Q METER

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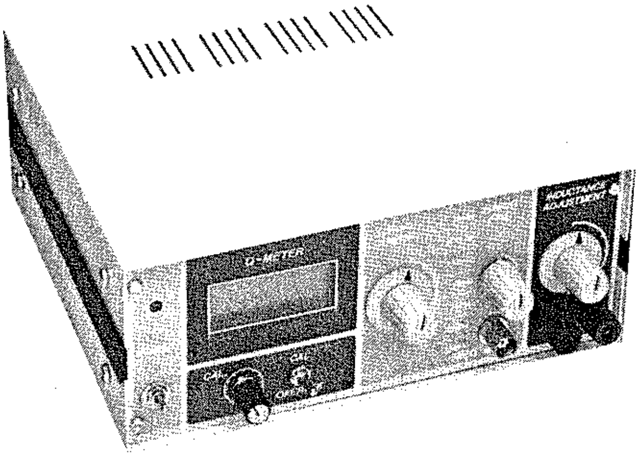

Among the main electrical properties of an inductor are its self-inductance, its quality (Q) factor and its self-resonance frequency. An instrument to measure the Q factor is described here. Based on resonance frequency measurement, the instrument can be used for testing inductors at frequencies up to about 50 MHz.

Many electronics experimentalists shy away from the design and use of inductors because they feel that these components are difficult to test and measure Also, often owing to lack of experience and suitable test instruments, these constructors are not always aware of the relative importance and meaning of inductor properties like the self-inductance and the quality factor Instruments for measuring self-inductance have been described for low-frequency and high-frequency inductors in Ref 1 and Ref 2 respectively The Q-factor, which is equally important for many applications, may be measured at reasonable accuracy with the present instrument The Q meter discussed is not intended for laboratory use where high accuracy and repeatability are prime considerations Rather, it is a low-cost test instrument for comparative Q measurements with an accuracy of about 10% Its usable frequency range extends from 70 kHz to about 50 MHz, while Q factors up to about 200 can be measured with reasonable accuracy

The principle

Since Q factor measurement is covered in detail in many electronics textbooks, a recap may suffice to explain the basic operation of the instrument —see Fig 1

A generator, G, with an internal resistance R_G is connected to an inductor and a variable capacitor. The voltage across the capacitor U_C, is measured The inductor, L_x is actually a combination of an inductance and a series resistance, R_S The variable capacitor is adjusted until the L-C tuned circuit resonates at the frequency set on the generator At the resonant frequency ω (= $2\pi f$), the voltages on the capacitor and the inductor are in opposite phase, so that

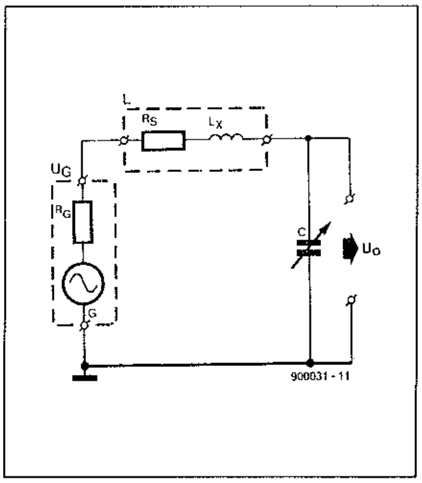

Fig 1 Principle of Q factor measurement

$$U_{(Lx)}/U_C = \omega L_x/(R_G+R_S) = Q_L$$

In other words, the loaded Q factor, Q_L, is the inverse of the loss factor of the inductor The higher its Q, the better the inductor, or in more practical terms, the more selective the parallel- or a series-tuned circuit that can be made by connecting it to a capacitor.

From the above formula, the internal resistance of the generator, R_G, determines the Q factor along with the self-inductance, the resonant frequency and the inductor's internal resistance Assuming that $R_G << R_S$, the real (or unloaded) Q factor may be calculated from

$$Q = \omega L_x/R_S$$

The unloaded Q factor exists in theory only since there is always a generator resistance, however small

A few points should be noted here. The loss resistance, R_S, is not simply the resistance measured by, say, an ohmmeter. For most small inductors, the d c. resistance is formed by the wire turns and remains smaller than 1 Ω or so The actual value of R_S, however, is a function of frequency because it is determined by the skin-effect which forces high-frequency currents to be 'pushed' towards the surface of the wire. The skin effect thus reduces the effective wire diameter and increases ohmic losses in the inductor owing to dissipation As a result, R_S of an inductor is often much higher than the ohmic resistance

The second point to note is evident from the equations: the internal resistance of the generator must be as low as possible to prevent large deviations of the measured Q factor of inductors with a relatively small R_S.

Finally, losses in the tuning capacitor and stray capacitance in the test circuit may lower the measured Q factor In practice, deviations of up to 10% must be allowed for, but these are not usually a problem in practical electronics work.

A more practical approach to Q factor measurement is illustrated in Fig 2. The voltage across an L-C tuned circuit is

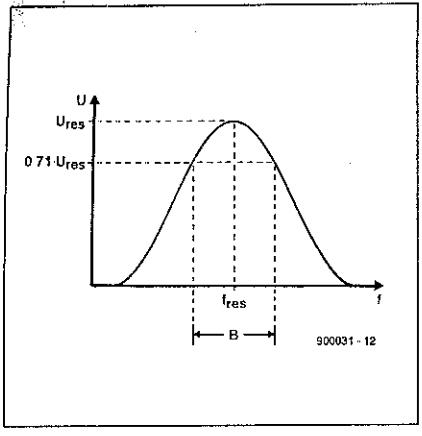

Fig. 2 3-dB bandwidth test method for establishing the Q factor of an inductor in a tuned circuit.

measured at the resonant frequency. This voltage is called the reference level, U_{res}. Next, the generator is tuned up and down to determine the frequencies at which the voltage drops to 0.71 U_{res}. These two frequencies are the –3-dB roll-off points and the range between them is the 3-dB bandwidth, *B*. A parallel combination of an ideal capacitor and inductor would result in a tuned circuit with an infinitely small bandwidth. In practice, however, there are small losses, so that

$$Q \approx f_{res}/B$$

This test method may be applied in practice with the aid of an RF signal generator to supply the required signal at the resonant frequency, and an oscilloscope to find the –3 dB points. Care should be taken, however, to couple these instruments as lightly as possible to the tuned circuit. Also, the previously mentioned loss factors in *L* and *C*, as well as stray inductance and capacitance, must be taken into account.

Practical circuit

All the ingredients mentioned in the context of theoretical Q measurement are found back in the circuit diagram in Fig. 3.

The RF signal generator is realized by an amplitude-controlled oscillator, T_5, with six frequency ranges. The oscillator is tuned by a variable capacitor, C_{13}, at the pole of the range selector, S_1. Amplitude stabilization is achieved by rectifying the oscillator output signal and using the direct voltage so obtained to control the current sunk by differential amplifier T_1-T_2. The RF rectifier for this purpose is formed by C_5 and D_1-D_2. The latter are two Schottky-barrier diodes Type HP2800 from Hewlett Packard. The voltage at the gate of FET T_4 goes more negative as the oscillator amplitude increases. Since the amplification of T_1 is inversely related to the negative control voltage, a tendency of the oscillator to produce a higher output voltage is counteracted by a smaller gain of T_1. When the oscillator starts, C_5 is rapidly charged and causes the gain control circuit to reduce the output amplitude until a stable level is achieved.

The function of the amplitude stabilization circuit is, of course, bound by practical limits. The actual oscillator output voltage varies between 0.9 V_{PP} and 1.6 V_{PP} at the lowest frequency in any range (C_{13} set to maximum capacitance). This variation may be greater in the highest frequency range as stray capacitance and inductance in the circuit become significant.

FETs T_6 and T_7 form a complementary power output amplifier capable of driving the 50-Ω RF test output, K_1, and impedance transformer L_8. The quiescent current of the power output stage is determined by P_1, which is adjusted for minimum distortion of the oscillator output signal.

Switch S_2 selects between the rectified oscillator output voltage (position B) and the rectified voltage developed across tuning control C_{24} (position A). Both voltages are obtained with the aid of virtually identical MOSFET buffers, T_8/T_9, which are followed by signal rectifiers D_3-D_4-C_{23}/D_5-D_6-C_{22}. The ratio of the resonant voltage to the reference voltage (= oscillator output voltage) is a direct measure of the Q factor of the inductor, L_x.

Inductor L_8 forms a wideband impedance transformer to ensure a low generator series resistance and stray capacitance. The importance of these characteristics is evident from the earlier discussion on basic Q measurement.

Opamp IC_1 forms the meter output driver. The maximum output voltage of 2 V corresponds to a Q of about 200. The actual read-out may be digital on a ready-made 3-digit LCD module, or analogue on a small moving-coil meter with a full-scale deflection of 2 V.

The circuit is powered by a symmetrical ±5 V supply obtained in a conventional manner by creating a virtual ground with the aid of an opamp, IC_3. The input voltage to the circuit may be unregulated between 12 VDC and about 18 VDC supplied by a low-power mains adapter. The current consumption of the circuit is smaller than 30 mA.

If used, the LCD must be powered by a separate battery, which will provide ample power for at least 200 hours of operation.

Construction

The first and foremost consideration that must be given to the construction of the instrument is to keep the connections between the inductor under test and the terminals marked Lx as short as possible. This is the reason that the printed-circuit board (see Fig. 4) is fitted vertically behind the front panel of the enclosure, a Type LC850 from Telet, which has been used for previous instruments in this series.

Inductor L_8

Start the construction by winding L_8 as shown in Fig. 5. Use 0.5 mm dia. enamelled copper wire. Winding A is simple to make because it consists of 40 turns on the ferrite ring core. Spread the turns evenly along the core, and at the same time ensure that the connections end up close together.

The low-impedance winding, B, consists of ten parallel-connected sub-windings on the ring core. Each of these sub-windings is formed by ¾ wire turn, the top and lower connection of which are connected to others by common wires that run round the outside of the ring core. First, make the ten sub-windings from 20-mm long pieces of enamelled copper wire, of which the enamel must be carefully removed over a length of about 1 mm at both ends. Next, cut off two 65-mm long pieces of the same wire and remove the enamel at the ends as well as at ten locations at 6-mm intervals. Clamp the ten sub-windings on to the ring core; the connections are at the outside. Run the first common wire around the outside of the core and join the ten top connections of the sub-windings. Next, do the same with the second common wire and the lower connections of the sub-windings. Press the common wires in place and bring their free ends together. Connect the B terminals to the respective points on the PCB —the wire that joins the top connections of the sub-windings goes to ground on the PCB. Solder the A terminals to the respective PCB connections.

The Type G 2-3/FT16 ring core from Micrometals may be hard to find locally. To enable constructors to find equivalents, the main electrical characteristics of it are given below.

outside diameter:	16 mm
inside diameter:	9.6 mm
height:	6.3 mm
relative permeability (μ):	4300
A_L value:	3280–5500
frequency range:	0.1– 50 MHz

Printed-circuit board

The printed-circuit board for the Q meter is double-sided but not through-plated. The large copper surface at the component side forms an earth plane to assist in RF decoupling.

Mount the six trimmer capacitors on to the board making sure that they are soldered rapidly to prevent deformation of the PTFE material by overheating. Next, fit the associated six inductors. Note that these are mounted alternately vertically and horizontally to prevent inductive coupling. As a further precaution, reverse the orientation of every second inductor. This is easiest done by noting the position of the coloured tolerance ring at one of the sides of the body.

The remainder of the passive parts on the printed-circuit board are fitted in the usual manner. Voltage regulator IC_2 is fitted upright (like all resistors) and does not need a heat-sink as it dissipates little heat under normal circumstances. Part terminals not shown with a small circle on

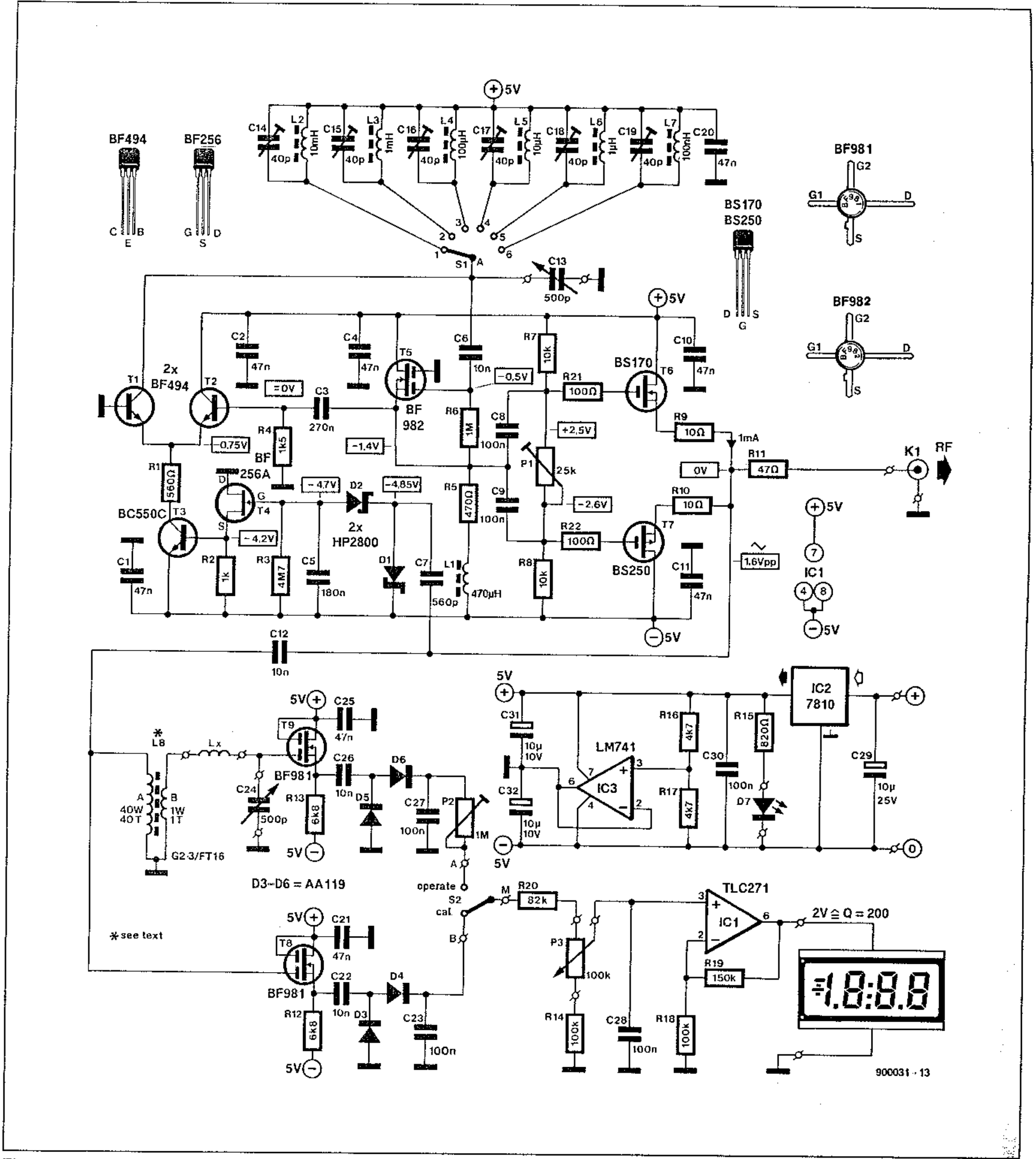

Fig. 3 Circuit diagram of the Q meter. The read-out is either digital in the form of an LCD module, or analogue in the form of a moving-coil meter —the choice between these is entirely up to the constructor.

the component overlay are soldered direct to the copper surface at the component side of the board

Solder rotary switch S1 direct on to the board (do **not** use a type with wire connections; these, however short, introduce unacceptable stray inductance). Only one section of a dual-pole 6-way switch is used.

The FETs are static sensitive and their terminals must remain short-circuited by a small piece of aluminium foil until they have been soldered on to the board. The actual solder operation should be as brief as possible, and take place with the solder tip connected to the ground surface of the PCB.

Finally, fit solder terminals for all external connections.

Mechanical work and connections

Study the lay-out of the front-panel (Fig. 6) and determine the location of the PCB to the right. Drill the front panel, using the ready-made adhesive as a template. At this stage, you have to choose between a digital read-out and a moving-coil meter before cutting the required clearance. If used, the moving-coil meter must be provided with a scale of 0–200. The f.s.d. voltage must be 2 V (if necessary fit the required series resistors to make this voltage correspond to the f.s.d. current of the meter).

Provisionally fit all controls and sockets on the front panel. Mark the location of the four holes in the PCB corners at the outside of the front-panel, to the right where the PCB is to be fitted vertically. Drill holes for M3×50 screws with countersunk heads. Insert these screws from the outside of the aluminium front panel. Secure them at the inside with a nut and a locking ring. Next slide approximately 30-mm long plastic PCB spacers over the screws and install the board with the components facing the inside of the front panel. Determine how much space you need for the tuning capacitors, the FREQ BNC socket and the Lx terminals, then cut the PCB spacers to the minimum required length. The Lx terminals are medium-duty binding posts for panel mounting.

Remove all controls and terminals from the front panel and apply the self-adhesive two-colour front panel foil. Mount all controls and sockets and tighten them without damaging the foil. Cut the spindle of the CAL potentiometer, P_5, to enable the knob to be fitted. Do the same with the spindle of the rotary switch on the PCB. Solder wires to the terminals of all controls and the meter (or LC display): those to the tuning capacitors, the FREQ socket and the Lx terminals must be kept as short as possible. Their length, inclusive of the cable connector, must not exceed 30 mm. Coax cable (RG174/U) may be used for the FREQ output, but given the short length ordinary screened cable is also suitable.

OPERATION AND CONTROLS

POWER switch: switch instrument on and off.

FREQ. socket: oscillator output for test purposes.

Lx sockets: connect to inductor to be tested. Do not use test leads.

METER: digital (LCD) or analogue (moving-coil); max. scale indication: 200.

CAL. control (P_3): adjust to set meter reading of 100 in calibate mode.

CAL./OPERATE switch (S_2): select between calibrate and Q measurement modes.

TUNING COARSE switch (S_1): select test frequency range. Always start measurement in 20–70 MHz range, switch to next lower ranges if no resonance is found.

INDUCTANCE ADJUSTMENT control (C_{24}): turn to find resonant frequency in selected range. Use before FINE TUNING control.

TUNING FINE control (C_{13}): peak resonant voltage indication on meter or display.

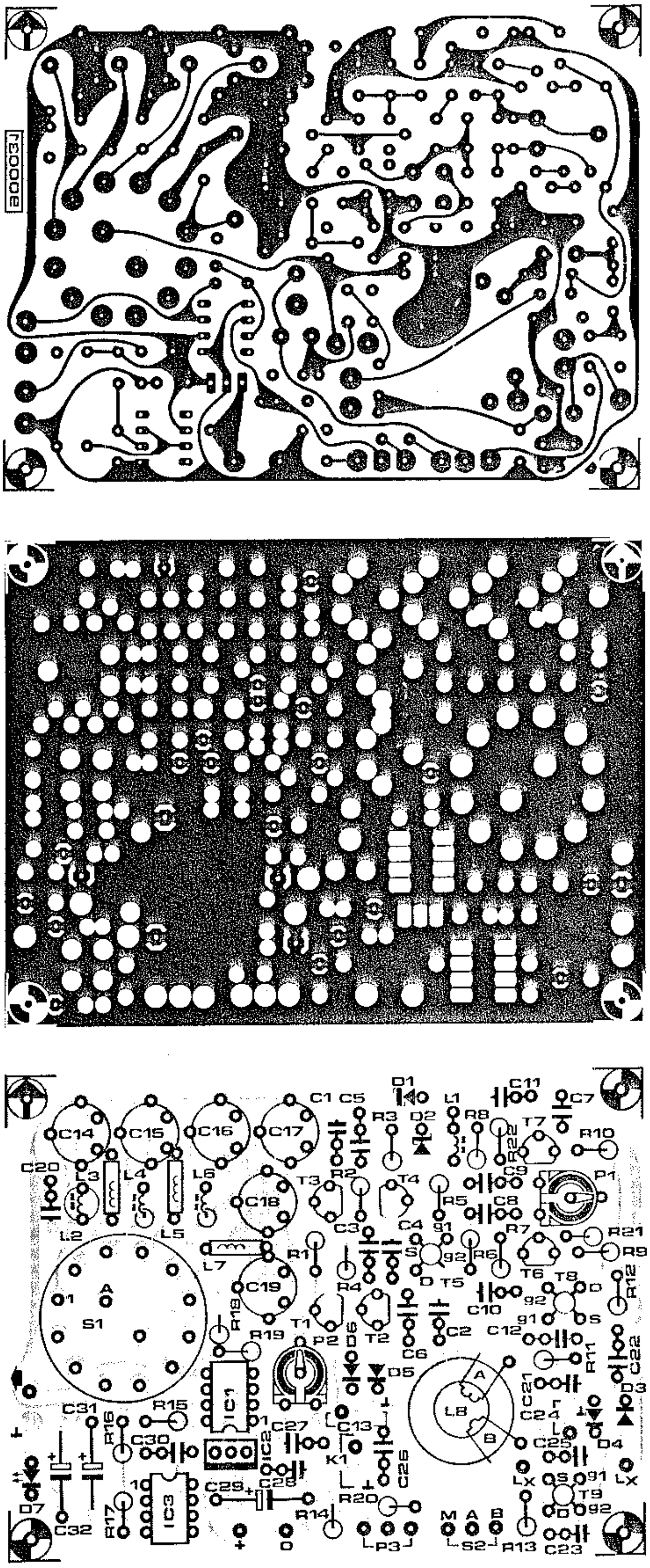

Fig. 4. Double-sided printed-circuit board for the Q meter

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Finally, drill a suitably sized hole in the back panel of the enclosure to enable the adapter (d c input) socket to be fitted If you use an LC display, install a battery holder for a single 9-V PP3 size battery, and use a double-pole (DPDT) on/off switch to power the display and the instrument simultaneously but separately

Ready for testing

Provisionally connect the PCB to the wires from the controls, the meter, the FREQ output socket and the binding posts Set all trimmers, P_2, and the front panel controls to the centre of their travel Only P_1 is set to minimum resistance (fully clock-wise)

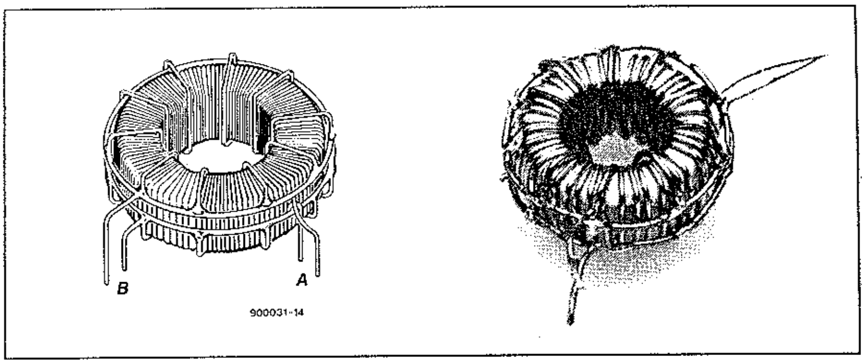

Fig. 5. **Construction of the wideband transformer, L_8 (left), and practical version (right).**

Setting up

Although the meter may be set up without the help of an oscilloscope and a frequency meter, it is recommended to use these instruments to achieve the best operation

Set the coarse tuning control to the lowest range (70 kHz) Switch on and use the scope to check the presence of a signal at the FREQ output on the front panel Adjust P_1 for minimum distortion of the sine-wave Do this for all ranges. In the highest range, a compromise will have to be reached between an acceptable output level and minimum distortion If you do not have an oscilloscope, use the meter on the instrument to adjust P_1: set C_{13} to maximum capacitance (fully cw) and adjust P_1 until the amplitude in the highest range (70 MHz) is not more than half that in the lowest ranges

The calibration preset, P_2, is adjusted with the aid of an inductor whose Q factor is accurately known (read the section on practical use below to find out how the Q factor is measured) Unfortunately, there is practically no other way to calibrate the instrument Owners of an oscilloscope and an RF signal generator may, however, use the previously discussed 3-dB bandwidth method to approximate the Q factor of a particular inductor If this method can not be used, or if a reference inductor is not available, P_2 is simply left at the centre of its travel

COMPONENTS LIST

Resistors:

1	560Ω	R_1
1	1k0	R_2
1	4M7	R_3
1	1k5	R_4
1	470Ω	R_5
1	1M0	R_6
2	10k	R_7;R_8
2	10Ω	R_9;R_{10}
1	47Ω	R_{11}
2	6k8	R_{12};R_{13}
2	100k	R_{14};R_{18}
1	820Ω	R_{15}
2	4k7	R_{16};R_{17}
1	150k	R_{19}
1	82k	R_{20}
2	100Ω	R_{21};R_{22}
1	25k preset H	P_1
1	1M0 preset H	P_2
1	100k lin potentiometer	P_3

Capacitors:

8	47n	C_1;C_2;C_4;C_{10}; C_{11};C_{20};C_{21};C_{25}
1	270n	C_3
1	180n	C_5
4	10n	C_6;C_{12};C_{22};C_{26}
1	560p	C_7
6	100n	C_8;C_9;C_{23};C_{27}; C_{28};C_{30}
2	500p mica-foil tuning capacitor	C_{13};C_{24}
6	40p PTFE foil trimmer	C_{14}–C_{19}
1	10µ 25V axial	C_{29}
2	10µ 10V axial	C_{31};C_{32}

Semiconductors:

2	BF494	T_1;T_2
1	BC550C	T_3
1	BF256A	T_4
1	BF982	T_5
1	BS170	T_6
1	BS250	T_7
2	BF981	T_8;T_9
2	HP2800	D_1;D_2
4	AA119	D_3–D_6
1	LED	D_7
1	TLC271	IC_1
1	7810	IC_2
1	LM741	IC_3

Inductors:

1	470µH	L_1
1	10mH radial	L_2
1	1mH	L_3
1	100µH	L_4
1	10µH	L_5
1	1µH	L_6
1	100nH	L_7
1	G.2-3/FT16 ferrite toroid	L_8

Enamelled copper wire 0.5 mm dia.

Miscellaneous:

1	6-way rotary switch for PCB mounting; 2 poles	S_1
1	miniature SPDT switch	S_2
1	BNC socket	K_1
2	binding post	
1	PCB	900031
1	front-panel foil	900031-F
1	enclosure LC-850 (Telet)	

Some manufacturers of small chokes and other inductors, e g , Siemens and Toko, state the approximate Q factor of their products in the related datasheets, extracts of which are often reproduced in catalogues of electronics mail-order firms. These values may be used as a guidance to verify the correct operation of the meter, and to provide the best possible setting of P_2 in the absence of a reference inductor.

The frequency ranges may be calibrated, although this is not strictly necessary If desired, connect a frequency meter to the FREQ output, and adjust trimmers C_{14}–C_{19} in the respective ranges for the maximum frequency indicated on the front panel Fine tuning control C_{13} is set to minimum capacitance (fully ccw) for this adjustment

Practical use

The meter is simple to operate: connect the inductor to be tested to the terminals Lx and set S_2 to OPERATE Starting in the highest range, find the resonant frequency by operating the FINE TUNING and INDUCTANCE ADJUSTMENT controls Step down to the next lower range if you do not find a clear resonance indication, which is marked by a sudden increase in the meter reading

When the resonant frequency has been found, the two tuning controls are adjusted for a maximum meter indication. Switch S_2 to CAL and adjust P_3 (CAL.) for ½ f.s.d. on the meter (indication '100'). Switch S_2 back to OPERATE and check that the resonance is still there by carefully turning the FINE TUNING control. The Q factor of the inductor can be read from the meter.

In the highest frequency range, it may be impossible to make the meter indicate 100 in the calibrate mode In that case, adjust the CAL control to set a reading of '50' and multiply the meter reading in the OPERATE mode by a factor of two ■

References:

1 Self-inductance meter *Elektor Electronics* September 1988.
2. RF inductance meter. *Elektor Electronics* October 1989