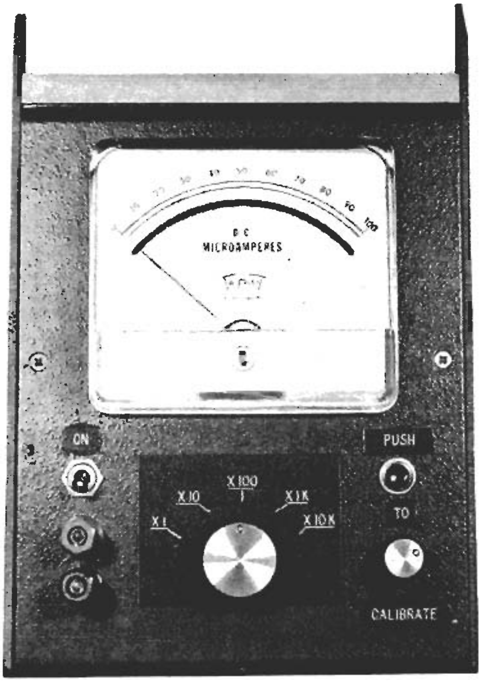
Build an Impedance Meter



MEASURE IMPEDANCE FROM ONE OHM TO ONE MEGOHM

BY CHARLES D. RAKES

THE ubiquitous volt-ohmmeter (VOM) can be used to make all kinds of resistance measurements, but it is an abject failure when it comes to measuring impedances. In fact, most hobbyists and technicians reach a dead end when they have to measure an impedance. There is no way to determine the impedance of a speaker, a transformer, an RL or RC network, etc.

The Impedance Meter, whose schematic is shown in Fig. 1, includes five impedance ranges from zero to 100, 1000, 10,000, 100,000, and 1,000,000 ohms. The measurements are made at 1 kHz and the readout is a relatively large 0-100 linear-scale meter. The device is battery operated and costs about $35.

The only restriction in using the meter is that the dc resistance path through the reactive component under test must be equal to or less than, the full-scale value of the range used to make the measurement. This restriction has never interfered with any impedance testing to date because, if a component is to be classified as reactive, it must have a higher impedance than the dc path. The only component that cannot be tested is a capacitor.

Circuit Operation. Transistor *Q1* and its associated components form a simple 1-kHz phase-shift oscillator that is buffered by *Q2*. The output of *Q2* is taken from the level control, *R9*, and applied to the primary of *T1*. Transistor *Q3* is connected as a constant current source, and its output (collector) is coupled to *IC1*, an op amp circuit having a high input impedance and a gain of about 10. The next stage is *IC2*, connected as an ac voltmeter.

The output voltage of the constant current source depends on the values of the collector and emitter resistors. The base is held at a fixed voltage by zener diode *D1*. When an unknown resistance or reactance is connected to *J1* and *J2*, the amount of voltage developed across it is read on the ac voltmeter.

Construction. Any type of construction can be used; but if you want to use a printed circuit board (the best way), the foil pat-

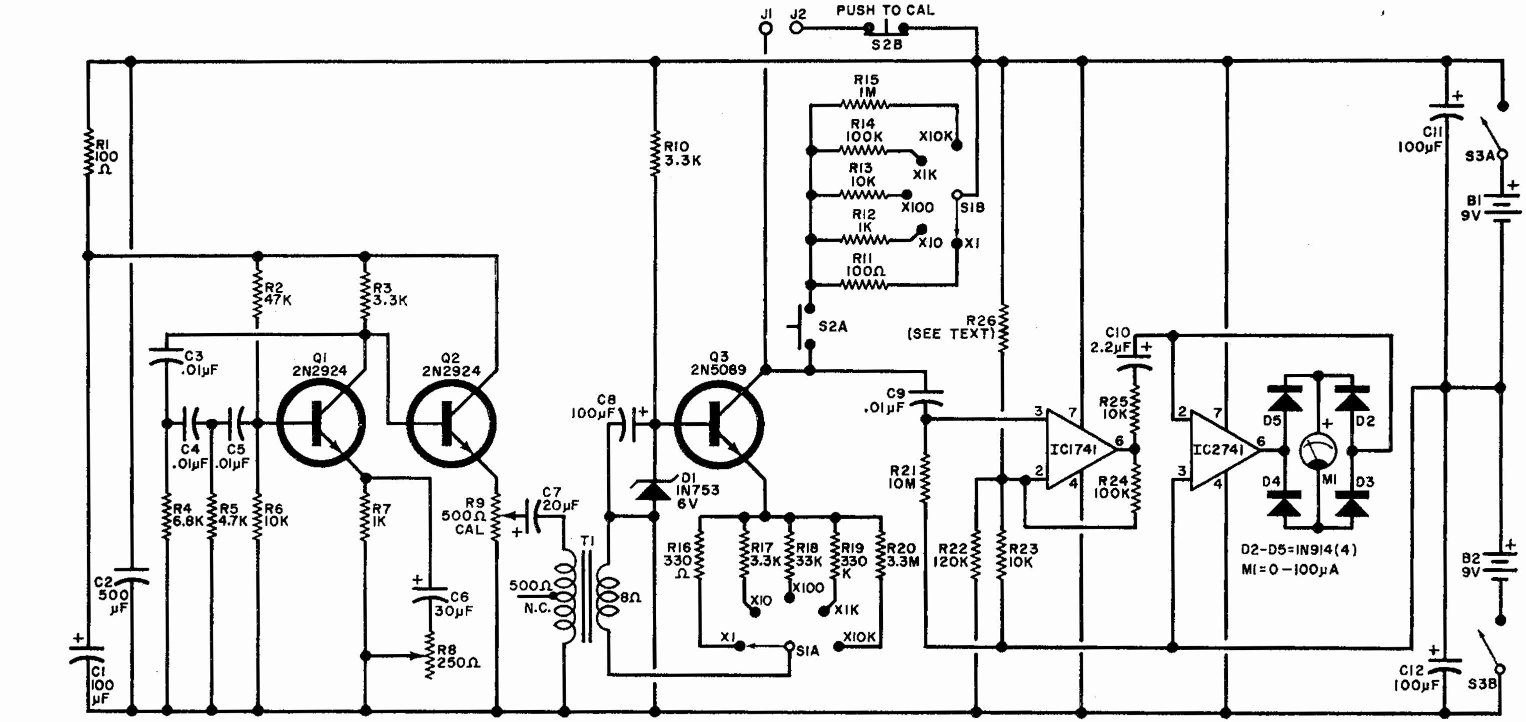
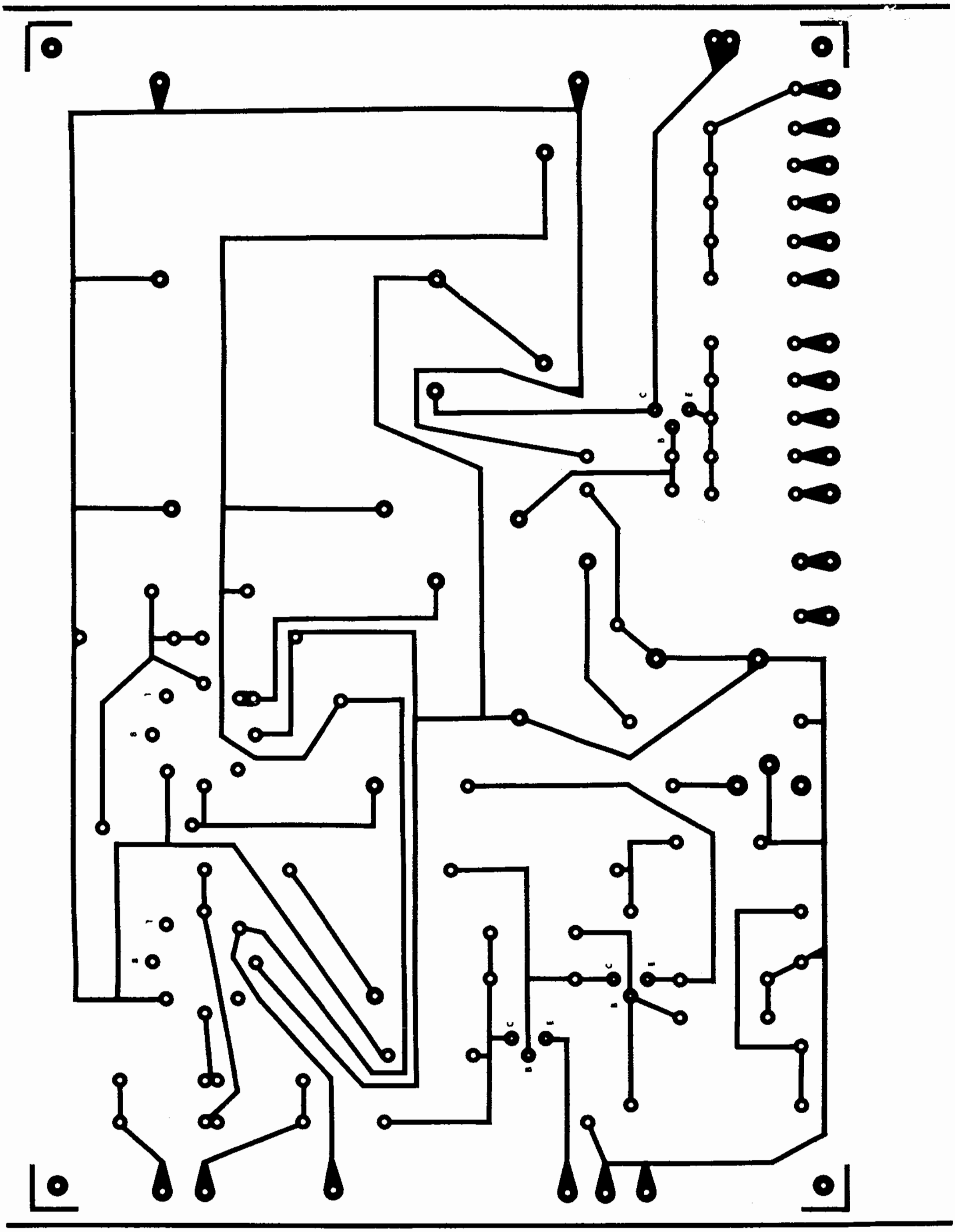


Fig. 1. The circuit is easily assembled using PC board.

PARTS LIST

B1, B2—9-volt battery (six AA cells)
C1, C8, C11, C12—100-µF, 25-volt electrolytic capacitor
C2—500-µF, 25-volt electrolytic capacitor
C3-C5—0.01-µF polystyrene capacitor
C6—30-µF, 25-volt electrolytic capacitor
C7—20-µF, 25-volt electrolytic capacitor
C9—0.01-µF paper capacitor
C10—2.2-µF, 50-volt polystyrene or Mylar capacitor
D1—6-volt zener diode (1N753)
D2-D5—Diode (1N914)
IC1, IC2—741 operational amplifier
J1, J2—Five-way binding post
M1—0-100-µA meter with linear scale
Q1, Q2—Transistor (2N2924)
Q3—Transistor (2N5089)
R1—100-ohm resistor
R2—47,000-ohm resistor
R3, R10, R17—3300-ohm resistor
R4—6800-ohm resistor
R5—4700-ohm resistor
R6, R23, R25—10,000-ohm resistor
R7—1000-ohm resistor
R8—250-ohm, PC potentiometer
R9—500-ohm standard potentiometer
R11—100-ohm, 1% resistor
R12—1000-ohm, 1% resistor
R13—10,000-ohm, 1% resistor
R14—100,000-ohm, 1% resistor
R15—1-megohm, 1% resistor
R16—330-ohm resistor
R18—33,000-ohm resistor
R19—330,000-ohm resistor
R20—3.3-megohm resistor
R21—10-megohm resistor
R22—120,000-ohm resisttor
R24—100,000-ohm resistor
R26—See text
S1—2-pole, 5-position non-shorting rotary switch
S2—Dpdt pushbutton switch
S3—Dpdt switch
T1—500:8 transistor output transformer
Misc.—Suitable chassis, battery holders, mounting hardware, etc.



tern and component layout are shown in Fig. 2. The housing for the prototype is shown in the photo; but this is not essential. The meter, the range selector switch *S1*, the calibrate switch *S2*, control *R9*, the power switch *S3*, and two connectors should be mounted on the front panel. Mount the circuit board on spacers and use appropriate holders for the batteries. The value of *R26* is selected in the calibration procedure.

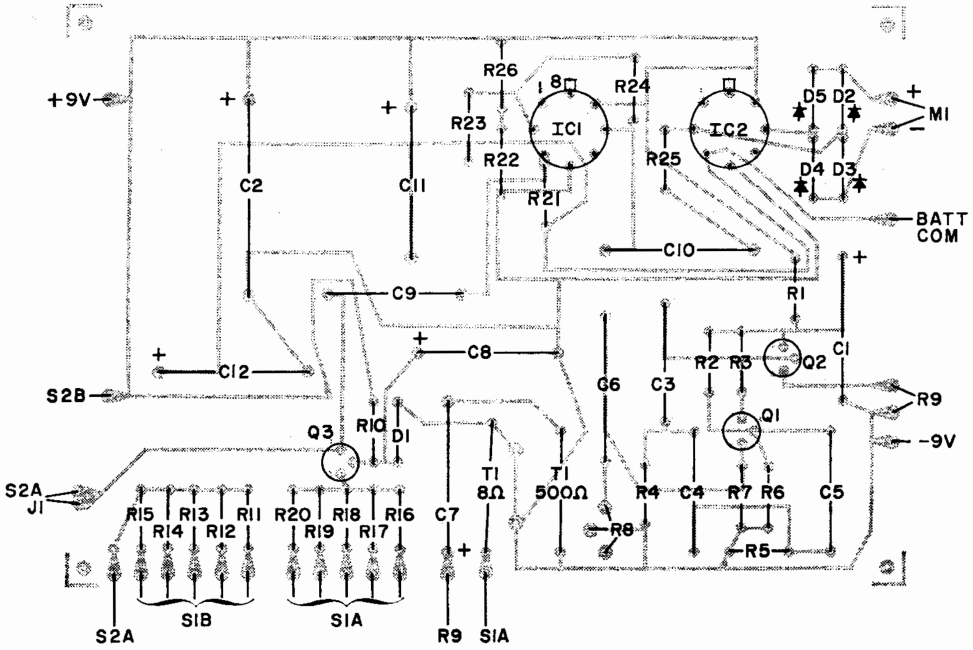


Fig. 2. The actual size foil pattern for a PC board is shown on facing page, while component layout is above. Perf board construction may also be employed.

Calibration. With all wiring checked, connect a 10-volt dc voltmeter between the common and pin 6 of *IC1*. With the power turned on, the meter can indicate either positive or negative at this point. Connect a resistance decade box between the *R26* terminals on the board and start with a resistance of 100,000 ohms. Increase this value until the dc voltmeter indicates zero. Select a standard resistor nearest to the decade-box value, and use this for *R26*. The voltage at pin 6 should be less than 1 volt.

Connect a 10,000-ohm resistor between *J1* and *J2*, and connect a scope in parallel with this resistor. Set *R9* about ¾ of the way toward maximum and put the range switch on RX100. Adjust *R8* (on the board) for the maximum peak-to-peak undistorted sine wave. Remove the scope and test resistor. Depress the calibration switch and adjust *R9* for a full-scale meter indication. Check each range of *S1* and note that a full-scale indication is obtained. If not, *R8* may have to be re-adjusted.

Applications. Any value of precision resistor (up to one megohm) can be used to check the various ranges. A wirewound resistor may provide false indications (not the same as the value marked on the resistor) because of the reactance of the windings.

To check speaker impedances, set *S1* to the lowest range. Use the same range for headphones and switch to higher ranges if necessary.

When testing transformers, load the secondary with the required resistance (to simulate the load) and read the reflected impedance on the meter.

If you suspect a shorted turn in a choke, transformer, speaker coil, or motor winding, the impedance meter can be used to verify your suspicion since even one shorted turn can cause the impedance of a normally high impedance to show some low value—near the dc resistance.

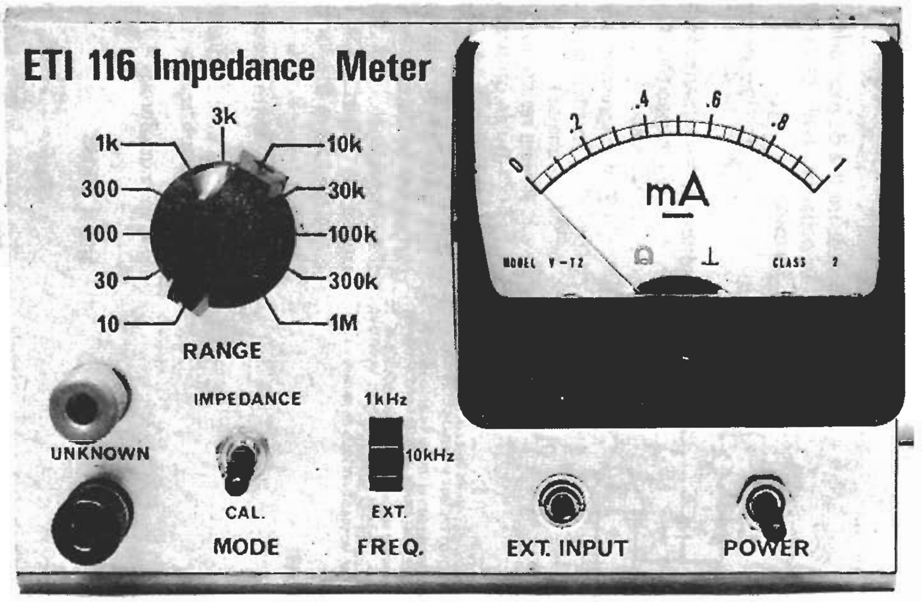
Either RL or RC networks can be checked easily but make sure there are no series capacitors in the circuit.

The first four ranges can be made as accurate as you wish by calibration (taking into account the tolerance of the meter and of the calibration resistors). The upper range (one megohm) can have an error as large as 5% due to the input impedance of *IC1*.

◆

IMPEDANCE METER

Measure impedance directly with ETI's new impedance meter — checks capacitance and inductance too!



THIS IS an unusual project — in that we started out designing one thing and finished up developing another!

We had intended to design an RLC bridge which is a very useful instrument and perhaps the next most commonly used after the multimeter, signal generator and scope.

But whilst it is useful to be able to measure the value of an individual component, on many occasions we are more concerned with the magnitude of the impedance than we are with the actual value of C or L.

For example assume that we require to know how the impedance of a speaker varies with frequency. Due to the effects of the crossover network it will not be known whether the speaker is inductive or capacitive in the crossover region. Additionally a speaker goes capacitive below its natural resonant frequency. Hence the use of an RLC bridge to plot impedance would be very tedious indeed. We would have to determine whether the speaker was capacitive or inductive, measure the actual value and then calculate the impedance for each point to be plotted.

With the ETI impedance meter impedance can be read *directly* as a function of frequency as shown in Fig. 7.

This is just one example of the many possible applications. In addition the meter may be used to measure component values by simply referring to a reactance chart or doing a simple calculation as detailed below.

Other applications include measuring the impedances of microphones, filters, transformers and amplifier inputs etc. All can be measured as easily as one would measure a resistor using an ohmmeter. Simply by connecting the device to the input terminals of the meter and making the measurement as detailed in the "How To Use" section.

In most practical applications we require to know the magnitude of the impedance — we do not care whether the device is predominantly inductive or capacitive.

On the rare occasions that we do require to know reactance we can

Fig. 1. Block diagram of the impedance meter shows that it consists of an oscillator an amplifier and a meter circuit.

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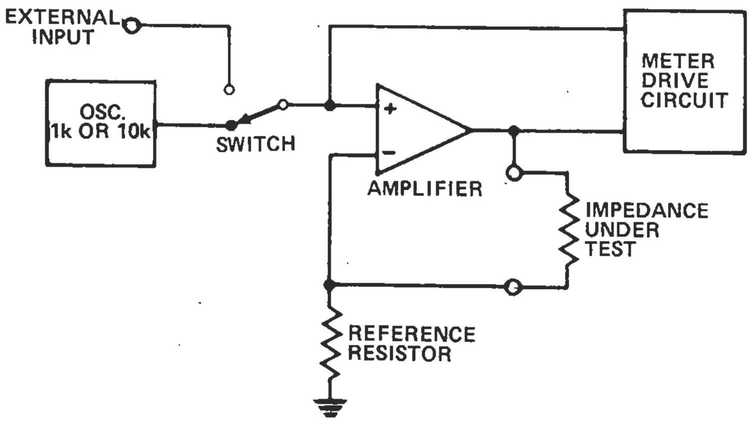


SPECIFICATION

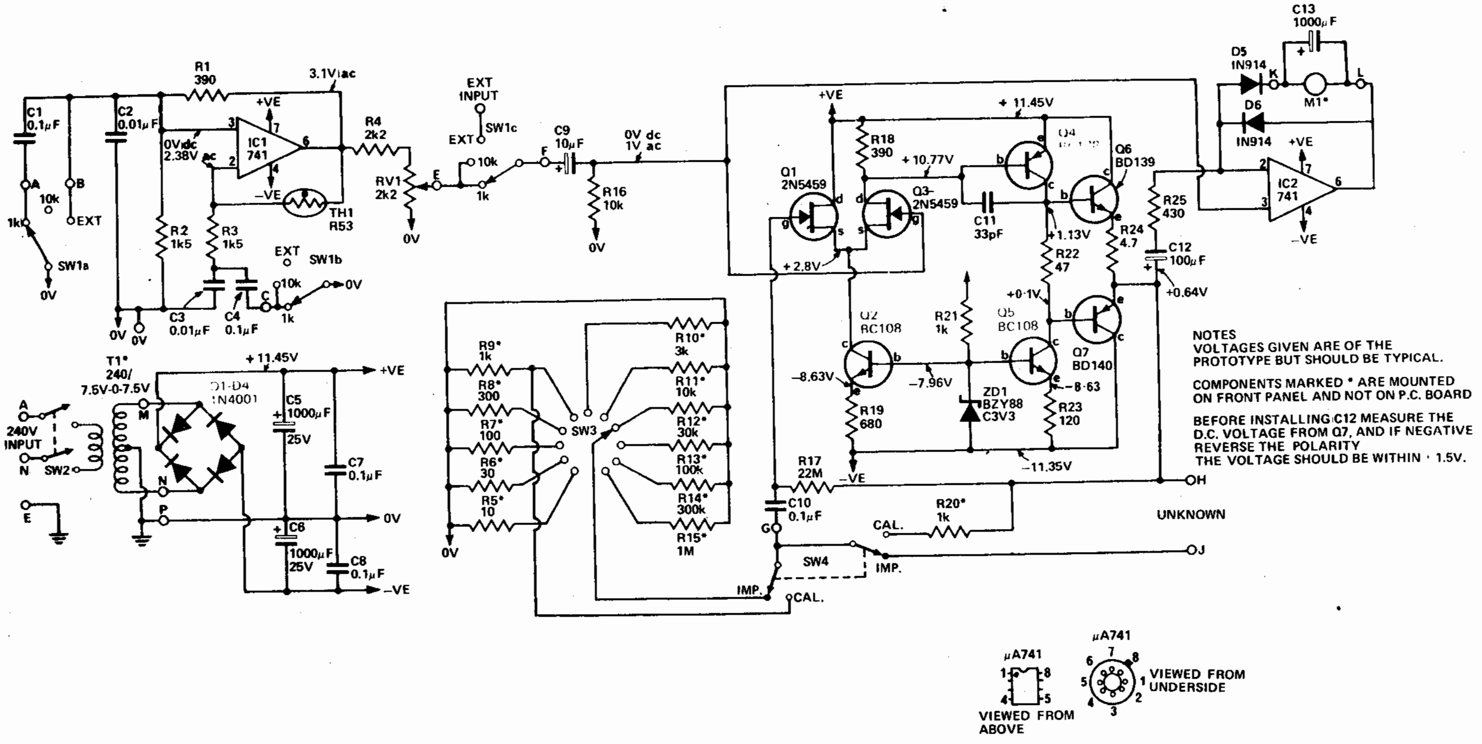
Impedance measuring range	1Ω – 1 Meg Ω	
Frequency of test	20 Hz – 20 kHz 1 kHz or 10 kHz	external internal
Range of inductance	10μH – 1000 H 20μH – 100 H	external internal
Range of capacitance	100 pF – 1000μF 100 pF – 100μF	external internal

Accuracy ± 5%

Voltage applied to unknown, max 1 V rms

When measuring items which are connected to the mains earth either the item, or the meter, must have the earth removed.

IMPEDANCE METER



NOTES
VOLTAGES GIVEN ARE OF THE PROTOTYPE BUT SHOULD BE TYPICAL.

COMPONENTS MARKED * ARE MOUNTED ON FRONT PANEL AND NOT ON P.C. BOARD

BEFORE INSTALLING C12 MEASURE THE D.C. VOLTAGE FROM Q7, AND IF NEGATIVE REVERSE THE POLARITY
THE VOLTAGE SHOULD BE WITHIN · 1.5V.

Fig. 2. Circuit diagram of the complete impedance meter.

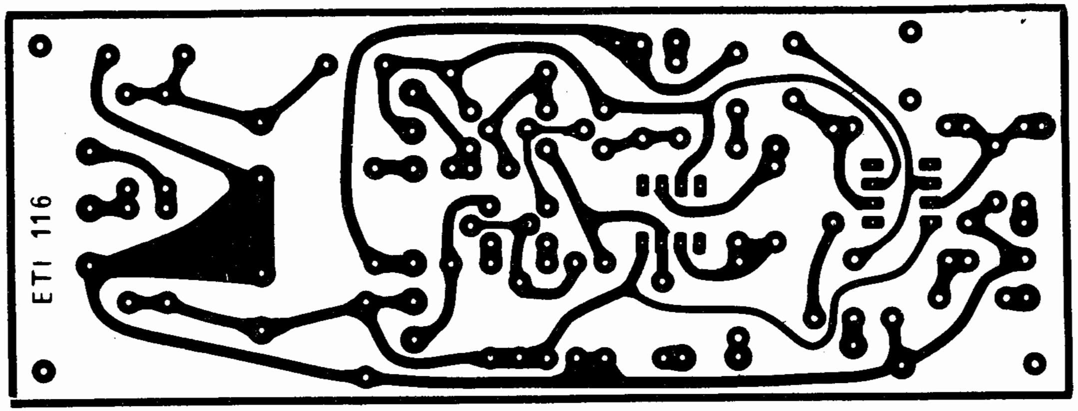


Fig. 3. Printed circuit board layout. Full size. 140 x 62 mm.

measure the dc resistance as well as the impedance and calculate from the formula

$$X = \sqrt{Z^2 - R^2}$$

where X = reactance inductive or capacitive at the frequency used

Z = magnitude of impedance (as measured on impedance meter)

R = dc resistance (as measured by an ohmmeter).

MEASURING CAPACITANCE

The value of an unknown capacitor can easily be determined by measuring the impedance and then using the reactance chart. Or, it may be calculated from the formula

$$C = \frac{1}{2\pi F X_c} \text{ (with capacitors } X_c = Z_c\text{)}$$

If the 10 kHz frequency is used this may be simplified to

$$\text{C in microfarads} = \frac{16}{Z_c} \text{ (}Z_c\text{ in ohms)}$$

and if 1 kHz

$$C\mu F = \frac{160}{Z_c} \text{ (}Z_c\text{ in ohms)}$$

Since the meter can resolve the range 1 ohm to 1 megohm this implies a capacitance range of 16pF to 60μF. But as explained elsewhere stray capacitance limits the lowest capacitance that can be resolved to about 100pF.

MEASURING INDUCTANCE

To determine the value of an unknown inductance the impedance is again measured and the value read off the reactance chart. Alternately the value may be calculated from

$$L = \frac{X_L}{2\pi F} \text{ high Q coils } X_L = Z_L$$

or

$$L = \frac{\sqrt{Z_L{}^2 - R^2}}{2\pi F} \text{ (low Q coils)}$$

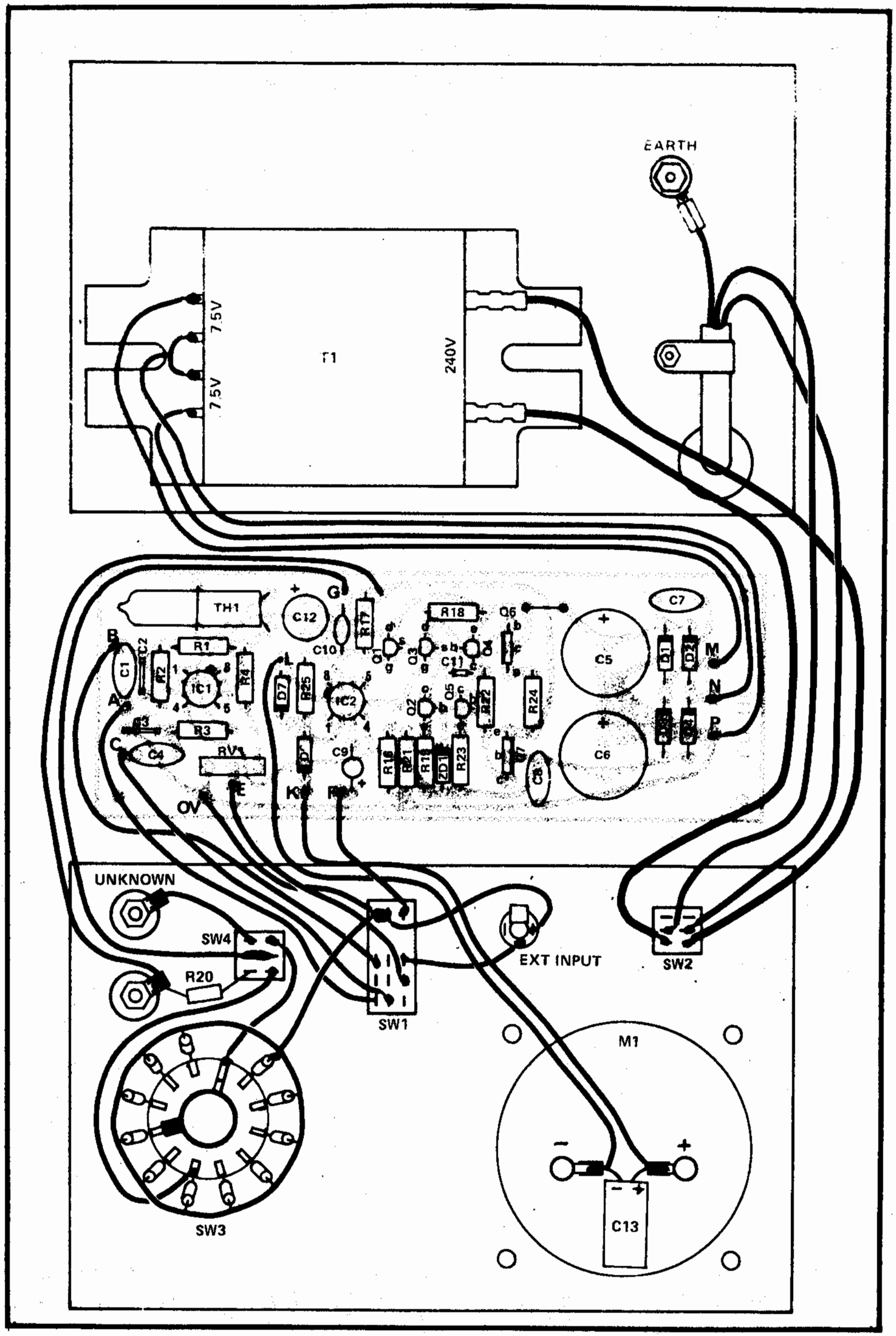


Fig. 4. Component overlay and wiring diagram for the impedance meter.

HOW IT WORKS ETI-116

The basic format of the impedance meter may be seen from the block diagram Fig.1. Firstly, we have an oscillator which may be switched to provide either 1 kHz or 10 kHz. Then we have a differential amplifier with a high input impedance, and lastly a meter drive circuit.

Either output of the oscillator, or an external frequency, as required, is passed to the non-inverting input of the amplifier. The amplifier gain is set by the ratio of the unknown impedance, Z, to the reference resistance, R. Due to feedback, the voltage across R is always equal to the input voltage and, as the amplifier requires no input current, the current through R must also flow through the unknown impedance, Z. The voltage across Z is therefore proportional to its impedance.

The meter circuit measures the output voltage by using the input voltage as a reference. Since the input voltage is equal to the voltage across R, we are effectively measuring the voltage across Z.

Refer now to the main circuit diagram Fig.2. The oscillator is of the Wein bridge type and uses a 741 IC as the amplifier and an R53 thermistor as the stabilizing element. The circuit oscillates at the frequency where the impedance of C2 and C3 is equal to the resistance of R2 and R3 respectively. Therefore, to change frequency, we simply change the values of C2 and C3. The output of the oscillator is attenuated by R4 and RV1 to approximately one volt.

The amplifier has a very high input impedance, can supply about 200 mA into a load, has an open-loop gain of 50 dB and can work into any load including a short circuit (unity gain).

An integrated circuit operational amplifier having the above characteristics (at reasonable cost) is not available, hence, a discrete seven transistor design was used. To obtain the high impedance input a pair of FETs, Q1 and Q3, used as a differential pair, operate with a constant current (4 mA) supplied by Q2. Transistor Q4 is supplied with a constant current of 22 mA by Q5, and Q4, in conjunction with the input pair, supplies the necessary overall gain. Transistors Q6 and Q7 buffer the output of Q4 and Q5 to provide the necessary current drive. The dc bias for the amplifier is provided by R17 such that an output voltage within ±1.5 volts of zero is always obtained.

The meter drive circuitry consists of a 741 IC with a meter, and half wave rectifier in series, connected in the feedback path. A second diode is used to prevent the IC being saturated on the opposite-polarity swing.

The current in the meter is half the current through R25 and, since this is proportional to the difference between input and output voltages of the amplifier, is proportional to the voltage across the unknown impedance. The meter scale is linear and the IC effectively compensates for the diode drop. Capacitor C3 provides the smoothing necessary when working at frequencies less than 40 Hz.

As previously stated the gain of the amplifier is set by the ratio of the unknown impedance 'Z' and the reference resistor 'R', and is equal to

$$\frac{Z + R}{R} \quad \text{(where Z may be complex)}$$

The value of R is switch selectable from 10 ohms to 1 megohm in eleven ranges. In the calibrate mode a 1 k resistor, R20, is substituted for the unknown impedance and the 1 k range selected. This provides a gain of two and thus with one volt in we have two volts out and hence 1 volt into the meter circuitry.

Thus, on calibrate, the output of the oscillator (or the external oscillator level) should be adjusted by RV1 to obtain full scale deflection on the meter. The calibrate position should also be selected before changing the unknown impedance, as an open circuit may damage the meter by driving it well beyond full scale.

IMPEDANCE METER

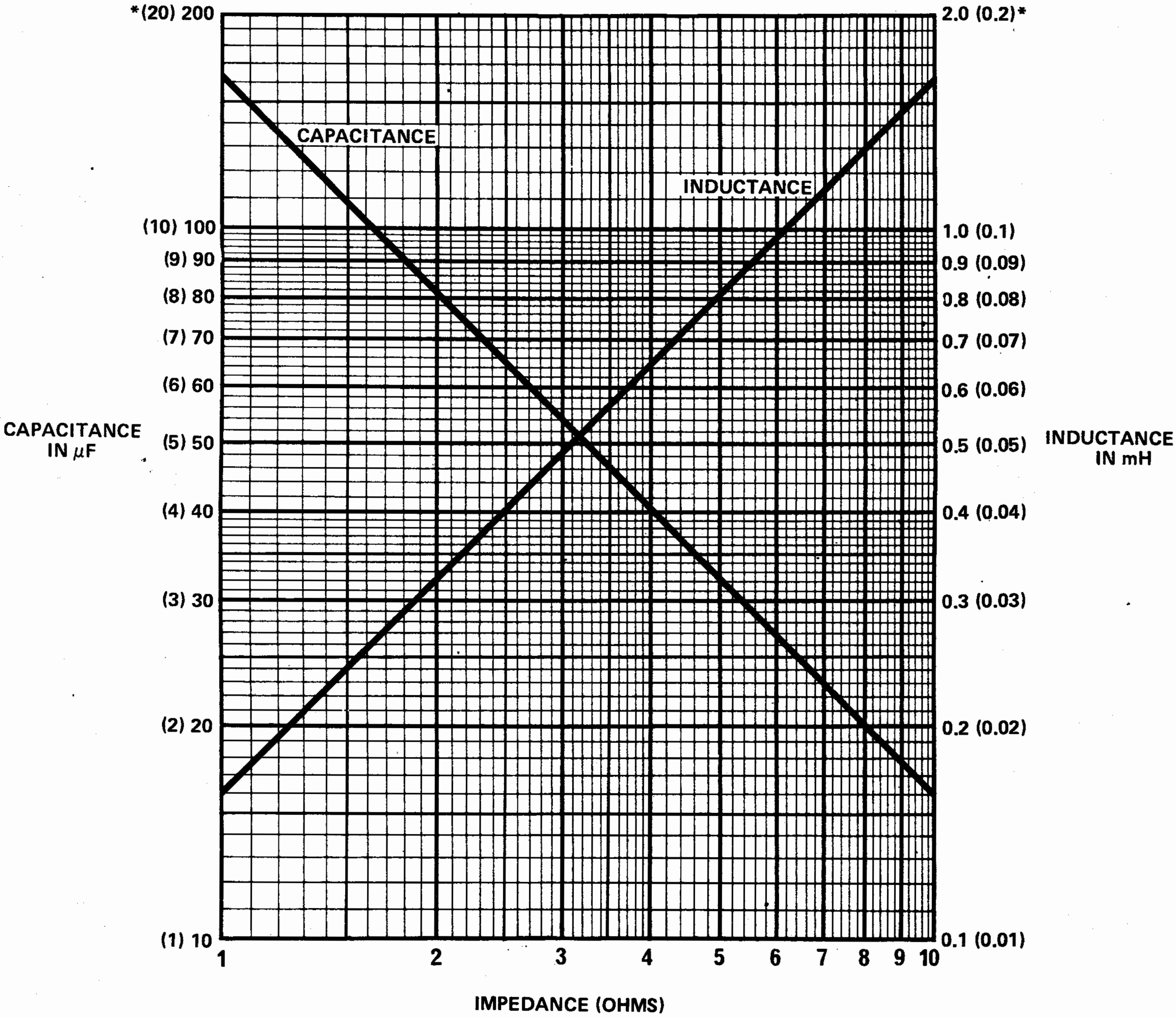
It should be borne in mind that we are determining impedances by using audio frequencies in this instrument hence components such as RF coils may well have a different impedance at RF frequencies (due to skin effect etc) than they do at audio. Additionally iron-cored coils have an inductance dependant upon the measuring frequency and upon dc current flowing. Hence such coils should be measured under conditions as close as possible to those when in circuit. Further the inductance value, as measured, will only be accurate on coils having a Q greater than 10.

If the dc resistance is greater than one tenth of the measured impedance the second formula should be used.

TURNS RATIO

To measure the turns ratio of an unknown transformer simply load the secondary with a value of resistance, R, which causes the impedance Zp (looking into the primary) to drop by 50% from the unloaded value. The turns ratio may then be calculated from

$$\frac{N_1}{N_2} = \sqrt{\frac{Z_p}{R}} \text{ (N = number of turns)}$$



FOR IMPEDANCES GREATER THAN 10Ω DIVIDE CAPACITANCE SCALE BY THE SCALING FACTOR AND MULTIPLY THE INDUCTANCE SCALES BY THIS FACTOR. e.g. A CAPACITOR WHOSE IMPEDANCE IS 6000 OHMS (SCALING FACTOR x 1000) AT 1 kHz VALUE IS 27/1000 = 0.027µF

*FIGURES IN BRACKETS ARE FOR 10 kHz

Fig. 5. Reactance chart for determining values of L or C from measured impedance at 1 kHz (10 kHz in brackets).

This calculation is based on the fact that an impedance in the secondary is transformed to an impedance in the primary that is proportional to the square of the turns ratio.

Many other applications can be devised for an impedance meter and the few mentioned here are indicative of the usefulness of such an instrument.

CONSTRUCTION

Any accepted construction method may be used but the use of a printed circuit board will greatly simplify the procedure.

Components should be assembled onto the printed circuit board, with the aid of the component overlay Fig 4, making sure that all polarized components are orientated correctly. Capacitor C12 should not be fitted initially as the required polarity must be determined as follows.

Temporarily connect the transformer to the otherwise completed board and switch on the power. Measure the voltage from the amplifier at point H. This should be within ± 1.5 volts of zero. If this voltage is negative reverse the polarity of C12 to that shown on the overlay. If the voltage is positive use the polarity shown. This variation of voltage at point H is due to differences in the FET transistors Q1 and Q3.

Attach wires to all output connections of the printed circuit board allowing sufficient length to terminate them in their respective positions. Instal the board in position using 12 mm long spacers and countersunk screws. Countersunk screws are necessary as they will be covered by the lid of the box. Instal the power transformer and power lead, on the rear panel, together with the power-cord clamp and earth lug. Mount the slide switch to the front panel using countersunk screws.

Resistors R5 to R14 should be mounted on the rotary switch SW3 before mounting it on the front panel. If the 30, 300, 3k etc resistors are not available they may be replaced by a parallel combination; eg 30 ohms is obtained from 33 ohm and 330 ohms in parallel and 3 k from 3.3 k and 33 k in parallel.

The rest of the front panel components, except the meter, (for ease of wiring) should now be mounted together with the escutcheon. The wiring can now be completed and the meter installed and connected.

USING THE METER

The meter should be used in the following manner:—

1. Switch the cal/impedance switch to cal.

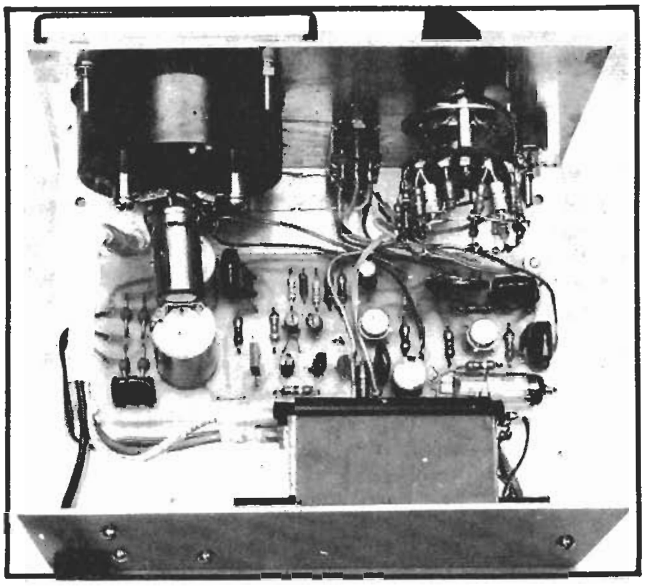


Fig. 4. Internal view of the meter shows how the board and other components are positioned.

2. Switch on power.

3. Select the required test frequency. The meter should read full scale, if not, adjust RV1.

4. If an external oscillator is used set the frequency and adjust oscillator output level to obtain full scale reading.

5. Connect the impedance to be measured.

6. Select the one megohm range.

7. Switch the cal/impedance switch to impedance.

8. Reduce the range, if necessary, to obtain a readable deflection. This reading is the required impedance; eg 0.6 on the 10 k range is an impedance of 6 k.

9. If desired the external frequency may be varied to obtain a plot of impedance versus frequency.

10. Switch back to 'Cal' before removing the impedance being measured.

TABLE 1

Error	Resistance (R2/R3)	Capacitor (C1,C4)	Capacitor (C2,C3)
1%	150k	0.001μF	100 pF
2%	68k	0.0022μF	220 pF
3%	47k	0.0033μF	330 pF
4%	39k	0.0039μF	390 pF
5%	27k	0.0056μF	560 pF
6%	22k	0.0068μF	680 pF
7%	18k	0.0082μF	820 pF
8%	18k	0.0082μF	820 pF
9%	15k	0.01μF	1000 pF
10%	13k	0.01μF	1000 pF

PARTS LIST — ETI 116

R24	Resistor	4.7 ohm	½W	5%
R5	"	10	" "	"
R6	"	30	" "	"
R22	"	47	" "	"
R7	"	100	" "	"
R23	"	120	" "	"
R8	"	300	" "	"
R1,18	"	390	" "	"
R25	"	430	" "	"
R19	"	680	" "	"
R9,20,21	"	1k	"	"
R2,3	"	1k5	"	"
R4	"	2k2	"	"
R10	"	3k	"	"
R11,16	"	10k	"	"
R12	"	30k	"	"
R13	"	100k	"	"
R14	"	300k	"	"
R15	"	1M	"	"
R17	"	22M	"	10%

RV1 Potentiometer 2k2 Trim type
TH1 Thermistor type R53

C11	Capacitor	33pF ceramic
C2,3	"	0.01μF polyester
C1,4,7	"	0.1μF "
C8,10	"	0.1μF "
C9	"	10μF 16V electrolytic
C12	"	100μF 6.3V electrolytic
C13	"	1000μF 6.3V electrolytic
C5,6	"	1000μF 25V electrolytic
Q1,3	Transistor	2N5459 or similar
Q2,5	"	BC108 "
Q4	"	BC178 "
Q6	"	BD137, BD139
Q7	"	BD138, BD140

IC1, 2 Integrated Circuit μA741C mini dip or T05

D1-D4	Diodes	1N4001 or similar
D5,6	"	1N914 "
ZD1	Zener Diode	3.3V, 400mW or similar

T1 Transformer 240V/7.5-0-7.5V @ 1A

M1	Meter	0-1mA FSD. 75 x 65 mm
SW1	Switch	three pole three position slide switch
SW2	"	DPDT 240V toggle switch
SW3	"	one pole eleven position rotary switch
SW4	"	DPDT toggle switch

PC board ETI-116, Metal box, Front panel, small phone socket, pointer knob, 3 core flex and plug, rubber grommet and cable clamp, four 12mm long spacers, two terminals, nuts and bolts etc.

IMPEDANCE METER

FREQUENCY CALIBRATION

The frequency should be within 10% of nominal if specified components are used. However, if a frequency meter is available the network can be trimmed to give the correct readings.

Measure both the 1 kHz and the 10 kHz and calculate the percentage errors. If either or both are low in frequency the resistors R2 and R3 can be paralleled with additional resistors to increase the frequency. Since this will affect both ranges choose the one with the greatest error. Table 1 gives the correct resistance to use.

Re-measure the frequencies. One frequency should now be right and the other high. The capacitors C1 and C4 or C2 and C3 can be paralleled by the appropriate capacitors as selected from Table 1.

LIMITATIONS

Due to stray capacitance, (about 15 pF) associated with the front panel terminals and the switches, the 1 megohm range is useful only up to about 4 kHz. The 300 k range is useful to about 10 kHz.

When measuring series LCR networks (where the impedance rises greatly off resonance) it is usually necessary to parallel a resistor across the network to stabilize it. Once at resonance, the resistor may be removed for the actual impedance measurement. The frequency can now be altered provided that the meter is not allowed to go off scale. The resistor used should be not more than 10 times the value of the network impedance at resonance. ●

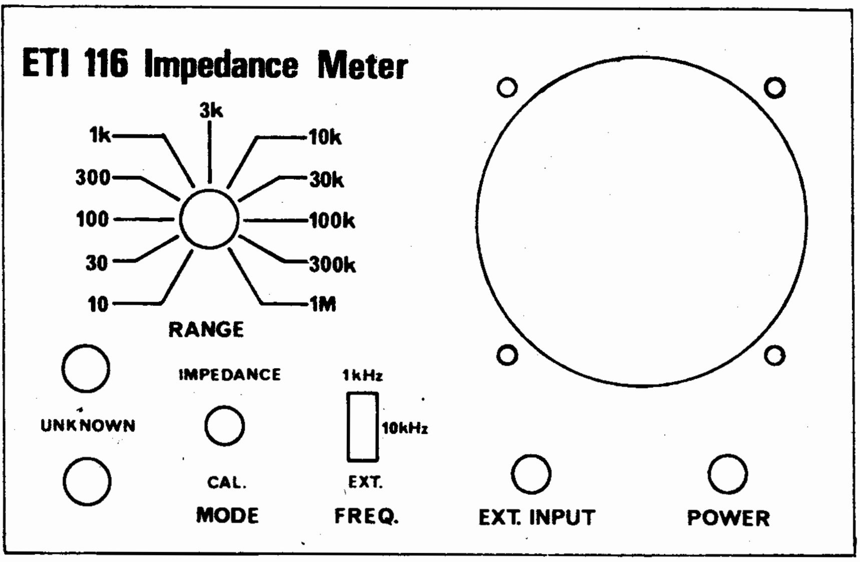


Fig. 6. Layout of front panel. Full size is 152 x 98 mm.

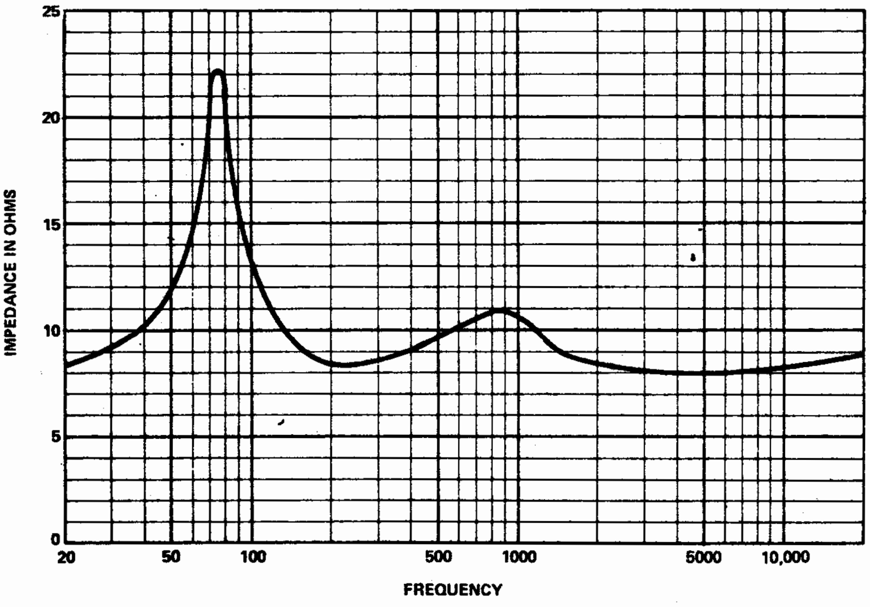


Fig. 7. Impedance-versus-frequency plot for a two-way speaker box. Note the combined speaker/box resonance is 75 Hz. The crossover frequency was 2 kHz. A plot such as this would be extremely difficult to generate using a conventional LCR bridge, but is very simply done using the ETI 116 impedance meter.