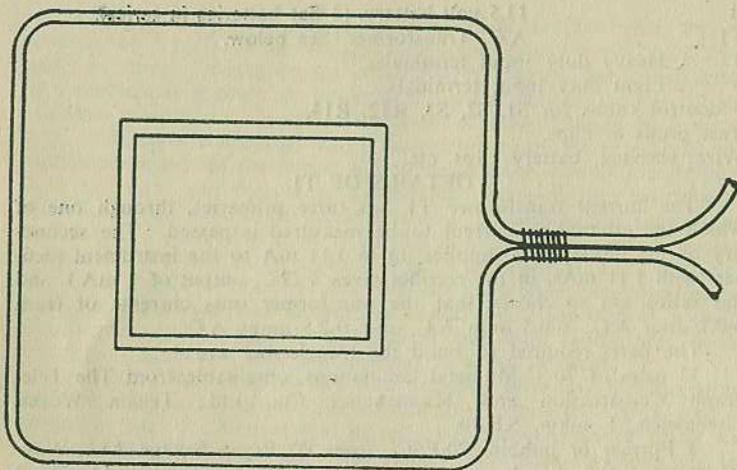


Fig. 6. Securing the Single Turn on the Current Transformer.

leads being identified by red and black spots respectively. Should one of the braided leads be broken it CANNOT be resoldered to its lug without ruining the rectifier.

The rectifier is mounted on a long 6 B.A. bolt which can be threaded into the rear of the panel.

The switches should be coded as follows:—

CODING ON S1.

Position 1.	1 mA. D.C. and Ohms.
Position 2.	10 mAs. D.C.
Position 3.	100 mAs. D.C.
Position 4.	1,000 mAs. D.C.
Position 5.	1 volt D.C.
Position 6.	10 volts D.C.
Position 7.	100 volts D.C.
Position 8.	1,000 volts D.C.
Position 9.	10 volts A.C.
Position 10.	100 volts A.C.
Position 11.	1,000 volts A.C.
Position 12.	AMPS. A.C. and CAP. TEST.

CODING ON S2.

Position 1.	mAs. and Volts D.C.
Position 2.	Volts A.C.
Position 3.	Ohms.
Position 4.	Amps. A.C.
Position 5.	Cap. Test.
Position 6.	OFF.

CODING ON S3.

Position 1.	0.1 amp. A.C.
Position 2.	0.5 amp. A.C.
Position 3.	2.5 amps. A.C.

CODING ON S4.

Cap. Test.	On-Off.
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The 18 ranges of the instrument, with the correct switch settings and working arrangements for each range are as follows:—

D.C. MEASUREMENTS.

1.	0-1 mA. D.C.	S1, Position 1.	S2, Position 1.
2.	0-10 mAs. D.C.	S1, " 2.	S2, " 1.
3.	0-100 mAs. D.C.	S1, " 3.	S2, " 1.
4.	0-1 amp. D.C.	S1, " 4.	S2, " 1.
5.	0-1 volt D.C.	S1, " 5.	S2, " 1.
6.	0-10 volts D.C.	S1, " 6.	S2, " 1.
7.	0-100 volts D.C.	S1, " 7.	S2, " 1.
8.	0-1,000 volts D.C.	S1, " 8.	S2, " 1.

A.C. VOLTS MEASUREMENTS.

9.	0-10 volts A.C.	S1, Position 9.	S2, Position 2.
10.	0-100 volts A.C.	S1, " 10.	S2, " 2.
11.	0-1,000 volts A.C.	S1, " 11.	S2, " 2.

A.C. AMPS. MEASUREMENTS.

For following ranges, set S1 at position 12, and S2 at position 4.

Select amps. ranges with S3.

12.	0-0.1 amp. A.C.	S3, Position 1.
13.	0-0.5 amps. A.C.	S3, " 2.
14.	0-2.5 amps. A.C.	S3, " 3.

RESISTANCE MEASUREMENTS.

15. 0-1 megohm. S1, Position 1. S2, Position 3.
Set the ohmmeter to zero by short-circuiting the main input terminals and rotating R12 until the meter shows the full scale reading. Connect the unknown resistance in place of the short-circuit, when the meter reading will fall, and either read off the resistance from the conversion chart of Fig. 7 or calculate from the formula

$$\text{Ohms} = \frac{13,500}{I} - 13,500$$

where I is the current reading on the 0-1 mA. scale.

CAPACITANCE MEASUREMENTS.

For all capacitance measurements ensure, before switching on, that R13 is turned to the off position, i.e., with the slider, as shown in the diagram, at the lower end of the resistance so that no voltage is applied across the two sections of S4.

Connect in to the voltage terminals, either 3, 12 or 230 volts A.C. according to the desired measurements range, obtaining these voltages from the centre tap of a 6-volt heater winding for 3 volts, from two 6-volt heater windings in series for 12 volts, using a small mains trans-

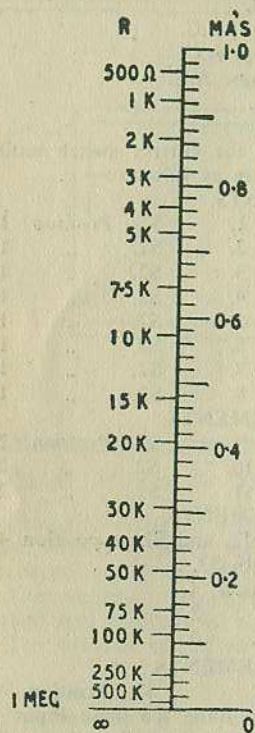


Fig. 7. Conversion Chart, mAs on scale to Ohms.

former. The 230 volts A.C. is, of course, supplied direct from the mains.

Turn S1 to position 12, and S2 to position 5.

Connect the unknown capacitance across the "Cap. Test" terminals. The component should previously have been tested for short-circuits. Electrolytic or leaky capacitors may not be tested by this method.

Close S4.

Rotate R13 slowly so that the full test voltage is applied across the capacitor and meter. As R13 is opened, the meter reading will rise from zero to some position on the scale determined by the capacitance, since the capacitor is acting as an impedance and its value is actually being measured in terms of impedance.

When the reading is taken, close down R13 until it is completely in its former OFF position. Open S4. Remove the capacitor under test.

Should there be no guide at all to the likely capacitance to be expected, commence by measuring on the highest range, increasing the meter sensitivity if the reading is too low.

- | | | |
|-----|-------------------------|-----------------------|
| 16. | 0.0001 mfd. — 0.01 mfd. | 230 volts A.C. input. |
| 17. | 0.01 mfd. — 0.1 mfd. | 12 volts A.C. input. |
| 18. | 0.1 mfd. — 1 mfd. | 3 volts A.C. input. |

To calibrate the capacitance ranges, make the tests as described using known values of capacitance, of the orders of 0.0001, 0.0005, 0.001, 0.005, 0.01, 0.05, 0.1, 0.5, 1 mfd. and so on, noting the meter reading for each capacitance in its correct range and making a conversion chart accordingly. Unknown capacitances may then be read off from the chart.

USE OF THE MULTIMETER.

Some precautions must be taken when using the multimeter. For example, the range switches must ALWAYS be checked for correct settings before the instrument is connected into circuit, and particular care should always be taken to ensure that the rectifier is never overloaded.

NEVER apply A.C. to T1 unless all the range switches are correctly set for A.C. amps. measurements, otherwise the secondary of the transformer will be unloaded and the calibration of the transformer will be ruined even though there is no physical sign of damage.

NEVER make a capacitance test without ensuring that R13 is turned off. If the voltage is applied directly across the test capacitor the resulting surge will almost certainly ruin the rectifier, even though it is protected to some degree by C1 across its output terminals. At the same time, never switch off S4 after a capacitance check without reducing R13 to its zero setting, otherwise there may be a reverse surge from C1.

If these points are observed the multimeter will give good and long service with accuracies of 1 per cent. plus or minus, or better, on D.C., about 2 per cent. on A.C. voltages, 2 per cent. or as good as 0.5 per cent. on A.C. amps. (which are read off the instrument scale and require no calibration) and accuracies depending on circumstances so far as the ohms and capacitance ranges are concerned.

If, as has been advised, two multimeters are constructed, the second instrument may be a replica of the first but this means that both will then have provision for capacitance and resistance checking, unnecessarily and uneconomically. The second multimeter may have these circuit details omitted, when S2 of Fig. 5 can then be a 3-pole 4-way switch. The leads to point 3 on both S2a and S2b are omitted and the transformer lead to point 4 on S2c is transferred to point 3, the switch being recoded accordingly with position 4 as OFF, and position 3 as amps. A.C.

The multimeter has a sensitivity of 1,000 ohms per volt on D.C., the sensitivity on A.C. being slightly lower. Nevertheless the power consumption is very low, whatever range is being used, and the meter error introduced into most circuits will be practically negligible. Meter

error is worse when making a measurement such as reading the anode voltage in a resistance-capacitance coupled stage, but if the reading is taken with the multimeter switched to the 1,000 volts range the series resistance is then 1 megohm, and the error of little account.

ELECTRICAL MEASUREMENTS AT R.F.

The A.C. volts ranges of the multimeter just described may be taken as fairly accurate up to 10,000 c.p.s. and will give a useful indication up to 100,000 c.p.s., so that the instrument can be used to measure audio voltages providing that a blocking capacitor is used. Such a capacitor is common to several circuits however, notably in output meter connections, and then the impedance of the capacitor, which changes with frequency, introduces an error into the reading.

At higher frequencies the meter error rapidly becomes greater until at a megacycle the reading would be valueless for at that frequency not only would the rectifier introduce error but the resistors themselves would exhibit the commencement of a frequency effect, whilst it is obvious that the transformer used in the measurements of current must be designed for one frequency—in this case, of course, the mains frequency of 50 cycles—and so is of no value for measuring alternating current at other frequencies.

For current measurements at all frequencies the thermo-couple ammeter can be recommended above all other types. It is relatively cheap to purchase and will give accurate readings on both D.C. and A.C. and at frequencies up to the lower radio frequencies. At very high frequencies an error is introduced by the skin effect present on the heated wire, but even so the thermo-couple ammeter is still valuable as an indicator, one example of its uses being the measurement of aerial feeder current when the final value is not so important as a comparative value for different transmitter adjustments.

The excellence of the instrument is only slightly marred by its two disadvantages, namely, that it is easily overloaded and burnt out and that thermo-couple ammeters are bought as essentially single range instruments. Both these disadvantages may be combated by shunting the instrument with a switched shunt, the value of the shunt being determined experimentally to increase the basic range of the instrument by say, 10. Since the shunt resistance will be low and a short length of heavy gauge resistance wire may be used, the shunt inductance will be negligible and the shunt will serve for both D.C. and A.C. measurements.

The instrument is connected in circuit with the shunt switched in, so that the current may be read and the instrument switched to its full sensitivity only when the current value is known to be less than the full current capacity of the meter.

The measurement of R.F. voltages is less easily accomplished, and calls for some form of valve voltmeter. If the voltages are low a simple device such as a slide-back valve-voltmeter may be used, the chief value of this instrument lying in the fact that it can be "made up" in a matter of minutes and needs no calibration since the applied voltage is read in terms of D.C. bias voltage supplied from a battery and measured by a D.C. moving coil voltmeter.

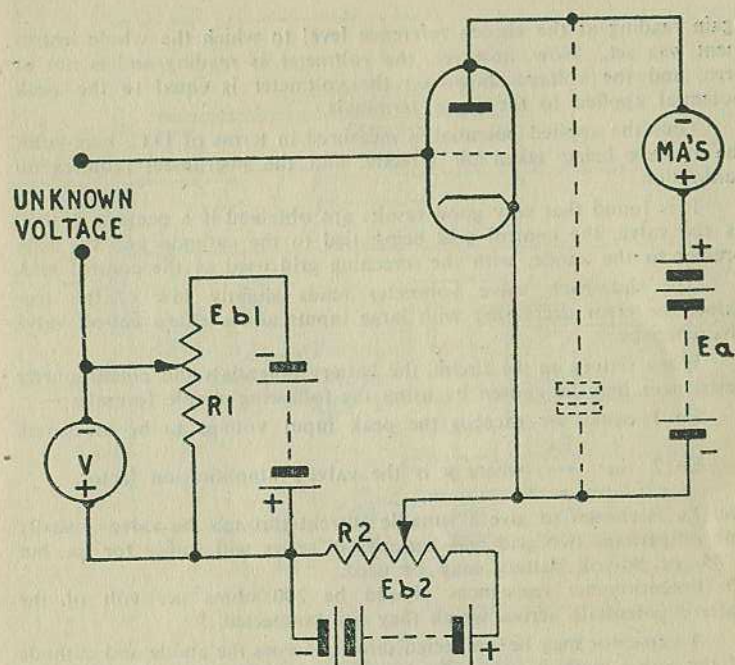


Fig. 8. The Slide-Back Valve Voltmeter.

A typical slide-back valve voltmeter circuit is shown in Fig. 8. In this circuit the valve (which may be practically any triode, either of the mains or battery type), acts as an anode rectifier, set up by short-circuiting the input terminals, adjusting R1 until the voltmeter reads at zero then adjusting R2 to give a small reference current reading on the milliammeter. On a 0.1 mA. instrument the reference current may be 0.05 or 0.1 mA. for A.C. readings.

This reading on the milliammeter in the valve's anode circuit may be imagined as a "false zero" to which the whole instrument is set before a measurement is made.

With the reference or false zero level adjusted, the short-circuit across the input terminals is removed and before any potential is applied to these terminals the bias on the valve is increased from zero to the maximum by rotating R1. Thus the anode current is reduced to a very small amount and the milliammeter will not be overloaded when the potential to be measured is applied.

The terminals are then connected to the source of the potential, and the bias potentiometer, R1, turned back until the milliammeter is

again reading at the chosen reference level to which the whole instrument was set. Now, however, the voltmeter is reading and is not at zero, and the voltage shown on the voltmeter is equal to the peak potential applied to the input terminals.

Thus the applied potential is measured in terms of D.C. bias volts, the reading being taken off directly, and the instrument requires no calibration.

It is found that very good results are obtained if a pentode is used as the valve, the control grid being tied to the cathode and the suppressor to the anode, with the screening grid used as the control grid.

The slide-back valve voltmeter reads slightly low of the true value, the error decreasing with large inputs and a sharp cut-off valve characteristic.

When setting up the circuit, the battery potentials and potentiometer resistances may be chosen by using the following simple formulæ:—

Eb 1 equals or exceeds the peak input voltage to be measured.

Eb 2 = $\frac{Ea}{\mu}$ where μ is the valve's amplification factor.

and Ea is chosen to give a suitable current through the valve—usually one or perhaps two grid bias batteries in series will suffice for Ea, but a 45- or 90-volt battery may be used.

Potentiometer resistances should be 200 ohms per volt of the battery potentials across which they are connected.

A capacitor may be connected directly across the anode and cathode of the valve, with a value of approximately 0.001 mfd. for R.F. and 0.01 for A.C. if found desirable. For the purposes of this manual, the term "A.C." should be taken to mean Audio and Mains frequencies only.

Of greater value than a temporary set-up, however, is a well-built valve voltmeter which is capable of reading over a wide voltage range on D.C., A.C. and R.F. with a diode probe for the latter measurements, and such a circuit is shown in Fig. 9.

Adapting the valve voltmeter to give D.C. readings which can be made on a moving coil instrument may at first appear unnecessary neglecting the fact that two D.C. measuring instruments are desirable but the valve voltmeter has the great advantage of a high input resistance, which is, moreover, constant on all ranges. This is accomplished by using an input "stick" as the range multiplier; applying the potential to be measured across the stick of resistors (the total resistance being of the order of 10 megohms for the majority of valve voltmeters) and tapping the measuring circuit progressively down the stick as the applied potential rises.

The instrument error is thus totally negligible, and the valve voltmeter may be used for such purposes as measuring A.V.C. voltages and bias voltages where a moving coil instrument invariably causes error

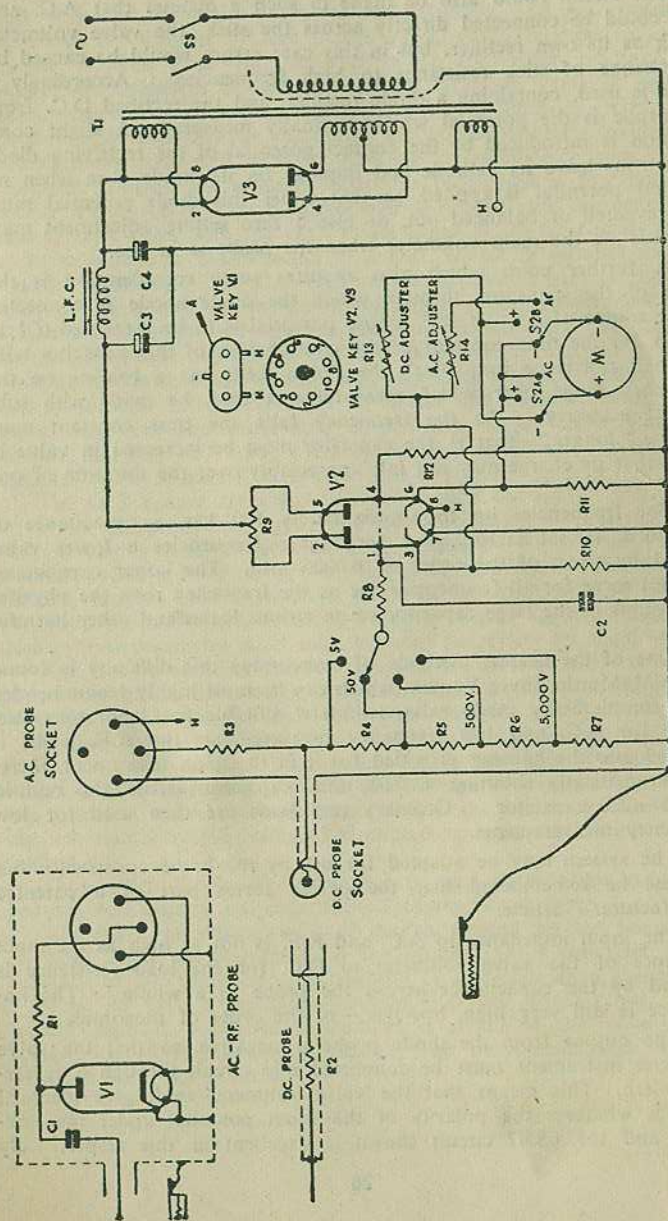


Fig. 9. The Valve Voltmeter.

The circuit could also be made in such a manner that A.C. and R.F. could be connected directly across the stick, the valve voltmeter acting as its own rectifier, but in this case errors would be caused by the change of stick resistance to high frequencies. Accordingly a probe is used, containing a diode rectifier, and the rectified D.C. from the probe is the potential which is finally measured. A slight complication is introduced by the contact potential of the rectifying diode—electrons leave its cathode and impinge on its anode even when no external potential is applied, so that either this diode potential must be prevented or balanced out, or else a zero setting adjustment must be made on the main voltmeter when the probe is in use.

A further point which also requires some consideration is the value of the capacitor through which the diode anode is connected to the source of A.C. or R.F. whose potential is to be measured (C1 in Fig 9), for the time constant of the combination of this capacitor with the load resistance into which the probe feeds has a bearing on the frequency range over which measurements may be made with substantial accuracy. As the frequency falls the time constant must become "longer"—that is, the capacitor must be increased in value in order that its charge may not fall appreciably over the duration of one cycle.

For frequencies up to approximately 100 kcs. a capacitance of 0.05 mfd. is satisfactory, but for higher frequencies a lower value should be used, of the order of 0.0005 mfd. The larger capacitance will not serve for all frequencies for as the frequency rises the physical dimensions of the large capacitor cause serious losses and other harmful effects.

One of the neatest methods of overcoming this difficulty is found in the McMurdo Silver Vomax (which can be most highly recommended as a commercially made valve voltmeter suitable for laboratory use) where for A.C. and low frequency measurements the R.F. probe is plugged into the housing provided for it in the main instrument, thereby automatically shunting a 0.03 mfd. capacitor across the built-in 0.0005 mfd. capacitor. Ordinary test leads are then used for low frequency measurements.

The system may be adapted for use by the home constructor but it must be remembered that the device forms part of a patented manufacturer's article.

The input impedance to A.C. and R.F. is not as high as the input resistance of the valve voltmeter to D.C. for the load resistance is shunted by the capacitance across the probe as a whole. The impedance is still very high, however,—of the order of megohms.

The output from the diode probe is negative, so that the valve voltmeter instrument must be connected into circuit through a reversing switch. This means that the valve voltmeter must give identical readings whatever the polarity of the input potential under measurement, and the 6SN7 circuit shown is excellent in this respect. By

using a double valve the circuit is self-balancing, and gas current in one triode is balanced by that in the other, whilst changes in supply or H.T. voltage have very little effect on the meter reading. By using large resistances in the two cathode lines the valve is working under considerable negative feedback, ensuring linearity, whilst the microammeter can then be connected across the cathodes, calibration controls being connected in series with the microammeter leads. These calibration controls are adjusted when the instrument is first put into service. First, the zero set potentiometer is rotated until the instrument reads at zero, then, with the D.C. range switch set to the correct range, the valve voltmeter is connected to a D.C. source in parallel with an accurate voltmeter. The D.C. calibration control is set to give the correct voltage reading on the microammeter scale, then the valve voltmeter is disconnected and the zero setting inspected. If the calibration adjustment has caused the zero setting to change, the zero set potentiometer must again be adjusted, and the calibration control then checked for the correct reading, the checks and re-adjustments being carried out until the instrument is properly set at zero with no potential applied, and reads correctly in agreement with the standard voltmeter when connected across the test source.

The D.C. ranges are then all in calibration.

When the probe is plugged into its socket, whether it is made for work at low or high frequencies, a correction of the zero set will be necessary on the lower ranges of the valve voltmeter. These ranges will also require correction charts since on low A.C. or R.F. voltages the probe output is not linear, but on the higher voltage ranges the ordinary microammeter scale may be used for direct readings.

The A.C. calibration control is set after the necessary zero correction has been made, using a known A.C. or R.F. voltage in just the same way as for the D.C. calibration control.

To use the valve voltmeter as a milliammeter, the electronic section of the instrument may be disregarded. A further pair of contacts on the microammeter reversing switch are arranged to isolate the instrument from the valve cathodes, connecting it instead across a series of switched shunts whose values are chosen to give the current ranges required.

Thus, when the whole instrument is used to measure current it need not be switched on, since the valves are not working.

The shunt resistances will, of course, depend on the instrument resistance. The microammeter in the original valve voltmeter has a resistance of 800 ohms and the majority of 100 microamp. meters will be found to have a resistance between 500 and 1,000 ohms. If a "round figure" resistance instrument is available the shunts will probably be obtainable commercially. The shunt resistances may be calculated from the formula

$$S = \frac{R}{X - 1}$$

where X is the factor by which the meter range is to be multiplied, R is the resistance of the meter and S is the shunt resistance.

Since the voltage ranges are 5, 50, 500 and 5,000 volts, the current ranges might well be made 5, 50 and 500 mAs. with possibly a heavy shunt for the measurement of 5,000 mAs., i.e. 5 amps. This shunt will, in most cases, be of such low resistance that it will require adjusting experimentally.

The highest voltage range, 5,000 volts, is intended for D.C. operation only. The diode probe cannot be expected to stand up to this high potential, but since the range will chiefly be used for the measurement of E.H.T. power pack voltages such as occur in oscilloscopes and television receivers this is no drawback.

It will be noted that apart from the main resistor range stick part of the input resistance is made up of a 5 megohm resistance mounted within the D.C. probe, and equivalent resistance appearing in the diode probe circuit. This resistance, right at the probe tip, effectively isolates the circuit undergoing measurement from stray and hand capacitances, so that the probe may be applied to the grids of I.F. amplifiers and similar stages with no appreciable effect upon the working conditions.

COMPONENTS LIST FOR THE VALVE VOLTMETER.

Fig. 9.

R1, R2, R3	5 megohms, 1%, high stability.
R4	4.5 megohms, 1%, high stability.
R5	450,000 ohms, 1%, high stability.
R6	45,000 ohms, 1% high stability.
R7	5,000 ohms, 1%, high stability.
R8, R12	470,000 ohms.
R9	100,000 ohms potentiometer. Zero set. Wirewound preferred.
R10, R11	20,000 ohms, 1%, high stability.
R13, R14	20,000 ohms, wirewound, variable.
	A.C. and D.C. calibration controls.
All resistors 1 watt type.	
C1	0.0005 mfd. Ceramic, for R.F. 0.05 mfd. Paper, 1,000 v.w. for A.C.
C2	0.02 mfd. Mica.
C3, C4	8 plus 8 mfd. 450 v.w. Electrolytic.
S1	S.P. 4 way switch, ceramic.
S2a, S2b	2 pole 3-way switch (4-way if current ranges are to be added).
S3	2 pole On-Off switch.
L.F.C.	20 henries L.F. choke. (Resistance smoothing can be used, but choke smoothing is found preferable).
M,	0-100 microamperes, Weston Model No. S.20. (Sangamo-Weston Ltd., Gt. Cambridge Rd., Enfield, Middx.).

T1, 230 volts primary.
300-0-300 volts 60 mAs. secondary
5v. 2a. 6v. 2a.

V1, EA50. Mullard.
V2, 6SN7. V3, 5Y3G.

1 B3G base for V1.

2 International octal chassis mounting v'holders.

3 control knobs, S1, S2, R9.

Chassis, screened cable, material for probe housing, etc. Test probes.

CONSTRUCTION

The layout of the valve voltmeter is by no means critical and the instrument may be built up into any convenient form. The range stick resistors R4 to R7 are best mounted directly onto the ceramic range switch; there is a slight chance of leakage if they are mounted on an ordinary tag or group board.

Screening of the grid lead, where shown in the diagram, is very necessary.

R10 and R11 are shown in the components list as 1% type resistors. The need for accuracy here is not actually as pressing as this might tend to indicate, but if ordinary 20% tolerance resistors are used the balance of the circuit might well be upset, a state of affairs which is reflected into the operation of R9.

The diode probe is built into a cylindrical housing made of wide gauge copper or brass tubing, each end of the housing also being closed by a disc of the same material sweated on, the whole probe case then being at earth potential. The test tip which makes the contact with the test point where the potential is to be measured protrudes through the top cover of the diode probe via an insulating bushing, the twin core shielded cable carrying the output voltage and heater current to the EA50 with the shield covering as the earth return passing through the bottom end plate or cover of the probe housing.

The cable terminates in a 4 pin valve base which may be plugged into a corresponding socket on the valve voltmeter housing. The D.C. test probe also has a shielded lead and probe, the 5 megohm isolating resistance being mounted directly behind the probe tip. The probe body may be made of ebonite tube drilled out to take the resistor, the tip being tapped into the end of the tube. The cable shield should for preference be carried into the body of the probe to prevent any chance of hand capacitance effects which, on the most sensitive range, can be troublesome.

R13 and R14 are chassis mounted and their spindles are not brought out as panel controls since, once adjusted, they are not further required.

THE MEASUREMENTS OF RESISTANCE, CAPACITANCE AND INDUCTANCE.

With the consideration of the measurements of resistance, capacitance and inductance the dividing line between home-made and commercial apparatus is reached. As has been seen, the construction of

gear capable of measuring with accuracy electrical units — volts, milliamperes and amperes—is quite possible and, indeed, simple, given a good basic instrument and well-made stable resistors. The only satisfactory method of measuring the units of resistance capacitance and inductance with real accuracy, however, is by means of a bridge. The Wheatstone's bridge circuit for resistance measurements alone is sufficiently difficult to build if accuracies of 1% and better are required, and when this bridge is developed into a universal type of bridge which is capable of measuring capacitance and inductance as well, the difficulties of calibration and a certain complication in operation are added.

A typical universal bridge circuit is shown in Fig. 10, where the two upper arms are the ratio arms and the decade variable resistance is switched as desired into either the "X" or unknown arm or into the "St" or standard arm. The decade box is the only satisfactory type of variable resistance for this purpose; a rotary variable resistance cannot be calibrated and set at each measurement with the requisite degree of accuracy.

The decade arms may be switched, in which case the switches must be absolutely above suspicion, since in the 0.1 ohm decade poor switch contacts could introduce more resistance into the circuit than the resistors they are controlling, or the arms may be plug selected, where resistances are shorted out of circuit by heavy brass plugs inserted into drilled sockets between brass blocks. To build a decade resistance box with the range shown—0 to 1,111 ohms—would be both difficult and expensive even were resistors of no greater accuracy than 1% to be used whilst this relatively simple bridge leaves a good deal to be desired when used for measuring capacitance, and especially inductance.

To measure resistance, the "St" terminals are shortcircuited and the bridge supplied with D.C. from a battery, the detector switch being thrown to the Galvo side.

The decade switch is thrown to the X side so that the decade box becomes the standard arm, and the ratio arms adjusted to a suitable ratio for the resistance under measurement. The bridge is then balanced, with the unknown resistance connected across the X terminals until the galvanometer shows no deflection when the galvo. key is depressed. The unknown resistance then is

$$X = \text{Ratio} \times R$$

where R is the resistance shown on the decade box. It must be remembered that when the resistance of the left hand ratio arm is greater than that of the right-hand arm the ratio is greater than unity, i.e., it will be 1, 10, 100, etc., but when the right-hand ratio resistance is greater than that of the left-hand arm the ratio will be a fraction, one-tenth, one-hundredth, etc.

To measure capacitance on this bridge the circuit must be powered from an oscillator. A.C. mains may be used, through a step-down transformer, but a higher frequency of the order of 1,000 c.p.s. is preferable. The detector switch is thrown to bring headphones into circuit in place of the galvanometer, and a standard capacitance connected across

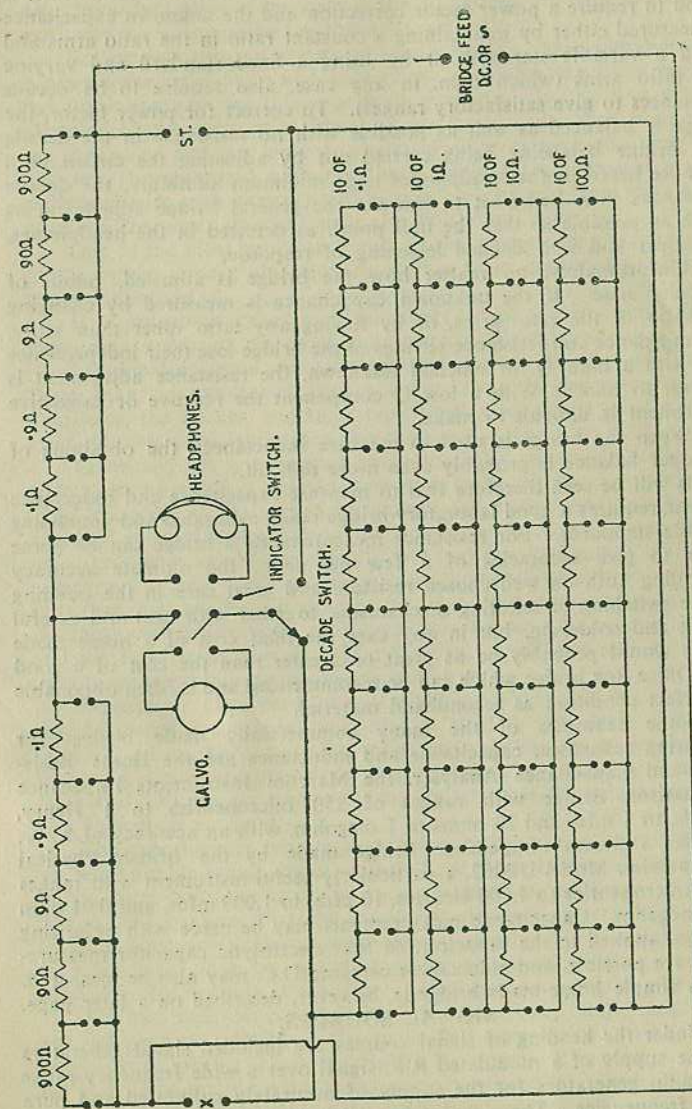


Fig. 10. A Universal Bridge.

the "St" terminals. The decade box is switched into the arm which is found to require a power factor correction and the unknown capacitance is measured either by maintaining a constant ratio in the ratio arms and using a variable standard, or by using a fixed standard and varying the ratio arms (which then, in any case, also require to be decade resistances to give satisfactory ranges). To correct for power factor, the bridge is balanced as well as possible with no resistance in the decade box, bridge balancing being carried out by adjusting the circuit until the note heard in the headphones is at minimum audibility, the decade resistances then being set to sharpen the general bridge adjustment as much as possible so that the null point, as detected in the headphones, is a clear and well defined lessening of response.

Unfortunately, no matter how the bridge is adjusted, points of difficulty arise. If the unknown capacitance is measured by changing the ratio of the ratio arms, or by having any ratio other than unity, the impedance and resistance settings of the bridge lose their independence and with a high Q, or efficient unknown, the resistance adjustment is difficult to make. With a low Q component the reactive or capacitive adjustment is difficult to make.

When the bridge is used to measure inductances, the obtaining of a proper balance is probably even more difficult.

It will be seen therefore that to measure capacitance and inductance at least, requires a good laboratory bridge ready calibrated and containing suitable standards. For resistance measurements a bridge can be home made to give accuracies of a few per cent., the ultimate accuracy depending both on well chosen resistors and great care in the building of the switching or selecting mechanisms, together with neat and careful wiring and soldering, but in any case the final cost of a home made bridge would probably be as great or greater than the cost of a good Post Office Box bridge which can be recommended and is often obtainable in perfect condition as secondhand material.

Some examples of the many commercially made bridges for measuring resistance, capacitance and inductance are the Hunts' Resistance and Capacitance Analyser, the Marconi Instruments Impedance Comparison Bridge with ranges of 250 microhenries to 1 Henry, 20 pfd. to 1 mfd. and 20 ohms to 1 megohm, with an accuracy of 0.2%, and the Universal Impedance Bridge made by the British Physical Laboratories, Model UB202, a particularly useful instrument with ranges of 10 microhenries to 1,000 Henries, 10 pfd. to 1,000 mfd. and 0.01 ohm to 1 megohm. Capacitance measurements may be made with polarising voltages applied to the capacitor, so that electrolytic capacitor measurements are possible, and inductances carrying D.C. may also be measured.

A simple home-made bridge is, however, described on a later page.

SIGNAL SOURCES.

Under the heading of signal sources are included signal generators for the supply of a modulated R.F. signal over a wide frequency range and audio generators for the supply of accurately calibrated and pure audio frequencies. The signal generator may well be described as the

most important piece of test-gear in the laboratory, for little experimental work can be accomplished without its aid.

For receiver repair and general service work a cheap signal generator is often quite satisfactory and, indeed, the apparatus can be home made, but for laboratory use this is scarcely practical. In the first place the shielding of the instrument must be perfect in order that stray signals are eliminated and the input to the receiver or experimental gear under test may be measured with exactitude, whilst the generator must be calibrated with spot accuracy and, if possible, checked from time to time against a frequency standard such as a crystal oscillator.

One of the most important points in the generator is the arrangement of the output circuit; this must be calibrated in microvolts and be true to its calibration.

It is unfortunate that even this short list of requirements rules out more than a few of the cheaper commercial signal generators.

Nevertheless some excellent models are obtainable, and amongst these may be mentioned the Advance Type E generator, the Avo Oscillator, the Hickok generator type 180X, and, in the most expensive class, the Marconi laboratory standard generator.

Practically all good signal generators also act as an audio supply source, giving a 400 cycles signal at an average output of zero to 1 volt. This frequency is the accepted standard for audio tests and for many kinds of work will be all the signal that is required. The experimenter who deals with amplifying circuits and high quality output will require something a good deal more versatile, however, and here again it is felt that his needs will hardly be met by home-made apparatus. Accurate calibration both of frequency and output voltage is necessary and the ideal instrument is a beat frequency oscillator although this is usually an extremely expensive piece of gear.

Perhaps the cheapest source of audio signals is a set of gramophone test frequency recordings such as the H.M.V. set, Nos. DB4033 to DB4037, where both constant tones and gliding tones between wide frequency limits are provided, at special levels. A really good turntable and pick-up are necessary, but in any case the quality enthusiast will have these to hand.

The experimenter who requires a less accurately calibrated but none the less variable signal source will find the Wien bridge oscillator suited to his purpose. The circuit of such an oscillator is shown in Fig. 11, and it will be seen that the oscillator depends on feedback over a variable resistance-capacitance network or bridge for its operation. An amplifier stage may be added if power rather than voltage output is needed as, for example, the testing of loudspeakers over the audio range.

The two controls of the Wien bridge oscillator, R1R2 and R3, are not independent. R1R2 is the main frequency control, with S1 as a range switch, whilst R3 is the feedback control. For purity of output R3 should be no more advanced than is needed to sustain oscillation, when the waveform of the output signal will be quite pure and sinusoidal. Increasing the feedback by advancing R3 further introduces a distortion

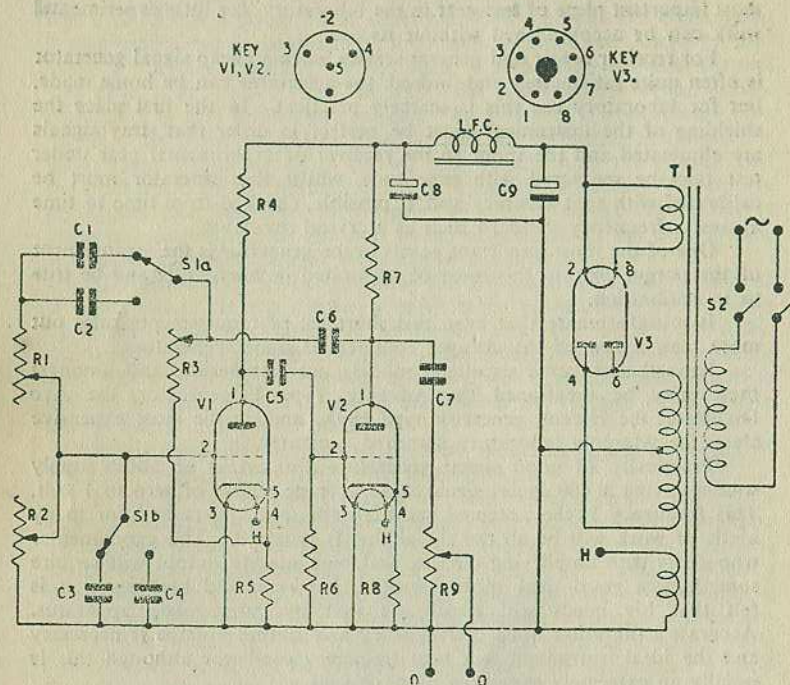


Fig. 11. The Wien Bridge Audio Oscillator.

into the waveshape which finally becomes almost a square wave, whilst at the same time there is a frequency shift. If the oscillator is to be calibrated, therefore, a suitable setting of R3 must be chosen and the instrument calibrated over the range, using as pure an output as possible. This means that R3 will also require a calibration, in that the operating point of this control must be marked.

R1 and R2 are ganged potentiometers, of the type often obtainable from surplus stores and trading houses. If ganged potentiometers are not obtainable it will be necessary to gang two separate 1 megohm potentiometers, using a screwed coupling between their spindles.

A simple attenuator output circuit is shown. A more elaborate circuit might be used but for most applications is unnecessary. If desired the output can be metered by the valve voltmeter.

Any convenient layout may be adopted for the oscillator, the only constructional point requiring attention being the connections to the ganged potentiometers R1, R2. As may be seen the two moving arms are connected directly together; the two connections to the tracks must

be made at the same side of the moving arms. That is, the lead from the chassis to R2 and the lead from C1 and C2 to R1 must go either to the right-hand terminal or to the left-hand terminal in each case. If one lead is taken to the right-hand terminal on one potentiometer and the second lead to the left-hand terminal on the second potentiometer, the frequency variation will become cramped to one end of the rotation of the control.

COMPONENTS LIST FOR THE WIEN BRIDGE AUDIO OSCILLATOR.

Fig. 11.

R1, R2	1 megohm potentiometers, ganged.
R3	0.5 meg., variable, feedback control.
R4, R7	47,000 ohms, 1 watt.
R5, R8	1,000 ohms, $\frac{1}{2}$ watt.
R6	470,000 ohms, $\frac{1}{2}$ watt.
R9	1,000 ohms, variable, output control.
C1, C3	0.0005 mfd., Mica.
C2, C4	0.005 mfd., Mica.
C5, C6	0.1 mfd., 350 v.w., Tubular.
C7	0.01 mfd., 350 v.w., Tubular.
C8, C9	8 plus 8 mfd., 450 v.w., Electrolytic.
S1a, S1b	D.P.D.T. Range Switch.
S2	D.P.S.T. On-Off Switch.
L.F.C.	20 Henries. L.F. Choke.
T1	200-250 volt primary. 250-0-250 v., 60 mAs. 4 v. 2a. 4 v. 2a.
V1, V2	354V. Mullard.
V3	AZ31. "
2	5-pin chassis mounting valve-holders.
1	International octal chassis mounting valve-holder.
Chassis, cover, output sockets, 3 control knobs, etc.	

INDICATORS.

Under the heading of indicators is included gear which is used to demonstrate visually an effect, no matter how the demonstration is accomplished. It might be thought that measuring instruments should also be included in this section, but the writer prefers to separate measuring and indicating instruments. An indicator may, under some conditions, also act as a measuring instrument, however—the oscilloscope may be quoted as an example.

One indicator of considerable use is the centre-zero galvanometer, as used in bridges operated from D.C. supplies. A galvanometer is a useful acquisition if experimental bridges are to be built up or if very low direct-current work of any sort is to be undertaken, and a quite sensitive instrument may be obtained as an ordinary pointer type meter. The Weston range of instruments includes an excellent pointer galvanometer with a sensitivity of 60 microamps per side, the scale being calibrated as 30-0-30. (Weston Model S.20, 2 microamps per division.)

The galvanometer is an indicator rather than a measuring instrument since it is so often used to indicate a null reading—that is, it is incorporated into a circuit which, when balanced, gives no reading on the instrument at all. Here the mirror galvanometer is often used; its sensitivity is very great and since the central or zero reading is the most important reading the instrument is fairly simple to set up. A light source focussed on the mirror and a translucent scale calibrated purely in arbitrary units are all that is required.

One of the most useful of all indicators particularly to the experimenter dealing with transmitters and oscillators of all sizes and powers is the neon lamp. A small flash lamp is often used, connected in series with a loop of wire, to detect R.F. oscillations in a circuit, but appreciable power is required before the lamp will light. A small neon bulb rated at 90 volts or so (such bulbs are often obtainable from surplus war equipment) is an invaluable R.F. indicator since it need only be held in the hand and have one electrode or contact touching the tank coil or any "hot" part of the oscillator, when even very low power oscillators such as the local oscillator of a superhet will cause a glow within the lamp.

The glow due to R.F. is moreover very easily identified. A capacitive coupling can cause the bulb to light when touched to a point of high potential as supplied from the power pack, when the bulb will glow with its ordinary red or pink light, but touching the bulb to a point at R.F. potential will cause it to glow with a bluish-violet light which is quite unmistakable.

The brilliance and extent of the glow within the bulb give some indication of the R.F. power present; an oscillator with an output of well below $\frac{1}{2}$ watt will cause the bulb to glow without any contact being necessary.

Ordinary beehive type neon lamps are less sensitive, but may be used on transmitters and higher powered oscillators, whilst they are also valuable as circuit indicators. A neon bulb connected across the outlet points for the soldering iron, power pack, etc., acts as an excellent pilot light whilst consuming very little power.

Performing, for the audio frequencies, what the neon bulb does at radio frequencies are the ordinary headphones. As straightforward signal tracers for use on any form of apparatus where audio frequencies are present the headphones are unbeatable. A good pair should be obtained and well treated. It is wise to include in one lead a 0.1 mfd. high voltage capacitor, for then the phones may be connected across practically any two points in an amplifier or receiver, etc., without damage.

An excellent indicator which may be used in several different ways is a Magic Eye valve. One method of using the Eye is as a null point indicator in bridges, while simple valve voltmeters may also use an Eye as an indicating device to show balance, the applied voltage being measured in terms of bias fed to the Eye to cause it to close after the applied voltage has caused it to open.

The circuit for a Magic Eye bridge indicator is shown in Fig. 12, together with the bridge connections. A sensitive Eye should of course be used, for which reason the 6E5 is recommended when available, but perhaps even more useful is the Mullard EM34 which has, in effect, two sensitivities since two shadows are produced on the screen, the maximum range of shadow angles being covered by a grid potential range of from zero to -5 volts in one case and zero to -16 volts in the other, the supply voltage being 250.

The EM34 is shown in the diagram.

When a Magic Eye indicator is used the bridge is fed from an A.C. source. In the writer's experiments the best results have been obtained using the mains frequency of 50 cycles, higher frequencies giving a blurring effect. The null setting or balance point of the bridge is shown by the full opening of the Eye—that is, with the shadow at its broadest—the Eye tending to close at either side of the null point. With a suitable voltage fed into the bridge the shadow edges of the Eye are sharply defined at the null point, the edges blurring slightly immediately the balance is upset, so that very sharp indications are possible.

The bridge in which the Magic Eye indicator is shown is suitable for resistance and capacitance measurements, the accuracy of the completed instrument depending to a great extent on the accuracy of the "standards" in the switched arm and on the calibration of the potentiometer which acts as the ratio arms. True precision is not obtained with so simple a bridge, but as a component check it is worth while constructing. A very similar bridge is described by M. G. Scroggie in the "Wireless World," June, 1938.

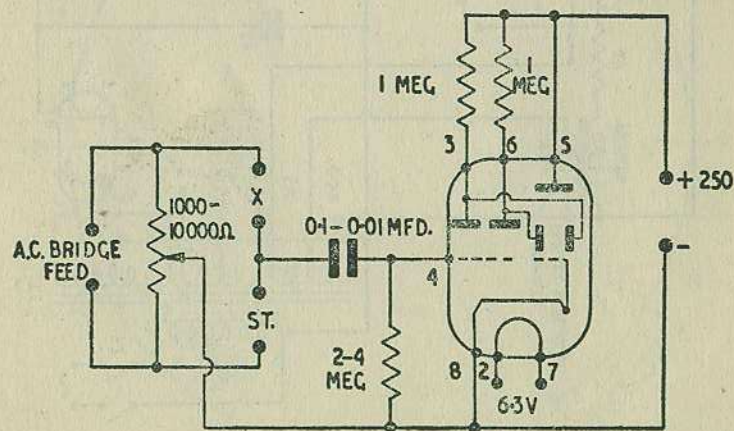


Fig. 12. Basic Magic Eye Bridge Indicator.

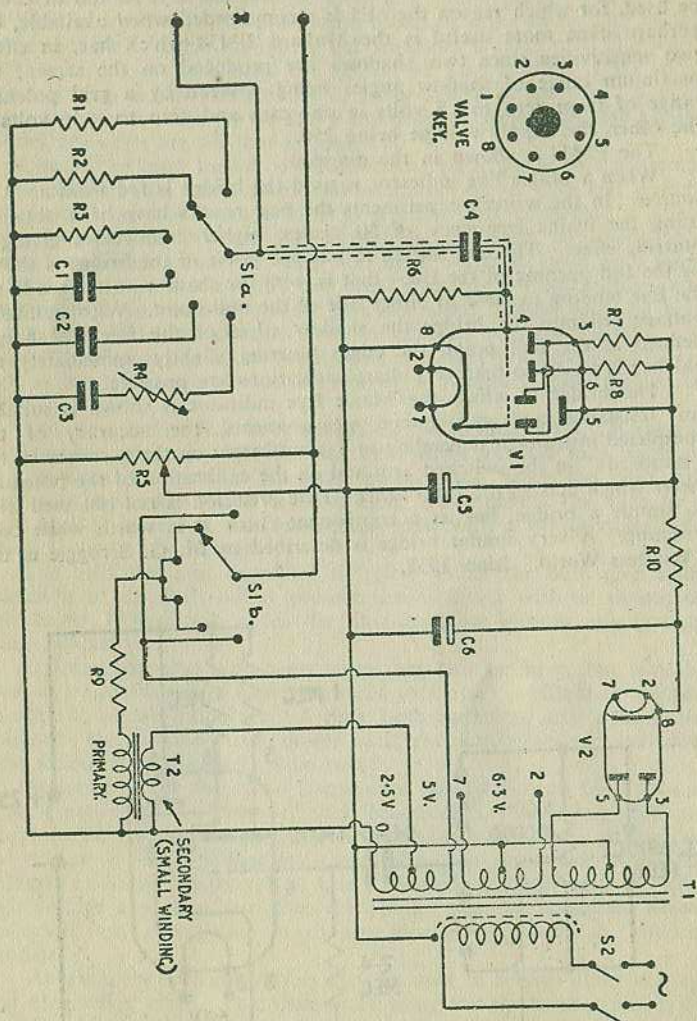


Fig. 13. The Resistance-Capacitance Bridge.

The complete bridge, based on the fundamental circuit shown in Fig. 12, is illustrated in Fig. 13. A set of standards are switched into circuit as desired, this switch being coded as 100, 10,000 and 1,000,000 ohms, 0.0001, 0.01 and 1 mfd. The potentiometer is calibrated in terms of ratios, so that if a resistance is being measured and the Eye shows balance with the range switch set to 10,000 ohms and the Ratio arms set to a ratio of 0.4 the final resistance is obviously $10,000 \times 0.4$ or 4,000 ohms.

Similarly if an unknown capacitance gave balance with the range switch on 0.0001 mfd. and the Ratio arms at 3.0 the value of the capacitance would be 0.0003 mfd.

Electrolytic capacitors may be measured on the bridge and power factors also measured by a direct reading for which R4 is calibrated. Power factors may be measured from about 0.1 mfd. upwards, over the useful range, zero to 60%.

The sort of calibration to be expected for a good potentiometer is shown in Fig. 14. The bridge is calibrated on the lowest range.

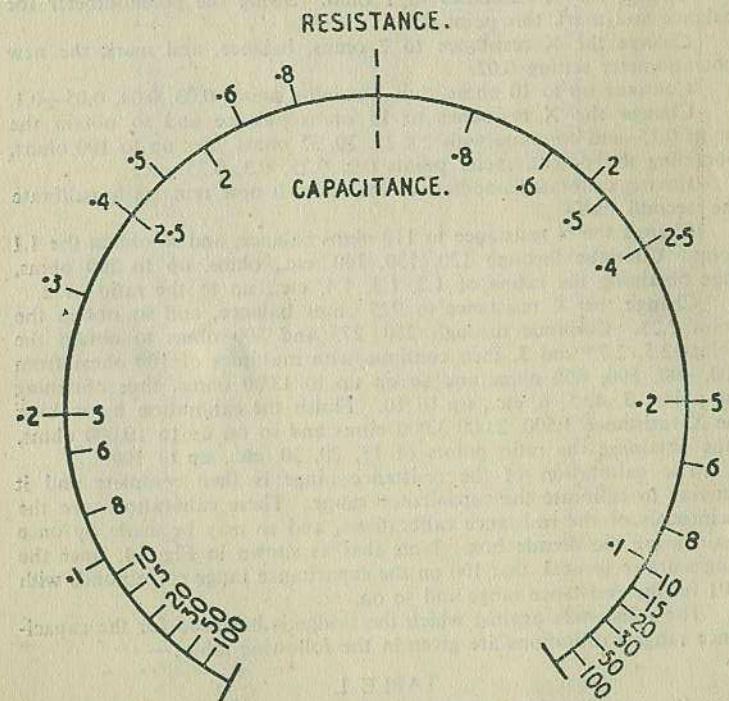


Fig. 14. Typical Calibration Scale for the Resistance-Capacitance Bridge.

Note that the bridge is powered from a heater winding giving 5 volts on the low resistance ranges and the high capacitance ranges, the voltage being stepped up considerably for the high resistances and low capacitances. The higher voltage is obtained from a spare output transformer, a cheap component with a ratio of about 60 : 1 serving admirably. A safety resistance is included in circuit. The voice coil winding, or secondary, is connected across the centre tap and one side of the 5 volt winding, so that something like 100 volts are obtained from the transformer primary. This higher voltage gives reasonably sharp indications on the appropriate ranges.

To calibrate the bridge set the range switch to 100 ohms and connect to the X terminals a standard resistance box. A set of 1% resistors could be used but if a good decade box can be obtained or borrowed the work will be considerably simplified. First check the bridge by setting the X resistance to 100 ohms. The Eye should show balance with the potentiometer at the centre point. This point is marked 1.

Change the X resistance to 1 ohm. Swing the potentiometer for balance and mark this point 0.01.

Change the X resistance to 2 ohms, balance, and mark the new potentiometer setting 0.02.

Continue up to 10 ohms, thus obtaining points 0.03, 0.04, 0.05—0.1.

Change the X resistance to 15 ohms balance and so obtain the point 0.15, and continue with 20, 25, 30, 35 ohms, etc., up to 100 ohms, obtaining the potentiometer points 0.2, 0.25, 0.3, 0.35, etc.

Having calibrated one-half of the scale, it now remains to calibrate the second half.

Change the X resistance to 110 ohms balance, and so obtain the 1.1 point. Continue through 120, 130, 140, etc., ohms, up to 200 ohms, thus obtaining the ratios of 1.2, 1.3, 1.4, etc., up to the ratio of 2.

Change the X resistance to 225 ohms balance, and so obtain the point 2.25. Continue through 250, 275 and 300 ohms to obtain the points 2.5, 2.75 and 3, then continue with multiples of 100 ohms from 300, 400, 500, 600 ohms and so on up to 1,000 ohms, thus obtaining the points 3, 4, 5, 6, etc., up to 10. Finish the calibration by making the X resistance 1,500, 2,000, 3,000 ohms and so on up to 10,000 ohms, thus obtaining the ratio points of 15, 20, 30, etc., up to 100.

The calibration of the resistance range is then complete and it remains to calibrate the capacitance range. These calibrations are the reciprocals of the resistance calibrations, and so may be made by once again using the decade box. Note that as shown in Fig. 14, since the ranges are reciprocal, that 100 on the capacitance range corresponds with 0.01 on the resistance range and so on.

The resistances against which the bridge is balanced for the capacitance range calibrations are given in the following table:—

TABLE 1.

Capacitance calibration resistances. Set Range Switch to 100 ohms as before and balance with decade box set at:—

Capacitance Ratio Calibration

100
50
40
30
20
10
9
8
7
6
5
4
3
2.75
2.5
2.25
2
1.8
1.6
1.4
1.2
1.1
1
.95
.9
.85
.8
.75
.7
.65
.6
.55
.5
.45
.4
.35
.3
.25
.2
.15
.1
.09
.08
.07
.06
.05
.04

X Resistance

1 ohm
2 ohms
2.5 "
3.3 "
5 "
10 "
11.1 "
12.5 "
14.3 "
16.6 "
20 "
25 "
33 "
36.3 "
40 "
44 "
50 "
55 "
62.5 "
71.4 "
83.3 "
90.9 "
100 "
105 "
111 "
117.6 "
125 "
133 "
142.8 "
154 "
166 "
181 "
200 "
222 "
250 "
285.7 "
333 "
400 "
500 "
666 "
1,000 "
1,111 "
1,250 "
1,428.5 "
1,666 "
2,000 "
2,500 "

Capacitance Ratio Calibration

Capacitance Ratio	X Resistance
0.03	3,333
0.02	5,000
0.01	10,000

To calibrate the power factor resistor R4 direct in terms of power factor, temporarily short-circuit the 1 mfd. standard capacitor. Set the Range Switch to 1 mfd. With the decade resistance box still connected into the X terminals, set the X resistance to 160 ohms, balance the Eye, LEAVING THE RATIO ARMS SET AT 1 AND BALANCING BY ADJUSTING R4. Mark the resulting setting of R4, 5%.

Continue by balancing the Eye against the following resistances still using R4, calibrating each setting as follows:

320 ohms.	10%
485 "	15%
650 "	20%
820 "	25%
1,000 "	30%
1,190 "	35%
1,400 "	40%
1,610 "	45%
1,830 "	50%
2,080 "	55%
2,370 "	60%

Remove the short circuit from the 1 mfd. capacitor.

In use, a sharp bridge indication will be obtained when large capacitances are being measured only when the power factor control is correctly set. To set R4, first balance the bridge as well as possible, using the correct setting of the range switch, then endeavour to sharpen the response by varying the setting of R4, re-setting or checking the setting of the ratio arms potentiometer after each variation of R4. An optimum position will be found, and then both the capacitance and the power factor of the capacitor may be read off from the scales.

Standard capacitors for the bridge will be obtained rather less easily than standard (i.e., 1%) resistors. If possible the capacitors should be checked on an existing bridge for values and the best accuracies chosen from a number of capacitors; alternatively a low capacitance can be brought up to accuracy by connecting small capacitances in parallel with it.

If the bridge is to be used for service work or components checking alone the capacitor accuracy will not be of prime importance, but if it is to take a place in the laboratory then an effort to ensure accuracy is well worth while.

The balance point is less easily observed when the potentiometer arm is at either extreme end of its range than when it is centrally situated. If the ratio is high, above 10, a better balance might be achieved on the next higher range setting of the range switch, but if the ratio is low, below, say, 0.1 and the range switch is already at the lowest range setting, then nothing can be done to improve the operating condition of

the bridge. Nevertheless resistances over the range of 1 ohm to about 10 megohms or more and capacitances from 10 pfs. to 10 mfd. or more may be measured with reasonable accuracy, whilst values considerably higher than these can be checked.

Balance is not so easily seen on the low capacitance value as on low resistance values, and the author has found a small lens mounted over the screen of the EM34 to be a decided asset.

COMPONENTS LIST FOR THE MAGIC EYE BRIDGE.

Fig. 13.

R1	100 ohms, 1%, high stability. 1 watt.
R2	10,000 ohms, 1%, high stability. 1 watt.
R3	1 megohm, 1%, high stability. 1 watt.
R4	2,500 ohms, wirewound variable. Power factor control.
R5	20,000 ohms wirewound, variable, Ratio Arms.
R6	4.7 meg. $\frac{1}{2}$ watt.
R7, R8	1 megohm, $\frac{1}{2}$ watt.
R9	47,000 ohms, $\frac{1}{2}$ watt.
R10	2,000 ohms, 5 watt.
C1	0.0001 mfd. 1%. Mica.
C2	0.01 mfd. 1%. Mica or paper.
C3	1 mfd. 1%. Mansbridge.
C4	0.01 mfd. 350 v.w. Paper.
C5, C6	8 plus 8 mfd. 450 v.w.
T1	200—250 volts primary. 250—0—250 volts. H.T. 6.3v. 2a. 5v. centre tapped. 2a.
T2	Output transformer, about 60 : 1. Inexpensive type satisfactory.
S1a, S1b	2 pole 6-way selector switch, Range and bridge feed. Yaxley type.
S2	2 pole On—Off switch.
V1	EM34 Mullard.
V2	6X5.
	2 International octal valveholders.
	Control knobs for S1, R5.
	Test terminals and prods.
	Chassis, cabinet, screened sleeving, wire, etc.

CONSTRUCTION.

The bridge may follow any convenient layout to suit the case or cabinet into which it is to be built. Note that the grid lead to the Magic Eye is screened; this is not, perhaps, essential, but prevents the chance of hum pick-up.

If desired a leakage indicator can also be fitted. This takes the form of a neon lamp connected on one side to the main positive H.T. line and on the other side to a test terminal marked Leakage, positive. A second test terminal, marked Leakage, negative, is connected to the negative H.T. line, i.e., the chassis. Thus across the terminals appears

about 200 volts with the neon lamp in series, and a good capacitor connected across the terminals will cause the neon to flash at long intervals. A poor capacitor will give rapid flashing and a bad or short-circuited capacitor will cause the lamp to glow steadily. A suitable neon lamp must be used, rated at about 200 volts, or below, though results can be obtained with a beehive lamp.

Possibly the most valuable of all indicators is the cathode ray oscilloscope, using as large a tube as can conveniently be supplied, the most usual tube size for laboratory work being about 3 ins. screen diameter. The tube alone, with its power pack, can be used for frequency comparison or phase comparison, and thus for frequency measurement over a wide range given a standard frequency such as supplied by the mains, whilst, with a graticule or squared sheet of celluloid over the screen the tube may be calibrated to measure voltages in terms of deflection at frequencies between zero and several kilocycles or even megacycles.

With a time base added the oscilloscope takes its usual form, capable of performing the tasks already mentioned and many more besides, from the demonstration of all types of waveforms onwards.

An oscilloscope may either be purchased or made. At the time of writing a wide variety of tubes, many with their associated power supplies already built, are available on the market, screen sizes from 2½ ins. to 6 ins. diameter being readily obtainable.

A wide range of commercial oscilloscopes are also made, and especial mention is deserved by the well-known Cossor Double Beam Oscilloscope by means of which, on a single tube, two waveforms at once may be inspected.

Highly recommended, too, is the Lydiate Ash Laboratories (L.A.L.) Unit Oscilloscope.

In a book of this size it is impossible to deal in full with all or even one or two of the many uses the oscilloscope has in the radio laboratory, and since a Cathode Ray Oscilloscope Manual already appears in Messrs. Bernard's List (No. 51, 2/-), the reader who requires more details of both the construction and application of oscilloscopes is referred to that publication.

In Fig. 15 is shown a simple yet, at the same time, a very effective oscilloscope, built round the Mullard ECR30 tube, although any similar 3 ins. tube may be used. A version of the Miller-Integrator timebase is used which gives a remarkably linear scan over the frequency range of from 15 to 20,000 cycles. Only four switch positions are needed to cover this range as a coarse frequency control; fine frequency control is given by R10 in the diagram.

The amplifier is compensated to some degree for high frequency operation, and an attempt has been made to retain reasonably high gain with a linear response up to approximately 200,000 cycles. With the oscilloscope the output from a signal generator can be inspected with perfect clarity, and a few cycles of a 200 Kcs. wave inspected on the screen, which may give some idea of the possibilities of the circuit.

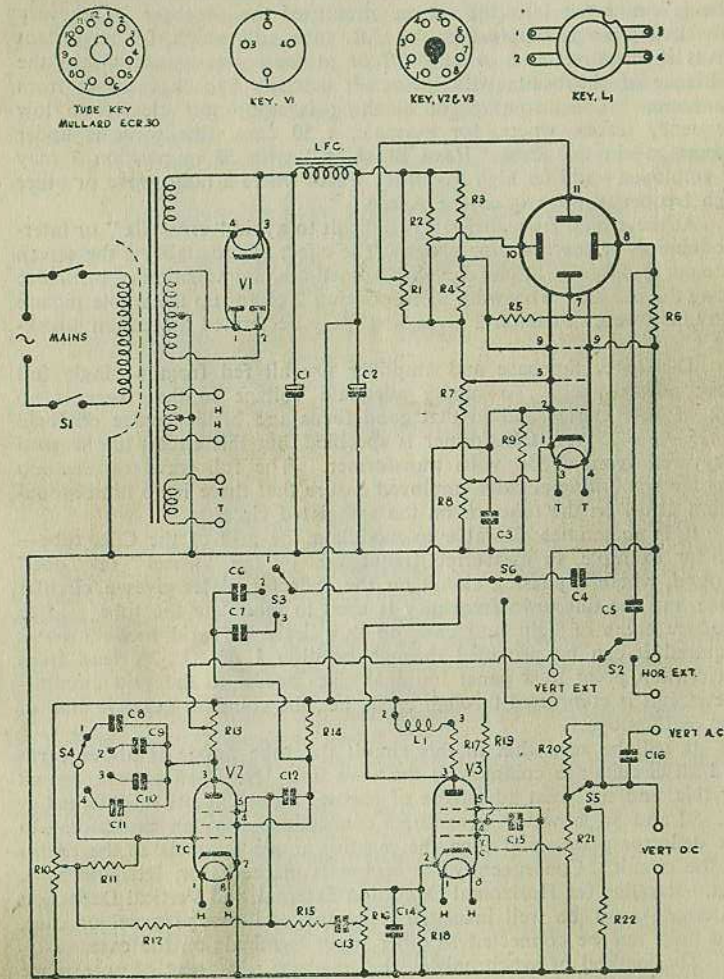


Fig. 15. The Oscilloscope.

In addition to a good timebase and amplifier, the circuit also contains beam-blanking, controlled by S3. In position 1 of the switch no blanking is applied, but on positions 2 and 3 the grid of the tube is connected into the screen circuit of the timebase. On every flyback a pulse is supplied to the C.R. tube grid which, for an instant drives it negative and so cuts off or at least greatly diminishes the brilliance of the beam, with the result that the flyback vanishes from the screen. The advantage of blanking is seen most clearly on low frequency traces, where, for example, a 50 c.p.s. sine wave is under inspection—in this case "Hard Blanking," with S3 in position 3 may be employed—and on high frequency traces where a radio wave or other high frequency wave is on the screen.

At these high frequencies it is difficult to avoid "crosstalk" or inter-modulation of the deflector plates. The effect of crosstalk on the screen is to curve the trace at one end with, sometimes, a graduation of brilliance along the picture. Throwing S3 to position 2 cleans up the whole picture extremely well. Position 2 gives what may be termed "Medium Blanking."

The tube, timebase and amplifier are all fed from a single full wave power pack. To supply adequate voltage so that there is no risk of bulb charge and so that good focus and brilliance are obtained a 425—0—425 volt transformer is specified, but this circuit has worked very well from a 350 volts transformer. The full wave rectification and the smoothing circuits employed ensure that there is no hum modulation at all on the tube, or on the associated circuits.

It is sometimes desirable to modulate the grid of the C.R. tube—as, for example, in measuring frequencies by the "wheel" or "dot" method, where a phasing circuit on the deflector plates gives a circular trace and the unknown frequency is used to modulate the tube grid to produce areas of light and dark on this circle. If grid modulation is required it can be provided through position 1 of S3. A lead from this switch point to a panel terminal gives access to the grid circuit—the circuit is completed through earth, i.e., the common negative line of the oscilloscope.

It will be seen that in this circuit the tube anode is above earth and all circuits are common to the —ve line. No ill-effects are caused by this, and the great advantage of earthed input circuits is obtained.

S2 and S6, however, give direct connection—through capacitors—to the deflector plates, and then the positive anode line acts as the return of the circuit. Consequently the terminals marked Hor. Ext. and Vert. Ext.—standing for Horizontal Deflection External, and Vertical Deflection External—must be well insulated from the oscilloscope panel or case, and must not be connected to other input terminals on the case.

The method of synchronising the timebase is worthy of note, since the sync. feed is taken from the cathode of the amplifier. This produces very little interaction between the two circuits even when the sync. control is fully rotated, and in the normal working position the control need only be slightly advanced. As a result in all normal operations there is no observable interaction at all.

When external signals are being fed through the amplifier the external circuit must be connected in the correct way, either to the Vert. A.C. terminal and the common earthed terminal for A.C. and wave signals, or to the Vert. D.C. terminal and the common earthed terminal for D.C. inputs. S5 controls an attenuator. With S5 down both the D.C. and A.C. input terminals are still operative but the input signal is attenuated in the ratio of 20 : 1. S5, therefore, allows large inputs still to be passed through the amplifier.

Amplifier gain is approximately 50 times, with a drop of approximately 4 dbs. at 200 kcs.

COMPONENTS LIST FOR THE OSCILLOSCOPE

Fig. 15

C1	8 mfd. 600 v.w. Electrolytic. T.C.C. 922.
C2	16 mfd. 500 v.w. Electrolytic. T.C.C. CE14P.
C3	0.001 mfd. Mica.
C4, C5, C13, C15	0.1 mfd. 500 v.w. Tubular.
C6	50 pfs. Ceramic.
C7	500 pfs. Mica.
C8, C12	0.01 mfd. 500 v.w. Mica or Tubular.
C9	0.00115 mfd. Use 0.001 and 150 pfs. mica capacitors in parallel.
C10	150 pfs. Mica.
C11	20 pfs. Ceramic.
C14	0.005 mfd. Mica.
C16	0.25 mfd. 500 v.w. Tubular.
R1, R2	2 megohm potentiometers. Shift controls.
R3, R4	100,000 ohms., $\frac{1}{2}$ -watt.
R5, R6, R11	2.2 megohms. $\frac{1}{2}$ -watt.
R7	1 meg. potentiometer. Focus control.
R8	100,000 ohms. potentiometer. Brilliance control.
R9	220,000 ohms., $\frac{1}{2}$ -watt.
R10	1 megohm potentiometer. Fine Frequency control.
R12, R20	1 megohm, $\frac{1}{2}$ -watt.
R13	100,000 ohms. potentiometer. Sweep Amplitude control.
R14, R17, R22	47,000 ohms., $\frac{1}{2}$ -watt.
R15	470,000 ohms., $\frac{1}{2}$ -watt.
R16	0.25 megohm potentiometer. Sync. control.
R18	3,900 ohms., $\frac{1}{2}$ -watt.
R19	150,000 ohms., $\frac{1}{2}$ -watt.
R21	1 megohm potentiometer. Vertical Gain control.
T1	200—250 volts primary. 425—0—425 volts H.T. Partridge 4v. 2a. 4v. 2a. 4v. 1a. T/425/150/E
L.F.C.	25 hys. choke. Partridge. C25/60.
S1	D.P. Mains On-Off.
S2	S.P.D.T. Horizontal, Internal, External.
S3	S.P. 3-way, rotary. Beam-blanking.

- S4 S.P. 4-way rotary. Coarse Frequency control.
 S5 S.P. 2-way. Vertical input attenuator.
 S6 S.P.D.T. Vertical, Internal, External.
 V1 UU5, with 4-pin chassis mounting holder.
 V2, V3, S.P.41's, with Mazda Octal chassis mounting holders.
 Tube, Mullard ECR30 or similar.
 Chassis. 14-ins. x 9-ins. x 2½-ins. aluminium or steel, or to suit constructor's requirements.
 Panel. 11-ins. x 9-ins.
 L1. Secondary winding of H.C. Atkins Coil, White, No. 2. (H.C. Atkins Laboratories, 32, Cumberland Road, Kew, Surrey).
 See coil key. Iron core screwed up into secondary.
 7 insulated terminals.
 9 pointer type control knobs
 Sleeving, wire, nuts, bolts, etc.

Note.—The method of high frequency compensation used in the amplifier is described in Chapter 3 and another circuit is given which provides for even greater compensation and a consequently higher frequency limit.

The same chapter also includes details of a very high speed timebase. The function switches on the oscilloscope panel should be coded as follows:—

- S3 Beam Blanking.
 Position 1 Blanking Off.
 Position 2. Blanking Medium.
 Position 3. Blanking Hard.
 S4 Coarse Frequency.
 Position 1. 15 — 50 c.p.s.
 Position 2. 50 — 1,000 c.p.s.
 Position 3. 750 — 5,000 c.p.s.
 Position 4. 3,000 — 20,000 c.p.s.

CONSTRUCTING THE OSCILLOSCOPE

Practically any layout may be used, and the oscilloscope may be fitted into any case which will comfortably hold the components.

The chief point to be observed is the usual oscilloscope requirement—the mains transformer should be mounted directly behind the tube so that stray fields cannot deflect the spot to one side.

All earth return and bypass circuits may be connected directly to the case or chassis as this is the common negative line, but it is wise to back the panel with a sheet of thin paxolin over the mounting positions of the shift and focus potentiometers to ensure good insulation at these points.

External circuits must always be connected in carefully, so that points of high voltage in the external gear cannot be short-circuited or cause a heavy current through R21, for example. When the grid is brought out for modulation from point 1 of S3 this circuit should also be used with care, and the grid must not be driven positive, with respect to earth. In any case of doubt the external apparatus should be connected in through a highly insulated capacitor, with as high a value as possible.

As with any other oscilloscope, the tube must always be run at as low a brilliance as possible, and the spot should never be allowed to remain stationary on the screen.

Constructors who have the American 3BP1 C.R. tube with a 6.3 volt heater may use this circuit by changing the SP41's to SP61's and the UU5 to a 5U4G. The 6 and 5 volt heater winding model of the Partridge transformer is then used, T/425/150/A.

OUTPUT METERS.

Still under the main heading of Indicators is included yet another meter, the Output Meter. The Output Meter may be an uncalibrated indicator such as an appropriate range of the Multimeter (either 10, 100 or 1,000 volts A.C.) connected in to the circuit under test via a suitable capacitor, when comparative readings can be made, or a properly calibrated instrument.

The multimeter type of output meter does not give a true reading since the impedance of the capacitor is in series with the instrument impedance, but for receiver alignment and similar work this type of output meter is all that is required. A greater output results in a greater voltage being indicated on the meter scale and vice versa, so that whilst the final output is not truly known the correct adjustments can be made to obtain the greatest output.

The design of a calibrated output meter is complicated to some extent by reason of the fact that every valve must deliver its output into the correct impedance or load, for full efficiency, whilst at the same time output is most conveniently measured in terms of voltage across a load.

For any one power output, therefore, changing the load impedance will cause a different voltage reading and thus an apparently different output reading unless some method of compensation is adopted. The same remarks hold true for decibel meters.

The simplest way out of the difficulty is to change the final voltage range of the output meter for each load across which it is to work. Using the formula

$$P = \frac{V^2}{R}$$

where P is the power in watts and R is the load into which the power is fed, V being the voltage across the load, specimen voltage ranges are, for 25 watts in each case:—

- V across 10,000 ohms = 500 volts.
 V across 5,000 ohms = 353.6 volts.
 V across 2,000 ohms = 223.6 volts.

So the A.C. voltmeter which forms the basis of an output meter can be calibrated in terms of watts only if its range is varied in accordance with the load across which the power is being measured. Using a rectifier instrument, similar to the basic circuit of the Multimeter, this may be accomplished by using differing range resistors, these range resistors being switched and coded not in voltages but in terms of loads across which the output meter gives a true reading.

The Output Meter shown diagrammatically in Fig. 16 uses this principle and has a range of from zero to 25 watts. The moving coil instrument used is a 100 ohms 0.1 millimeter, and the multiplier resistances are calculated for true watts readings at 10 loads chosen as the most useful, from 2,000 up to 15,000 ohms. The multiplier resistances, as calculated, work out to odd figures and not to standard values, but the resistances can be made up by adding various standard value resistors in series where necessary. Some endeavour at bridging the resistances to ensure reasonably accurate results is worth while although 10 parts of error in each thousand ohms will still be no more than a 1% error for that range.

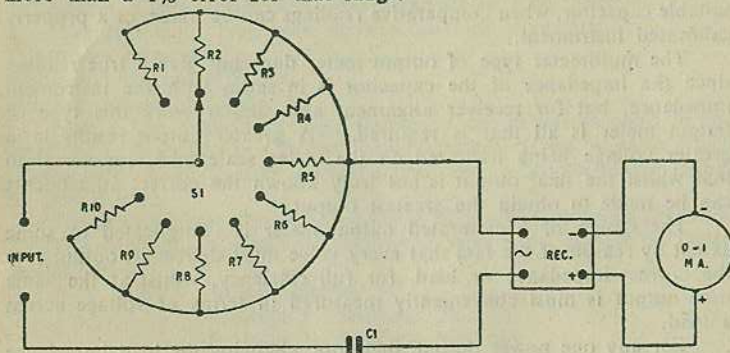


Fig. 16. The Output Meter.

COMPONENTS LIST FOR THE OUTPUT METER.

Fig. 16.

R1	200,000 ohms.
R2	245,000 ohms.
R3	285,000 ohms.
R4	320,000 ohms.
R5	350,000 ohms.
R6	390,000 ohms.
R7	425,000 ohms.
R8	450,000 ohms. 1 watt.
R9	495,000 ohms. 1 watt.
R10	550,000 ohms. 1 watt.
All fixed resistors except R8, R9, R10, $\frac{1}{2}$ watt types.	
C1	8 mfd. A Mansbridge type capacitor is necessary, and the value is best made up of 2 or 4 mfd. units. The capacitor must be non-polarised and non-inductive.
W	Westinghouse 1 mA. Instrument Rectifier.
S1	S.P. 10-way switch (or 10 points of a 12-way switch), Yaxley type.

M, 0.1 mA. moving coil. Resistance 100 ohms or thereabouts. Not higher than 500 ohms. Weston Model S.20. (Sangamo-Weston Ltd., Gt. Cambridge Rd., Enfield Mddx.)
Control Knob for S1. Suitable case.

Note: Due to rectifier characteristics the reading is true only for sinusoidal waveforms, but under general conditions this may be disregarded.

Instrument error due to the use of a capacitor in circuit is small since a large capacitance is used, and may be disregarded.

The range of the output meter is from 0.25 watts, but since the instrument used is a milliammeter and calibrated from 0.1 mA. either the scale must be recalibrated or, preferably, a conversion chart must be used by means of which the current shown on the instrument scale may be converted immediately to watts or fractions of watts. Such a conversion chart may be drawn from Table 2, given below.

TABLE 2.
CONVERSION FIGURES, mAs. TO WATTS, FOR THE
OUTPUT METER.

FIG. 16.

mAs.	Watts
0.1	0.25
0.14	0.5
0.17	0.75
0.2	1
0.283	2
0.35	3
0.4	4
0.45	5
0.49	6
0.53	7
0.56	8
0.6	9
0.63	10
0.66	11
0.69	12
0.72	13
0.75	14
0.77	15
0.8	16
0.82	17
0.85	18
0.87	19
0.89	20
0.92	21
0.94	22
0.96	23
0.98	24
1.00	25

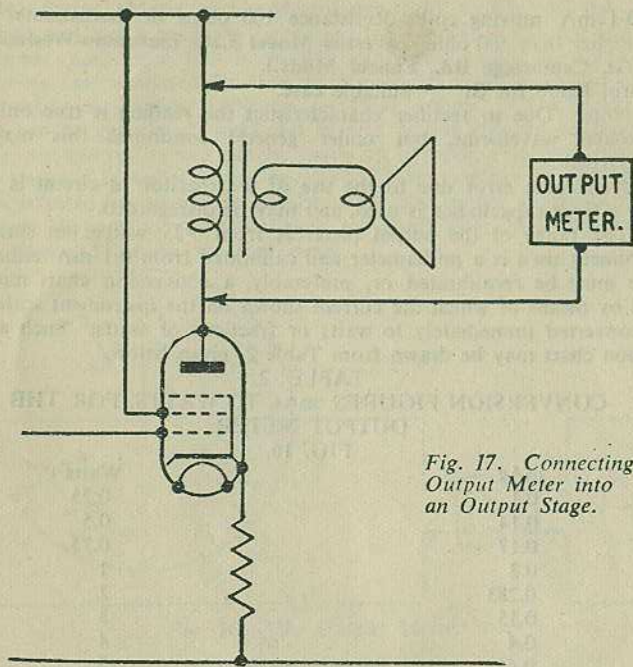


Fig. 17. Connecting the Output Meter into an Output Stage.

The output meter is connected into the circuit under test as shown in Fig. 17. The loudspeaker or other load **must** be left connected for this sets the working conditions of the circuit. It is necessary to assume, in the case of commercial receivers, that the valve manufacturer's conditions obtain, and the load impedance of the output valve is found from valve data tables. The output meter switch is then set to the correct load, the switch coding being as follows:—

CODE FOR OUTPUT METER SWITCH S1
(AS MARKED IN Fig. 16).

Position 1	2,000 ohms load.
" 2	3,000 " "
" 3	4,000 " "
" 4	5,000 " "
" 5	6,000 " "
" 6	7,500 " "
" 7	9,000 " "
" 8	10,000 " "
" 9	12,000 " "
" 10	15,000 " "

Thus, to measure the output from a Mullard Pen4VA, for example, the output meter switch is first turned to position 5, for the required load for this valve is 6,000 ohms.

With the stage and valve working, the output meter is connected across the primary of the output transformer, the gain of the receiver or amplifier in which the valve is working being turned up full if the full output measurement is needed. The meter will then read, if the valve is delivering full output, somewhere in the region of 0.35 or 0.4 mA.

If it is required to mute the loudspeaker then, before the output meter is connected into circuit, the voice coil connections must be broken and a resistance exactly equivalent to the voice coil impedance substituted in its place. The resistor must have an adequate wattage rating for the power output of the circuit. In the majority of cases a 3 ohms resistance will be needed, but for a 15 ohms speaker a 15 ohms resistance must be used, and so on.

Disconnect the output meter before switching off the receiver or gear on which it is operating, and similarly always switch on the gear and allow it to reach operating temperature before connecting the output meter.

The output meter may also be calibrated in decibels. The following table shows the decibel readings relating to power gains, since the meter is a power measuring instrument, and the zero db. level is chosen to be 1 watt.

TABLE 3.
DECIBELS CONVERSION CHART AGAINST WATTS AND mAs.
FOR THE OUTPUT METER.

db.	Fig. 16.	
	Watts.	mAs.
- 6	0.25	0.1
- 3	0.5	0.14
0	1	0.2
+ 3	2	0.283
+ 6	4	0.4
+ 9	8	0.56
+ 12	16	0.8
+ 14	25	1.0

It should be pointed out that whilst in actual fact the decibels calibration is not so accommodatingly exact as the above table shows—plus 6 db. is really a power gain of 3.981, for example, rather than the gain of 4 shown—the calibration is quite sufficiently accurate for all practical purposes.

If a different zero level is desired, the meter can be recalibrated to suit the new conditions from any db. table.

CHAPTER 3.
TEST EQUIPMENT—PART 2.
TELEVISION TEST GEAR.

Practically all of the test apparatus so far described is of great use when experiments are to be performed in the reception of television signals, or when television receivers are to be developed, but further gear, or developments in existing gear, can assist the television worker considerably.

The television receiver, no matter whether it is of the T.R.F. or superhet type, is specialised, and contains timebases and very high voltage supplies not found in other receivers, so that in broad outline the test gear for the television section of the laboratory must include a special signal generator, measuring instruments capable of dealing with high potentials, and an oscilloscope. This is a very short list yet a television set can be developed at home with little more than a knowledge of what is required, a good stock of patience and a test signal from the London transmitter, but for those preparing for television in areas where the service is not yet provided the gear mentioned must be considered as essential.

So far as the measuring instrument is concerned, the valve voltmeter described in Chapter 2 is quite satisfactory. The high voltages can be measured as D.C. voltages after rectification and the 5,000 volts range will handle practically all types of power supplies whilst the input resistance of the meter, 10 megohms, is sufficiently high to cause little error. This point is of importance; television tubes, like oscilloscope tubes, are fed from a potentiometer chain across their power pack output circuit and since high voltages are present and high voltage rectifiers pass only low currents, of the order of 3 mAs. maximum, the potentiometer chain has a very high overall resistance. If, then, a voltmeter requiring appreciable current is connected across part of the chain the extra current required to operate the voltmeter is drawn through some part of the high resistance with the result that a serious fall in potential ensues. The voltage reading obtained is incorrect and an existing fault might be masked, or a non-existent fault suspected.

The range of the moving coil Multimeter can easily be extended to cover, say, 5,000 volts by switching the instrument to the 1,000 volts range and adding external resistance in series with one test lead to a value of 4 megohms. The instrument will still draw a current of 1 mA. for full scale deflection, however, and this is too high to be satisfactory.

At 5,000 volts the valve voltmeter will draw a current from the circuit of 0.5 mA., which is better, but an even higher input resistance of the order of hundreds of megohms would be better still and undoubtedly an electrostatic voltmeter is the ideal instrument for measuring high voltages across high resistances.

Theoretically the resistance of this instrument is infinite and no current at all flows for the pointer deflection depends on the charges across a set of fixed and moving vanes. Usually a minute current flows

as a result of leakage, but this will affect the accuracy of the reading hardly at all.

A warning concerning the dangers of television power packs must be given. The voltages are so high that all non-enclosed television gear must be considered as extremely dangerous and must be treated with respect. When voltage measurements are being taken the equipment must, of course, be switched on but the voltmeter should be connected up with the power supply switched off and the switch closed only when the hands are clear. For all other adjustments and circuit changes the receiver should be switched off and, for safety, have the supply plug withdrawn from the socket.

When the set has been working, discharge the capacitors in the high voltage supply circuits after switching off the set before making any changes or readjustments. The high resistance chain allows the charge to leak away only slowly, and a 100,000 ohms resistance, fitted with heavily insulated leads or prods, should be connected across the E.H.T. smoothing capacitor for several seconds. The discharge must never be made by a short-circuit.

Television gear can be aligned with an ordinary signal generator, but if serious work is contemplated a commercial television generator is of great assistance. One excellent example is the Pye Television Signal Generator No. 940008.

This is an instrument with a frequency range of from 40 to 50 Mcs., so that both the vision frequency of 45 and the sound frequency of 41.5 Mcs. are covered. For vision tests two modulations are provided, consisting of square waves fully modulating the carrier over about 50% of the line or frame time, so that a black bar across the screen, vertically for the line and horizontally for the frame, can be produced. These modulating signals may also be fed directly to the tube grid thus cutting out the R.F. circuits of the receiver under test.

For sound section checks a 400 cycles sine modulation may be switched on to the carrier.

A diode valve voltmeter enables the output from the generator to be fed at a level of 0.1 volt to a double attenuator so that accurate outputs from 1 microvolt up to 0.1 volt may be drawn.

The Pye Generator costs £24.

An ordinary signal generator is still required if I.F. transformers in the television receiver are to be aligned. The usual I.F. chosen is in the region of 12 or 13 Mcs. At the same time the commercial signal generators already recommended cover the television frequencies and will give a "picture" of sorts if their modulated output is fed into a receiver at 45 Mcs. The 400 cycles modulation produces 8 horizontal bars, the frame time base frequency being 50 half-frames per second to give 25 whole pictures per second, the half-pictures being interlaced.

To produce vertical lines on the television screen using an ordinary signal generator an external modulation must be fed into the "External Mod." terminals of the generator. The line frequency of the

television is 10,125 lines per second so that the modulation frequency must be a multiple of this frequency. The modulation efficiency is bound to be poor but if a strong signal at, say, a little over 100 kcs. is fed into the modulation terminals of the ordinary generator a vertical set of bars will result. The modulating frequency may be produced from a second ordinary signal generator or from a temporary oscillator.

When testing or aligning television receiving circuits with signal generators it must never be forgotten that the circuits are essentially very unselective and the receiver should be tested over a bandwidth rather than solely at the central frequency. The transmitted bandwidth is of the order of 6 Mcs.—i.e., the signal "stretches" from approximately 42 to approximately 48 Mcs.

To maintain bandwidth in the I.F. amplifier, the I.F. transformers or couplings are usually stagger tuned, so that here again alignments are not so straightforward as are broadcast receiver alignments. Stagger tuning reduces the efficiency of the I.F. amplifier but, if carried to the correct amount, it produces an overall response curve with an admirably flat top. An I.F. amplifier with 5 tuned circuits operating at a nominal frequency of 13 Mcs. might have 1 tuned circuit actually set at this frequency, the other circuits being tuned 2 to 14 Mcs. and 2 to 12 Mcs. The I.F. amplifier as a whole, therefore, requires very careful setting in order that distorted or poor response curve may be avoided. Each tuned I.F. circuit must be set or adjusted by feeding in a signal from the generator at the correct frequency, the overall response afterwards being tested by sweeping the generator over the band and noting the output obtained from the whole amplifier.

A cheap, simple and yet very useful generator has been in use in the author's laboratory for some time, and the circuit is shown in Fig. 18.

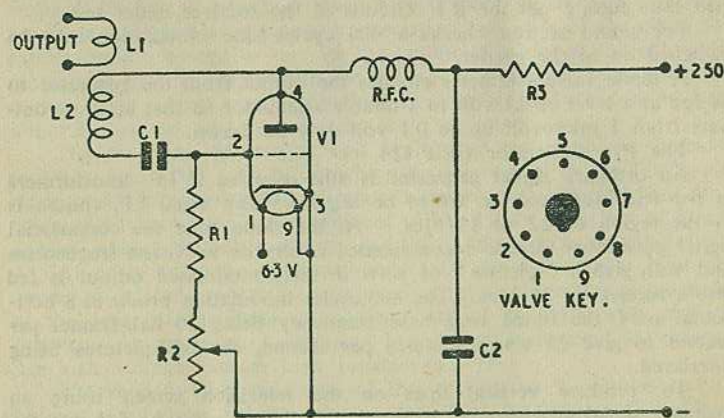


Fig. 18. A Simple Television Test Generator.

An ordinary super regenerative detector is fitted with a variable grid leak and the tuned circuit is adapted to give a very broad band of frequencies centred on 45 Mcs. by enlarging the tuning coil and omitting the tuning capacitor. The resulting oscillator has the signal frequencies modulated by the super regenerative or quench frequencies over a range variable by rotating R1, and if the output coil is coupled into a television receiver—only a very loose coupling is needed and it is usually sufficient merely to place the oscillator close to the television—the resulting screen "picture" is of a number of vertical bars, the number changing as R1 is varied. The bars should be perfectly upright and straight, and since synchronisation of the receiver is automatic the signal tests not only the R.F. circuits of the receiver but also the time bases, the focussing and the general behaviour of the tube circuits. If the oscillator is fed from a power pack whose smoothing is made deliberately poor a 50 cycles hum signal is also modulated on the carrier, giving a hum bar or faded portion over the picture, thus testing, if only roughly, the frame timing of the receiver.

Since oscillator tuning is effected solely by coil and stray capacitances slight adjustments to the coil will probably be necessary in individual generators, these adjustments consisting of either lengthening or shortening the coil by squeezing or stretching the turns until the signal is centred correctly on 45 Mcs.

It need hardly be mentioned that this oscillator is a powerful generator of interference, and should not be used during programme times nor coupled to an aerial of any description.

COMPONENTS LIST FOR THE TELEVISION TEST GENERATOR.

Fig. 18.

- | | |
|--------|--|
| L1 | 1 turn 16 S.W.G. enam. and D.C.C. $\frac{1}{4}$ in. diameter.
At anode end of L2. |
| L2 | 20 turns 16 S.W.G. enam. and D.C.C. $\frac{1}{4}$ in. diameter.
Turns closewound. |
| C1 | 0.0002 mfd. Mica. |
| C2 | 0.005 mfd. Mica. |
| R1 | 20,000 ohms. $\frac{1}{2}$ watt. |
| R2 | 0.5 meg. variable. |
| R3 | 100,000 ohms, $\frac{1}{2}$ watt. |
| R.F.C. | 60 turns 30 S.W.G. enam. closewound on $\frac{1}{4}$ in. diameter
former. 1 meg. resistor may be used as former for
choke. |
| V1 | EC52. Mullard. |
| 1 | B9G valve-holder.
Small chassis, wire, sleeving, etc. |

Construction of the unit follows ordinary high frequency practice in that all leads are kept short and direct and all the components are wired directly below the valve-holder, being supported, finally, by the holder pins.

The characteristics of the oscilloscope required for the television laboratory vary according to the nature of the work it is intended to

carry out, and if the chief interest lies, for example, in time bases the oscilloscope circuit exactly as shown in the preceding chapter will be found satisfactory.

Generally speaking the upper limit of the oscilloscope as it stands, about 20,000 cycles, is more than adequate for television work, for a scan frequency of a little above 5,000 cycles allows two complete lines of picture content to be examined, taking the line frequency as 10.125 lines per second. To examine detail and for special work a very high sweep frequency is sometimes needed, however, and in this case a special time base may be built up and coupled in to the oscilloscope, switching the horizontal deflecting plates to "external" for the purpose. A gas triode time base is limited at the higher frequencies, and a hard valve time base is much more satisfactory besides being more flexible and simple to construct.

A hard valve time base to give sweep frequencies of the order of 200,000 cycles is shown in Fig. 19 where a pentode valve is shown in a relaxation type of oscillating circuit. This time base is also useful from the experimental point of view for producing wave forms other than the sawtooth time base wave which appears at the anode. A rectangular wave is produced at the screening grid, and variation of circuit constants will give variations in the wave shapes.

A synchronising signal may be fed to the grid of the valve.

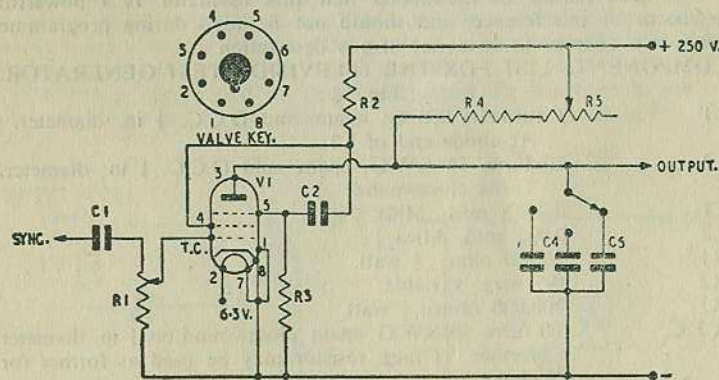


Fig. 19. The High Speed Time Base.

Note that the output line from the time base selector switch is taken directly to the horizontal deflection socket on the oscilloscope. This is possible since the oscilloscope circuit has its own isolating capacitor C3 (Fig. 15). If this high-speed time base is used with other oscilloscopes it will probably be necessary to use an isolating capacitor in the output lead from the selector switch, of the value of about 0.1 mfd. with a working voltage of, say, 1,000 volts.

COMPONENTS LIST FOR THE HIGH-SPEED TIME BASE.

Fig. 19.

R1	0.5 meg. variable. Sync. control.
R2	22,000 ohms, 1 watt.
R3	100,000 ohms, $\frac{1}{2}$ watt.
R4	10,000 ohms, $\frac{1}{2}$ watt.
R5	2 meg. variable. Fine frequency control. For greater frequency variation this may be increased to a maximum of 5 megs, by including switched fixed resistances in series with the variable resistor.
C1, C3	0.1 mfd. 500 v.w. Tubular.
C2	1 mfd. 500 v.w. Tubular or Mansbridge.
C4	0.01 mfd. 500 v.w. Tubular.
C5	0.001 mfd. Mica.
S1	S.P. 3-way coarse frequency selector.
V1	EF39. Mullard.

I International octal valve-holder.
Small chassis, sleeving, wire, etc.

Since the high-speed time base may be supplied from the bench power sockets no power pack is shown.

The point at which the oscilloscope is most likely to be lacking is in the frequency range and response of the vertical amplifier, the circuit built around V2 in Fig. 15. This amplifier will work well up to about 200,000 cycles and somewhat above, and at first this might seem perfectly adequate since the line frequency of the television line time base is 10.125 cycles. It must be remembered, however, that in this ten-thousandth of a second the whole of the line information is transmitted, so that if a line or a pair of lines are to be inspected on the oscilloscope the frequency response of the vertical amplifier must be very much higher if detail is to be visible. To take but one example, the sync. pulse on a line lasts for 9.88 micro-seconds which corresponds, very approximately, to a frequency of 100 kcs. and if the line sync. pulse is to be inspected on the screen then the amplifier must have good response at 100 kcs. Even so this frequency refers to the pulse as a whole, and if the sharp transitions of the line shape at the leading and trailing edges of the pulse are to be reproduced then the amplifier frequency response must be higher still.

The frequency response of an amplifier is affected by the various stray capacitances of the circuit but chiefly by the output capacitance of the valve. This capacitance is admittedly small but far from negligible and as the frequency rises so does the impedance presented by this capacitance fall, with the result that losses are increasingly serious as the frequency increases. The amplification or gain is thus far from linear.

To compensate for this state of affairs an inductance may be introduced into the anode circuit of the amplifier, the value of the inductance and the Q of the circuit being adjusted to suit the final required frequency response. By resonating over a band of frequencies the

inductance increases the gain of the stage by increasing the impedance of the anode load, the resistance having been reduced in order that the gain at the lower frequencies and the gain at the higher frequencies are balanced. The circuit Q is kept low so that the inductance is effective over a band of frequencies.

The final gain of the amplifier is, of course, lower than the gain obtainable when the frequency limit is low, but good amplification is still possible.

The simple design formulae for this "shunt peaking" circuit are (referring to Fig. 20):—

$$R_a = \frac{1}{2\pi f_{\max.} C_o}$$

and

$$L = 0.5 C_o (R_a)^2$$

where R_a is the anode load resistance, f_{\max} is the highest frequency to be dealt with, C_o is the total output capacitance over the anode circuit and L is the necessary inductance. The units are the fundamental units of ohms, farads, cycles and henrys.

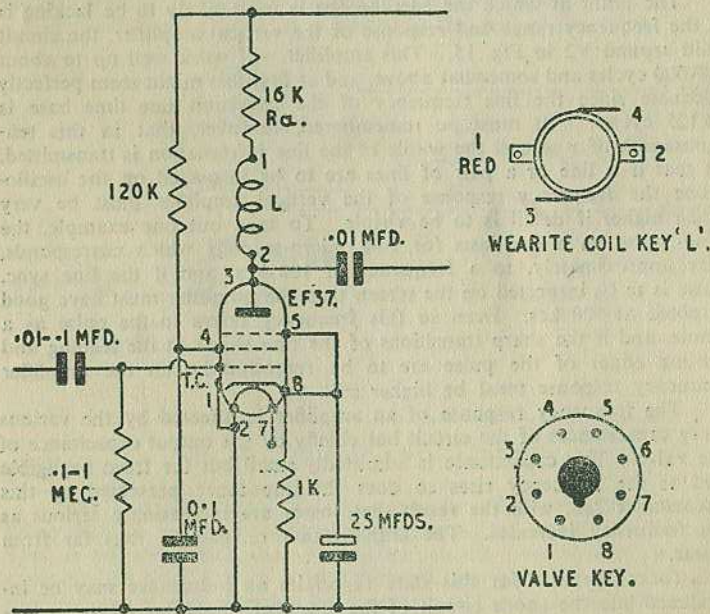


Fig. 20. High Frequency Compensator Amplifier.

In the case of the EF37 the output capacitance may be taken as 14 pfs. whilst, adding an allowance for the capacitances to earth of the wiring, valveholder, etc., the total output capacitance may be presumed as 20 pfs.

For response over a range extending up to 500 kcs., therefore, R_a may be calculated as 16,000 ohms (to take the nearest standard value resistance) when L is calculated as 2.5 millihenrys. Since the main tuned winding of a Wearite long-wave coil, either the PA1 or PHF1, is quoted by the makers as having an inductance of 2.2 millihenrys this coil might very well be used.

The gain of a shunt peaking stage is calculated very easily, since it is equivalent to the product of the valve's mutual conductance and the anode load resistance for the flat portion of the frequency response curve. The gain is thus

$$g_m R_a$$

and since the g_m of the EF37 is given as 1.8 mA./V the gain may be taken as 16×1.8 (converting to the fundamental units of amps. per volt by reducing the load to kilohms). The stage gain is thus practically 30.

Other values for resistance in the amplifier may be taken as 120,000 ohms for the screen resistor (to suit the valve limiting conditions) and 1,000 ohms for the cathode bias resistor. This resistor should now be bypassed with a 25 mfd. capacitor in the usual way. Note that for television video amplifiers this type of bypassing is not used although the shunt peaking correction circuit is employed. In this amplifier, however, considerations of zero frequency are not so important as they are in a television video amplifier.

The high frequency response amplifier may also be constructed as a supplementary unit to the oscilloscope and coupled into the vertical deflection circuit by using the "vertical deflection direct" sockets, the amplifier, like the high speed time base, drawing its supplies from the bench sockets.

CHAPTER 4. TEST EQUIPMENT, PART 3. VERY HIGH FREQUENCY TEST GEAR.

For experimental work at very high frequencies the gear in probably the greatest demand is that connected with the generation and measurement of v.h.f. together with apparatus capable of showing the operation of various types of aerial. The point at which very high frequencies become ultra high frequencies has not yet been defined satisfactorily although various proposals have been made, so that for the purposes of this manual the term "very high frequencies" has been taken to cover the frequency range from about 40 or 50 Mcs.—say, television carrier frequencies—up to the oscillating limit of "normal" valves. The frequency limits of valves vary with type, of course, but certain triodes built to the orthodox pattern—in that they have a cathode, grid and anode—are now capable of operation at several hundreds of megacycles. The Acorn triode works at 700 or 800 Mcs.;

the "lighthouse"—so called from its appearance, more properly named the disc-seal valve—can accept an input of approximately 20 watts at between 400 and 500 Mcs. (with forced ventilation); and the new Mullard valves of the E90 class, together with the well-known E50 class valves deserve special mention. The EC52, for example, operates up to a maximum oscillating frequency of 400 Mcs., gives excellent super-regeneration in a receiving circuit and has a maximum anode dissipation rating of 7.5 watts so that it is also of considerable use for transmission purposes. The EC53, only slightly larger than the EA50 diode, also operates up to 400 Mcs. as a power oscillator with an input of 2.5 watts and an output of 0.3 watt at the highest frequency.

If much v.h.f. work is to be carried out the laboratory should certainly be fitted with permanent Lecher wires. A Lecher wire system for 50 or 60 Mcs. will be beyond the possibilities of most home laboratories for the lines require to be a wave-length long at least, preferably more, but for frequencies above, say, 100 Mcs. the system can be fitted along a wall or even at the rear of the test-bench. Lecher wires are two parallel transmission lines of bare wire spaced an inch or slightly more apart—for the highest frequencies tubing might be used instead of wires—and a shorting bar is provided which runs along the wires short circuiting one to the other at any point along the system.

The wires should be stretched between two firmly positioned supports in order that they may be really taut and friction between them and the shorting bar, which should slide along a runway or groove or other positioning device, may be avoided by having the wires slightly higher than the shorting bar so that they must be pressed down by an ebonite or polystyrene rod to make actual contact.

The shorting bar should have a sharp edge, and the groove or runway along which it moves on its carriage may be calibrated either in terms of inches or centimetres. An indicator on the carriage exactly beneath the shorting bar shows the distance between the bar and a reference point at the feed end of the wires.

At each end of the system the wires or tubes are insulated one from the other, but power from the oscillator under test whose operating frequency is to be measured is fed to the system by connecting a single turn loop across the two Lecher wires, coupling this loop to the oscillator tank. Thus the whole system is as shown in Fig. 21.

Frequency measurements are made by virtue of the fact that the double transmission line is resonant, and so absorbs power. A simple

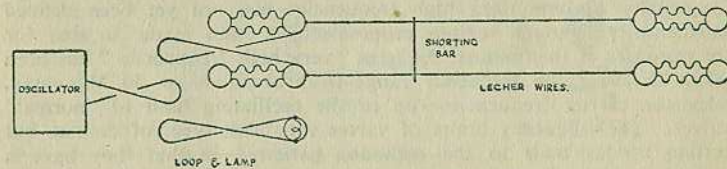


Fig. 21. Lecher Wire System.

indicator such as a loop and bulb is also coupled to the oscillator tank circuit so that the bulb glows, then the Lecher wire shorting bar is slid along the wires, starting from the feed end of the system. At some point or other the bulb brilliancy will suddenly fall, showing that the system is resonant and absorbing power. This point is noted and the shorting bar moved still further along the wires until the lamp dims again. The distance between the two positions of the shorting bar at which the bulb brilliancy dims is equal to a half wave-length.

The couplings between the Lecher wires and the bulb and the oscillator tank circuit must be adjusted experimentally for sensitivity, and the point arises that with some oscillators sufficient power will not be generated to give good bulb indications. In such a case a field strength meter may be used, and since this instrument is also of great value for use with experimental aerials it is described in some detail.

A field strength meter is rarely calibrated in units of field strength for almost without exception its main use is as a comparative indicator. When adjusting an aerial, for example, it is necessary to know whether the adjustments are being made in the correct direction and whether the field strength is increasing or decreasing; the field strength meter gives this information with no other calibration than that on the scale of the moving coil instrument which acts as the indicator.

Of the many types of circuit available undoubtedly the most useful is the "remote-reading" meter, for here the pickup system may be placed wherever desirable—at some distance in front of an aerial for example—whilst the indicator itself may be on the testbench or beside the transmitter or oscillator under test.

When used with the Lecher wires the indicator may be set at any part of the bench from which it is conveniently visible, the pick-up section being beside the oscillator.

All field strength meters consist essentially of a tuned circuit set to the frequency under consideration, a detector and an indicator. The circuit of the meter under discussion is shown in Fig. 22.

Whilst a diode detector could be used with no change of circuit a germanium or silicon crystal detector operates at practically any frequency and requires no heater supply. A resistance between the detector and indicator reduces loading on the tuned circuit and crystal, although for low power work this resistor may be switched out of circuit. A good crystal can pass several milliamperes of current and the meter as a whole would work well with a 1 mA indicator, but, again for satisfactory operation at low powers, a 100 microamps meter is used. Some care must be taken, however, to ensure that this meter is not overloaded or even burnt out with large inputs, and for this reason a shunt may be fitted to increase the meter range to 500 microamps or even 1 mA. This shunt is shown switched in the indicator unit.

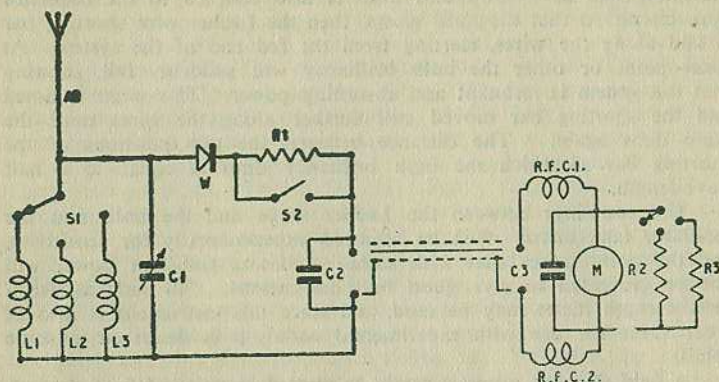


Fig. 21. Remote-reading Field Strength Meter.

Overloading is also prevented by enclosing the tuning unit in a shielding case. When necessary a short aerial is then fitted to the meter consisting either of a few inches of wire or a one or two foot rod. A short length of wire only will be required for work such as Lecher wire indication, whilst the pick-up rod will be needed when aerial characteristics are under investigation.

The coupling lead between the units may be of any length up to several hundreds of feet. By this means the detector unit may be placed several wave-lengths in front of an experimental aerial. At the same time if one unit is fitted with a two-pin plug and the other with a corresponding socket the units may be plugged together and used as a whole. The coupling lead may be formed of practically any two-way cable, either twisted flex or single cored coaxial line with the screen as the return lead.

COMPONENTS LIST FOR THE REMOTE-READING FIELD STRENGTH METER.

Fig. 22.

- L1, 18 turns 18 S.W.G. enam. close wound $\frac{1}{2}$ in. diam.
- L2, 8 turns 18 S.W.G. enam. 1 in. long, $\frac{1}{2}$ in. diam.
- L3, 4 turns 18 S.W.G. enam. $\frac{3}{4}$ in. long, $\frac{1}{2}$ in. diam.
- To cover 28 to 200 Mcs. band continuously.
- C1, 40 pfs. tuner. Raymart VC40X.
- C2, C3, 0.0005 mfd. Mica.
- R1, 1,500 ohms, $\frac{1}{2}$ watt.
- R2, 0.5 mAs. shunt.
- R3, 1 mAs. shunt.

The values of R2 and R3 depend on the instrument resistance. For a Weston S20 100 microamps movement, their values are approximately 220 and 97 ohms respectively.

- R.F.C.1,2, 60 turns 30 S.W.G. enam. closewound on $\frac{1}{4}$ in. form.
- M, 0-100 microamps. Sangamo-Weston Model No. S.20.
- W, Crystal "Diode," B.T.H.
- S1, S.P.3-way, range selector.
- S2, S.P.S.T. Series selectivity switch.
- S3, S.P.S.T. Shunt selector switch.

Two metal cases, plug and socket, 2-way, aerial standoff or terminal, coupling cable, sleeving, etc.

3 control knobs.

Using this field strength meter as a sensitive indicator, the Lecher wires may be employed to measure the frequency of very low power oscillators. The lines are coupled to the oscillator in the ordinary manner and the detector unit of the meter placed at a suitable distance from the oscillator with a short rod aerial fitted if necessary. When tuning the field strength meter the sensitivity should be reduced to the minimum by throwing in both the series resistance and the highest range shunt. Once the signal is found and the meter is reading the selectivity can be improved to give a convenient reading. The meter unit may be placed in any position for clear visibility.

The Lecher wires are operated in the usual manner, the shorting bar being moved along the lines until the first resonant point is found where the field strength meter will show a pronounced dip in its reading. The shorting bar is then carried further along the lines until the second dip is found, the distance between the two shorting bar positions giving the measure of a half wave-length.

When very high frequency receivers are being developed a v.h.f. oscillator is required, preferably one calibrated against Lecher wires or some other frequency determining device. The circuit of a suitable oscillator is shown in Fig. 23, using the EC52.

The three coils, wound to the same dimensions as those specified for the field strength meter, give the same frequency range, 28 to 200

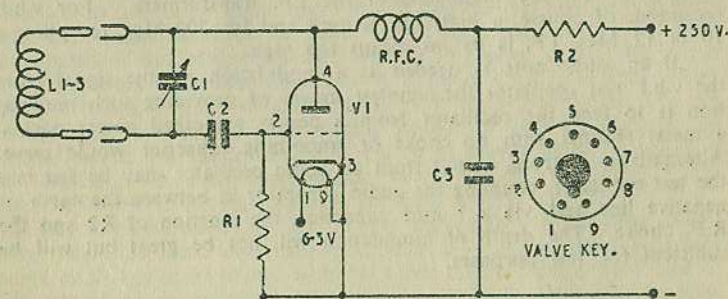


Fig. 23. V.H.F. Test Oscillator.

Mcs. but in the case of the oscillator they are not switched but plugged into circuit. A pair of sockets from an old valveholder are soldered one to the stator and one to the rotor contacts of the tuner and the coils wound with the ends of the winding left as short legs which may be inserted into these sockets, the coil thus being supported directly across C1.

COMPONENTS LIST FOR THE V.H.F. OSCILLATOR.

Fig. 23.

L1	18 turns 18 S.W.G. enam. closewound, $\frac{1}{2}$ in. diameter.
L2	8 turns 18 S.W.G. enam. 1 in. long, $\frac{1}{2}$ in. diameter.
L3	4 turns 18 S.W.G. enam. $\frac{1}{4}$ in. long, $\frac{1}{2}$ in. diameter.
C1	40 pfs. tuner. Raymart VC40X.
C2	50 pfs. Ceramic.
C3	0.001 mfd. Mica.
R1	33,000 ohms, $\frac{1}{2}$ watt.
R2	33,000 ohms, 1 watt.
R.F.C.	60 turns 30 S.W.G. enam. closewound on $\frac{1}{2}$ in. former.
VI	EC52.
1	B9G valve-holder.

If the unit is to be calibrated obviously the coils must be rigid in order that they may be handled and changed without altering shape and thus upsetting the frequency calibrations. In this case they may be wound on $\frac{1}{2}$ in. diameter tubing, polystyrene tube being excellent for the purpose if available. Alternatively a good grade paxolin may be used. The turns of the coils may be cemented to the tubing with cellulose cement, or a solution of celluloid in acetone may be used. In either case the amount should be as little as possible to fix the coil turns rigidly.

This oscillator will provide an input signal for testing and calibrating all types of v.h.f. receivers, but if superhet circuits are incorporated in the receiver design an ordinary signal generator will also be required for the alignments of the I.F. transformers. For v.h.f. reception, of course, a high I.F. is used and for 200 Mcs. reception a 10 or 12 Mcs. I.F. is by no means too high.

If an audio note is needed as a modulation on the signal from the v.h.f. test oscillator the simplest means of providing such modulation is to feed the oscillator from a poorly smoothed power pack—a metal rectifier with no choke or smoothing capacitor would serve. Alternatively a strong output from an audio oscillator may be fed into the test oscillator, coupling the audio generator in between the earth or negative line and, via a 1 mfd. capacitor, the junction of R2 and the R.F. choke. The depth of modulation will not be great but will be sufficient for test purposes.

CHAPTER 5. LABORATORY APPLICATIONS.

Throughout the writing of this Manual the author has borne chiefly in mind those workers and experimenters who intend to develop or design complete, multi-stage equipment such as receivers, amplifiers, televisions or new types of test gear.

This being so, it is therefore difficult to discuss the applications of the laboratory as a whole for obviously different aims and interests must lead to different uses and methods for and in the laboratory, so that this chapter is comprised of a few examples of the uses to which the gear may be put.

As a starting point it may be of value to illustrate one of several methods by which the inductance of a tuning coil may be measured without an inductance bridge. As has already been mentioned such bridges are costly if bought commercially, and difficult both to build and operate. In place of a bridge the signal generator and valve-voltmeter, together with a capacitor of known value, may be used.

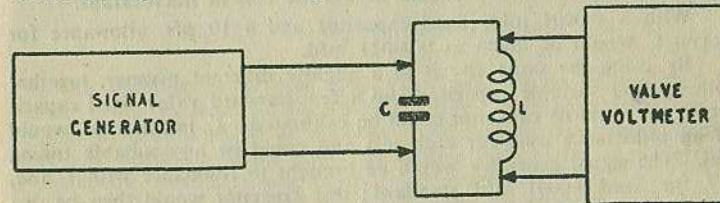


Fig. 24. Measuring Inductance.

The circuit is shown in Fig. 24 and it can be seen that the coil whose inductance is to be found is connected across the capacitor C in an ordinary parallel tuned circuit. From the point of view of convenience an accurately calibrated variable capacitor is obviously preferable, but a fixed capacitor of about 0.0001 mfd. will serve. The final capacitance is not of importance; what is important is that the value of the capacitor is known correctly. A range of capacitors with values in the "tuning" range—0.0001, 0.0003 mfd. etc.—accurate to 1% can be obtained from many good trading houses or ordered through the normal dealer and trade channels, and it is worth while to spend a few shillings on such components, keeping them carefully in the store cupboard to act as standards for such jobs as this.

The valve-voltmeter is set to the appropriate range—the 5-volt range using the meter described in Chapter 2—and the signal generator tuned until it is in resonance with the tuned circuit formed by L and C, this setting being indicated by a rise in the valve-voltmeter reading. There is little chance at medium and low frequencies of tuning to a harmonic, but if this should occur with coils of low inductance such as short-wave coils the valve-voltmeter reading will enable the fundamental

frequency to be chosen since the reading will be highest at this setting. Other types of indicator could be used, even to a diode detector (or germanium or silicon crystal) and headphones, but in this case a fairly large capacitance and load would be shunted by the detecting device across the coil in parallel with C. Even the diode probe head of the valve-voltmeter places some extra capacitance in shunt, but if an allowance of 10 pfs. is made over the value of C this probe capacitance and any further stray capacitances should be compensated for with fair accuracy. The self-capacitance of the coil can hardly be compensated for, since it will vary between wide limits with different coils.

With the signal generator at resonance with the tuned circuit, the inductance of the coil may be found from the formula—

$$L = \frac{1,000,000}{4\pi^2 f^2 C}$$

Where L is the inductance in microhenries, π^2 is taken as 9.866, f is the frequency to which the generator is tuned, in megacycles, and C is the value of the capacitance across the coil in microfarads.

With a 0.0001 mfd. fixed capacitor and a 10 pfs. allowance for strays, C would be taken as 0.00011 mfd.

By using the same circuit in a slightly different manner, together with a good variable capacitor and a few standard value fixed capacitances the variable capacitor could be calibrated. L, in this case, would be an inductance used for each test and could be any suitable tuning coil. The signal generator would be brought to resonance with L and, say, the fixed 0.0001 mfd. standard; this capacitor would then be disconnected and the variable capacitor connected in and tuned until the coil-capacitor circuit was again in resonance with the signal generator. The variable capacitor could then be calibrated at this point as 0.0001 mfd. No compensation for stray capacitances is necessary for these are now common to both fixed and variable capacitors.

The variable tuner is then disconnected and a 0.0002 mfd. standard connected in. The generator is again brought to resonance, the standard disconnected, the variable capacitor connected in and the tuned circuit resonated against the generator when the variable capacitor could then be calibrated as 0.0002 mfd. and so on.

Ganged capacitors may also be matched against a coil. The coil is connected across the first section of the capacitor and the signal generator tuned until the valve-voltmeter indicates resonance. The coil is then connected across the next section of the ganged tuner and should, of course, also be tuned to the same frequency as was the case with the first section of the capacitor. Any discrepancy will be shown by a lower reading of the valve-voltmeter and the trimming tabs on the moving vanes of the capacitor may be adjusted to correct the error.

Tests such as these, should be carried out over the whole tuning range of the ganged capacitor.

The constructor of amplifiers can put the oscilloscope to excellent use as a means of examining linearity and phase distortions at various frequencies, the circuit being as shown in Fig. 25. To avoid using the amplifier within the oscilloscope which might introduce distortion on its own account a simple potentiometer or voltage divider is used. The output from the audio oscillator is connected across the ends of the potentiometer, as is one pair of deflector plates, the amplifier being connected in so that it receives a fraction of the full signal.

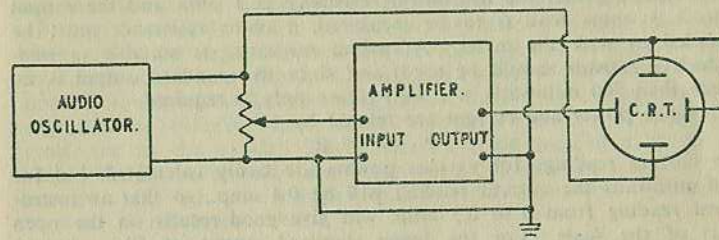


Fig. 25. Testing Amplifier Linearity.

The oscilloscope is used with both pairs of plates switched to "direct" or "external" deflection. The audio oscillator should be set so that as pure a signal as possible is supplied to the apparatus, but since any distortion in the source is applied both to the amplifier and the indicator, absolute source purity is not essential.

When the two inputs to the oscilloscope are equal in amplitude a line across the screen inclined at 45 degrees to the vertical will appear, and if the line is straight without kinks or bends, especially at the ends, the amplifier is free from amplitude distortion. Phase distortion causes the line to open out into an ellipse, this condition obtaining for the great majority of amplifiers at low frequencies, but amplitude distortion is still visible as distortion or curves in the ellipse. Phase distortion is chiefly serious when negative feedback is to be applied over the amplifying circuit, and in some cases can lead to the setting up of oscillatory conditions over some part of the signal cycle. Such spurious oscillation is visible as a type of "wave form" on what should be the straight line across the screen.

When finished receivers, or sets of commercial design, are being tested in the laboratory it is usual to make sensitivity and similar tests to a standard output power, 500 milliwatts in the case of receivers capable of outputs of more than 1 watt and 50 milliwatts in the case of receivers rated to have outputs of 1 watt and less.

The output meter described in an earlier chapter is designed to have a range covering the full outputs of all types of receivers and amplifiers and a meter with a higher sensitivity is required to measure outputs of the order of 50 and 500 milliwatts. Such a meter can be made up from a thermo-couple ammeter connected in series with a

resistance so that the total resistance of the two is equal to the voice coil impedance to which the output transformer of the apparatus under test is matched. Thus no capacitance will appear in the circuit and at the same time wave form error will not be so serious for the thermo-couple ammeter will give current indications on any wave shape corresponding to the R.M.S. indication of a sine wave.

Any good thermo-couple instrument should have its internal resistance printed on the scale; common values are 1 ohm and less.

Assuming that the instrument resistance is 1 ohm and the output into a 3 ohms load is to be measured, 2 ohms resistance must be coupled in with the meter. A carbon resistance is suitable (a non-inductive resistor should be used) and since the standard output is no more than 500 milliwatts, a $\frac{1}{2}$ watt rating only is required.

Since power and current are related by—

$$P = I^2 R$$

the current readings for various powers are easily calculated, but for 500 milliwatts the current reading will be 0.4 amp., so that an instrument reading from 0 to 0.5 amp. will give good results on the open part of the scale. For the lower standard output of 50 milliwatts the current reading will be rather low—0.13 amp.—but still clearly readable on a well-printed scale.

The multimeter A.C. section cannot, of course, be used for this purpose since the transformer is made for 50 cycles work and will give meaningless readings on the 400 cycles audio note which is the standard input (as a 30% modulation) on the signal generator carrier.

The low-power output meter circuit is shown in Fig. 26.

The full range of receiver tests may be summarised as follows.

First, check the receiver for correct operating voltages on all lines.

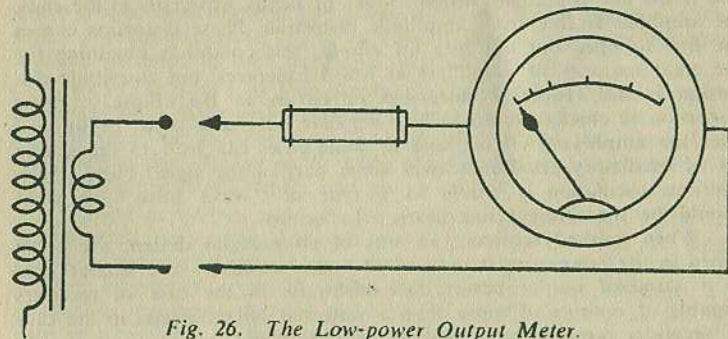


Fig. 26. The Low-power Output Meter.

Receiver sensitivity is checked by applying a test signal to the receiver of such a magnitude that the standard output is obtained. To obviate the receiver's noise output a measurement of absolute sensitivity is to be preferred, and this is made by feeding in an unmodulated

carrier to the receiver, then switching on the carrier modulation, adjusting the two inputs until the output power difference with modulation on and modulation off is either 50 or 500 milliwatts. The receiver sensitivity may then be expressed as the difference in microvolts between the two input signals. Obviously the noise power output of the receiver should be less than the signal power output, otherwise extremely poor design would be apparent.

If the gain of any single stage (such as an I.F. amplifier) is required it may be measured by connecting a valve-voltmeter across the input terminals and a second valve-voltmeter across the output terminals of the stage in question, when the stage gain is E_2/E_1 . Stray capacitances are introduced, however, and even if the stage is temporarily re-aligned so that the tuning is corrected the working conditions will still be different from those obtaining with no external gear connected to the circuit. Nevertheless a good indication of gain is obtained; if the second valve-voltmeter required is of a good commercial type with a very high input impedance for R.F. this should be used as the input meter.

The gain over the converter stage of a receiver is best measured by connecting a valve-voltmeter across the circuit preceding the converter—or, since in most sets the converter is the first stage, a known signal may be fed into the aerial terminals—and measuring the resulting voltage across the following stage, i.e., across the I.F. grid. The first I.F. transformer is thus included in the measurement but if a reputable component is in use its full data will have been published and allowance may be made for its portion of the overall gain.

The valve-voltmeter may also be used to measure the oscillator voltage injected into the mixer, or as an alternative the oscillator grid leak may be disconnected from the cathode or earth line and a milliammeter inserted into circuit to measure the grid current of the oscillator. The second method is, perhaps, more convenient than the first especially where the valve manufacturers specify the correct grid current. As one example, the Mullard ECH35 should have a grid current of 0.2 mA. flowing through 50,000 ohms.

The working of the oscillator should be checked at the main test frequencies, which may be taken for all tests concerning the tuned circuits of the receiver as—

600 kcs., 1,000 kcs. and 1,500 kcs. for the medium waveband.
160 kcs., 200 kcs. and 300 kcs., for the low frequency band,
although the Light programme transmitter may cause trouble at 200 kcs. in which case a slightly different test frequency may be chosen, and, for the short-wave broadcast bands—
6 Mcs., 9 Mcs., 12 Mcs., 15 Mcs., 17.5 Mcs., 21.5 and 26 Mcs.

The oscillator should be checked on each short-wave band at the low frequency end of the tuning range, however, since here the inductance-capacitance ratio is at its lowest and any failure in oscillation will be shown up.

It is of interest to check the tracking of superhets with a resonator or tracking rod which can be made up from a piece of narrow bore paxolin tubing or from a bakelite rod with the plugs tapped into either end. Two plugs are required, a small brass plug fitted to one end of the rod and an iron dust plug fitted to the other. The iron dust plug may be obtained from an old tuning coil or I.F. transformer.

To test the tuning of any coil, insert first the brass plug into the coil, then the iron plug. If the brass plug causes the receiver output to increase the coil inductance is large, whilst if the iron plug, inserted into the coil, causes an increase in receiver output, the coil inductance is too low. If the coil inductance is correct either end of the rod, inserted into the coil, will cause a drop in the receiver output.

To measure selectivity probably the band width measurement is the most simple to carry out. The test may be made at 600 and 1,500 kcs. The receiver is tuned to the signal generator and the generator input adjusted to give the standard output. The signal generator is then detuned by varying amounts on either side of the resonant frequency—say, by increments of 2, 3 or 5 kcs., depending on the genera-

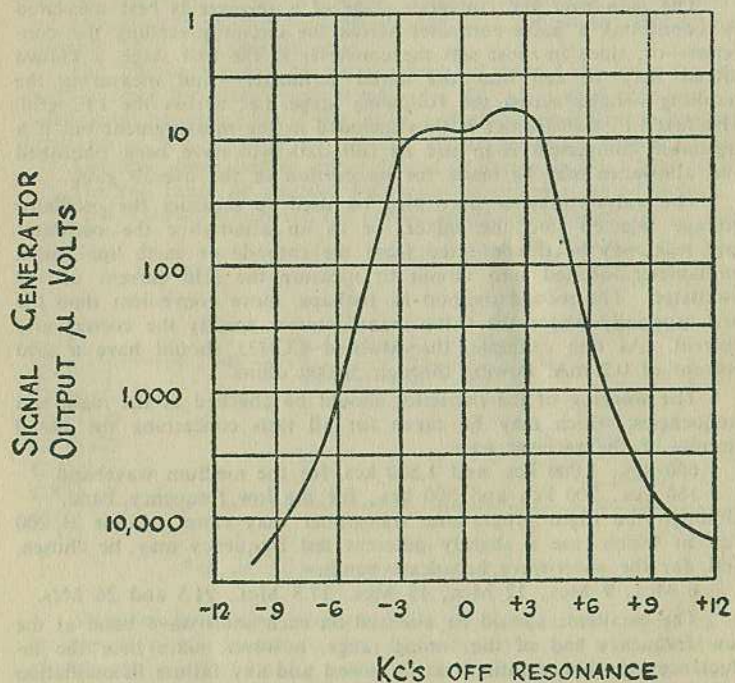


Fig. 27. A Tuning Curve or Bandwidth Check.

tor calibration—and the generator input adjusted at each detuning to bring the receiver output back to the standard amount until the ratio of input at resonance to the input off resonance is 10,000 times. The receiver A.V.C. line should be put out of action for this test.

A curve may be plotted showing generator input strength against kcs. detuning on either side of resonance when the curve illustrates the tuning curve of the receiver as a whole. A specimen curve is shown in Fig. 27, and it can be seen that the curve in this case shows up a lack of balance in what should be a double-peaked curve.

By using two signal generators a cross modulation or interference curve may be drawn. The two generators are connected into the receiver as shown in Fig. 28 so that their outputs are in series, and applied to the receiver through the artificial aerial (which is used in all cases where the signal generator is connected into the aerial-earth terminals of the receiver). The transformer by means of which generator No. 1 feeds into the receiver may have a primary and secondary consisting of 15 or 20 turns each of 20 S.W.G. enamelled wire close-wound on a $\frac{1}{4}$ in. former, the windings being in line. The output of both generators should have a high maximum—0.5 or 1 volt.

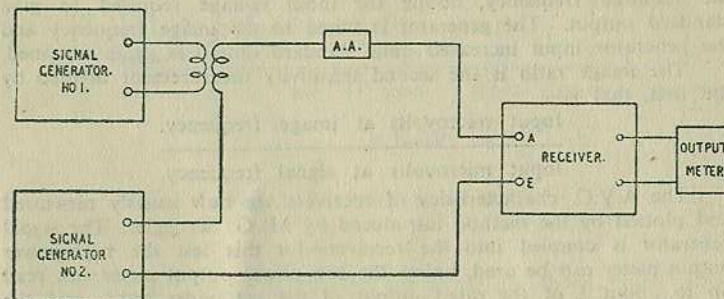


Fig. 28. Cross-modulation or Interference Check.

The test is conducted as follows:—

Switch on generator No. 2 and feed in a 1,000 microvolt signal, i.e., 1 millivolt—to the receiver. Adjust the receiver volume control until the standard output of 500 milliwatts is indicated. Switch off generator No. 2 and switch on generator No. 1, adjusting its input until the receiver again gives a 500 milliwatts output. By this means the effect of the transformer on the circuit can be neglected, for the final output of generator No. 1 after the transformer must be a standard 1 millivolt signal.

Switch off the modulation from generator No. 1, leaving the carrier on.

Switch on generator No. 2, modulated to 30% with 400 cycles in the normal way, and tune this generator to either side of the test frequency by increments of 9 kcs., increasing the generator output at each setting until the output due to the interference signal is the standard interference output which is 0.5 milliwatt.

Continue with the settings and increased input signals from generator No. 2 until its input is as high as 1 volt.

The interference signal in microvolts from generator No. 2 may then be plotted against the frequencies to which generator No. 2 is tuned—9, 18, 27 kcs., etc., with intermediate points if desired—and curves produced for each test frequency.

All users of short-wave superhet receivers know that a high image ratio is very desirable, the image ratio being the ratio of signal voltage at the image frequency to that input voltage at the signal frequency which is required to give the same output. The image frequency is the signal frequency minus twice the I.F. if the oscillator works at a frequency lower than signal frequency, or the signal frequency plus twice the I.F. if the oscillator works at a frequency above the signal frequency.

The ratio is obtained by feeding in a signal from the generator at the required frequency, noting the input voltage required to give standard output. The generator is tuned to the image frequency and the generator input increased until standard output is again obtained.

The image ratio is the second sensitivity measurement divided by the first, that is—

Input microvolts at image frequency.

Input microvolts at signal frequency.

The A.V.C. characteristics of receivers are now usually measured and plotted by the method introduced by M. G. Scroggie. The signal generator is coupled into the receiver—for this test the high-power output meter can be used, unless the low-power output meter can read up to about $\frac{1}{4}$ of the rated output of the set under test—and the receiver volume control is set to give full volume with no input from the generator. The first point plotted on the curve is thus the residual noise level of the receiver.

The input from the signal generator is now increased until the output meter shows the receiver giving about $\frac{1}{4}$ of its rated output when the volume control is turned down (leaving the generator alone) to reduce the output power to one-tenth of its reading on the meter. Again the generator input is stepped up until once more the output meter shows $\frac{1}{4}$ of the full output, and again the volume control is reduced to give a power output of one-tenth of the meter reading. The test continues until a signal generator input of 1 volt, or the maximum generator output is attained.

The results are plotted on logarithmic graph paper with a resulting curve similar to that shown in Fig. 29.

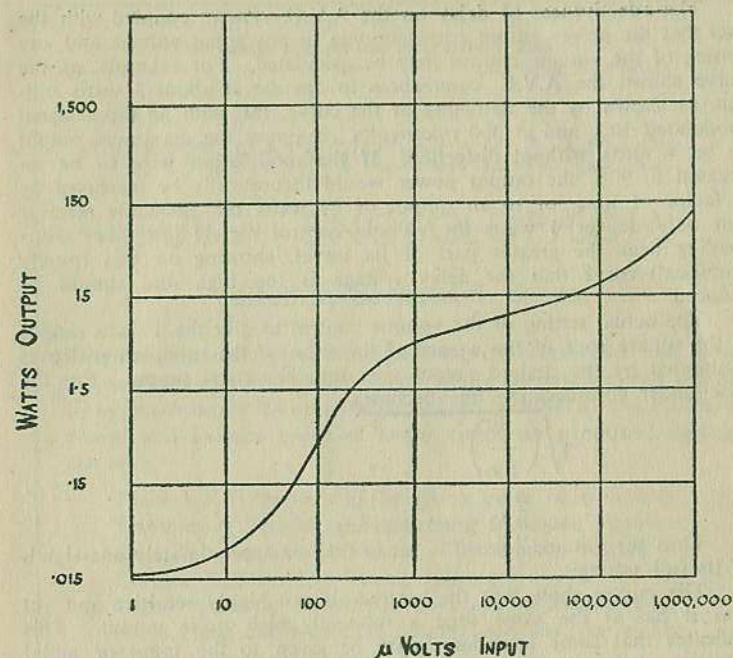


Fig. 29. An A.V.C. Curve.

The output powers plotted on the curve are those which would be obtained if the volume control were left at the maximum position throughout the test and supposing the audio section of the receiver to be capable of giving such outputs. For example, suppose that at 100 microvolts input the output meter read 500 milliwatts and the volume control was then turned down to give the one-tenth reading of 50 milliwatts. At 150 microvolts input the reading might rise again to 100 milliwatts but this would be plotted as 100×10 milliwatts, that is, 1 watt, and so on for each reduction in the setting of the volume control.

From the curve various points can be seen, including

The receiver residual noise level.

The output power at any level for any input in microvolts (including noise) may be read off from the curve.

The effectiveness of delay on the A.V.C. system, coupled with the fact that the power output corresponding to any input voltage and any setting of the volume control may be calculated. For example, on the curve shown the A.V.C. commences to operate at about 3 watts output, as shown by the flattening of the curve, this with an input signal modulated 30% and at 300 microvolts. Suppose the maximum output to be 4 watts without distortion. If the modulation were to be increased to 90% the output power would theoretically be increased by a factor of nine, or to an output of 27 watts but since the receiver can only deliver 4 watts the volume control merely intensifies overloading over the greater part of its travel, showing on this (purely empirical) curve that the delay voltage is too high and should be reduced.

The actual setting of the volume control to give the 4 watts output is the square root of the square of the ratio of the modulation depths multiplied by the desired output over the theoretical output. For the case under consideration this becomes

$$\begin{aligned} & \sqrt{\left(\frac{30}{100}\right)^2 \times \frac{4}{27}} \\ &= 0.3 \times \sqrt{0.148} \\ &= 0.12 \text{ approximately.} \end{aligned}$$

Thus the volume control is set to 0.12 or approximately one-eighth of its full setting.

The curves show that the receiver is not highly sensitive and yet that it has at the same time a relatively high noise output. This indicates that some attention might be given to the input or aerial coupling stage.

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