The measurement of "Q" —and an Economy Q-Meter

Used in conjunction with a familiar RF signal generator or modulated oscillator, this solid-state instrument will facilitate measurement of RF coils and transformers for Q-factor, inductance, inductive reactance and self-capacitance. It will also permit measurement of the value of small capacitors.

by Jamieson Rowe

The need to make measurements of coils (inductors), transformers and capacitors arises frequently in any experimental activity and development work concerning RF (radio frequency) circuits and equipment. Of the types of instrument available to perform such measurements, perhaps the most convenient is the so-called **Q-meter.** A modest but very useful instrument of this type is described in the present article.

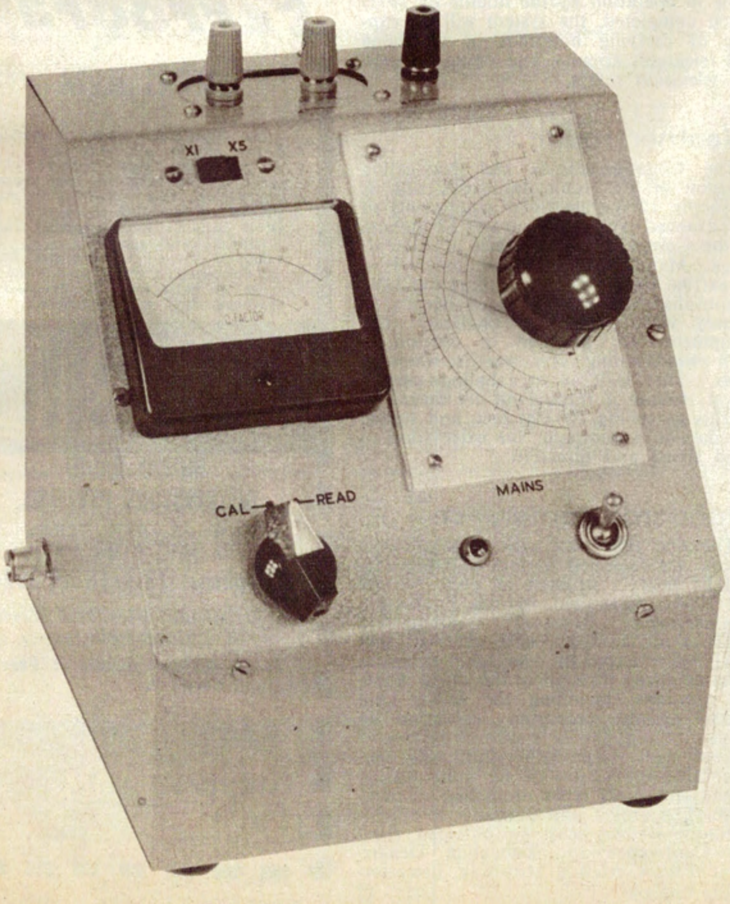
Basically, the Q-meter permits measurements on inductors and capacitors by indicating their behaviour at and near electrical resonance, and this being the case some fundamental knowledge of the phenomenon of resonance is essential both in order to understand instrument operation and in order to use it efficiently and effectively. Before introducing the instrument itself, it may therefore be worthwhile to review briefly the basic concepts associated with resonance.

When inductance and capacitance are associated together in a circuit, there is natural tendency for a portion of any energy present in the circuit to be stored alternately in, and transferred periodically between, a magnetic field associated with the inductance and an electric field associated with the capacitance. The frequency at which this energy oscillation tends to take place is known as the **natural resonant frequency** of the circuit, and is determined by the values of the circuit inductance and capacitance.

The resonant frequency of such a circuit can be found to an accuracy quite sufficient for most practical purposes using the expression

$$Fo = \frac{1}{2\pi\sqrt{LC}} \qquad \ldots (1)$$

where Fo is the resonant frequency in Hertz, L is the inductance in Henries, and C is the capacitance in Farads.



The way in which such a resonance may influence the operation of a circuit as a whole depends upon the effective position of the inductance and capacitance components, with respect both to each other and to the remainder of the circuit. This is most clearly illustrated in circuits where the inductance and capacitance are "lumped," or for practical purposes present solely as distinct inductor and capacitor elements.

In cases where an inductor and a capacitor are effectively connected in series with each other relative to the "input" or "output" of the circuit, or both, there is an effective reduction in their combined AC impedance in the vicinity of resonance, and this is usually taken as a characteristic of **series resonance.** On the other hand, if an inductor and capacitor are effectively in parallel relative to the circuit "input" or "output," or both, there is an effective magnification of their combined AC impedance in the vicinity of resonance, and this is usually described as **parallel resonance** or **antiresonance.**

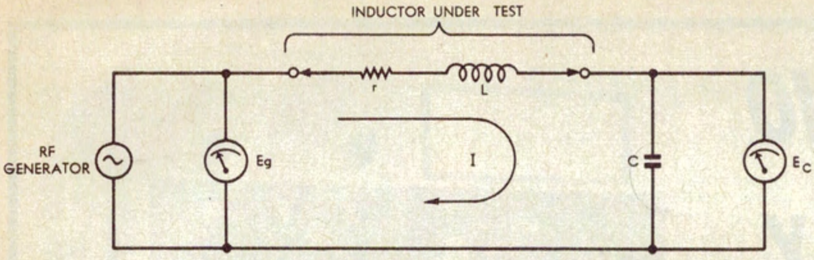
It is important to realise that series and parallel resonance are, in fact, only complementary manifestations of the same basic effect. Because of this, and despite certain second-order differences between the two, both may be described for practical purposes quite accurately by the expression of figure (1) and those which follow.

SPECIFICATIONS

An economy solid state instrument designed to be used in conjunction with a modulated RF signal generator or test oscillator for the convenient measurement of Q-factor, inductance and self-capacitance of inductors, and the value of small capacitors, at frequencies between approximately 200KHz and 30MHz.

The instrument requires approximately 80-100mV of RF input, modulated at approximately 30 per cent at a modulating frequency of between 400Hz and 1KHz. Input impedance is approximately 600 ohms.

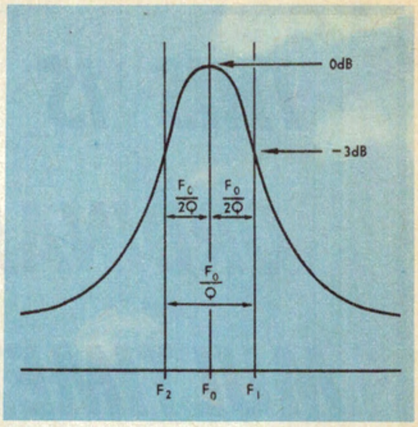
The internal resonating capacitor is variable between 25-415pF, and is calibrated in terms of C, (X.f) and (L.f^2). The Q-factor measuring range of the instrument is from below 20 to above 500.



$$\text{AT RESONANCE} \quad X_L + (-X_C) = 0$$
$$\text{SO} \quad I = I_0 = \frac{Eg}{r}$$
$$\text{I.E.,} \quad Eg = r.I_0$$
$$\text{BUT} \quad |E_C| = |X_C|.I_0 = X_0.I_0$$
$$\therefore \quad \frac{|E_C|}{Eg} = \frac{X_0.\cancel{X_0}}{r.\cancel{X_0}} = \frac{X_0}{r} = Q$$

* ASSUMED INFINITELY HIGH IMPEDANCE METER

Figure 1: BASIC PRINCIPLE OF THE Q-METER



$$F_1 - F_2 = \frac{F_0}{Q}$$
$$\text{I.E.,} \quad Q = \frac{F_0}{F_1 - F_2}$$

Figure 2: INCREMENTAL FREQUENCY METHOD

In both cases resonance takes place at a frequency where the AC impedance of the inductor, a positive reactance, is equal in magnitude to that of the capacitor — which is a negative reactance. In other words, there is cancelling of the two reactances Xl and Xc, where Xl is the inductive reactance, given by

$$Xl = wL \qquad . . . (2)$$

and Xc is the capacitive reactance, given by

$$Xc = -\frac{1}{w.C} \qquad . . . (3)$$

Here Xl and Xc are in ohms (reactive), L and C are in Henries and Farads as before, and w is "angular frequency" —equal to 2π.F, where F is the frequency in Hertz.

From (2) and (3) it may be seen that inductive reactance is zero at zero frequency (DC), and rises directly proportional to frequency, while capacitive reactance is infinitely high but negative at zero frequency, and falls inversely proportional to frequency. For any combination of an inductor and a capacitor there will thus be a frequency at which the reactances of the two will be equal and opposite, and this in fact is the resonant frequency given by expression (1).

Because of the mutual reactance cancellation, the impedance of a "perfect" inductor and capacitor combination connected effectively in series would fall at resonance to zero — a short circuit. However practical inductors and capacitors are not perfect but have losses; inductors have a finite resistance, and capacitors a finite leakage and series resistance. Thus the impedance of practical series inductor-capacitor "tuned circuits" does not fall at resonance to zero, but rather to a finite low value "dip" determined by losses.

Similarly the impedance of a "perfect" parallel tuned circuit would at resonance rise to infinity, whereas with practical inductors and capacitors it rises to a peak which is again determined by the circuit losses.

In both series and parallel resonant circuits the effective circuit losses determine not only the extent of the impedance dip or peak, but also—and often equally, if not more importantly — the "sharpness" of these effects. Hence in a twofold manner the performance of a resonant circuit is very much determined by the effective losses.

A very useful measure of the general "performance" of a resonant circuit, and one which takes the circuit losses into account is the Q-factor, otherwise called the "quality factor" or simply the "Q" of the circuit. Probably the expressions most often used to find Q-factor are

$$Q = \frac{Xo}{r} \qquad . . . (4)$$

$$\text{and } Q = \frac{R}{Xo} \qquad . . . (5)$$

Here Xo is the magnitude of the circuit reactances at resonance (equal to either Xl or Xc, as both are equal), and r and R are alternative representations of the circuit losses. The former, r, represents the losses considered as lumped into a hypothetical series resistance, while R alternatively represents the losses considered as lumped into a hypothetical parallel resistance. As this might suggest, expression (4) is usually most appropriate for series resonance, and expression (5) for parallel resonance.

At the present state of the electronic art it is not difficult to produce capacitors with leakage and series resistance losses kept to an extremely low level; however the best inductors which can be produced, while having low losses, are still relatively lossy in comparison. As a result the losses in most practical resonant circuits are almost completely associated with the inductor.

Because of this, it is common practice to assume that the capacitor of a resonant circuit is "perfect," and that the Q-factor of the circuit is determined solely by the inductor. The Q-factor of the circuit thus becomes identified with the inductor, and in fact it is quite common to speak of the "Q-factor of the inductor." The effective Q-factor of an inductor tends to vary with frequency, as in practice many of the losses are frequency dependent.

The Q-meter is used to measure the effective Q-factor of an inductor at any particular frequency by arranging for it to form part of a series resonant circuit at that frequency, the behaviour of the circuit being arranged to directly indicate the inductor Q-factor. The basic circuit and relationships used are shown in figure 1.

It may be seen that when capacitor C is adjusted for resonance at the particular frequency of interest, Xl and Xc effectively cancel so that the current Io is determined only by Eg and the losses represented by r. Thus we can write that Io=Eg/r, or by rearrangement Eg=Io.r.

While the reactances of the circuit do not determine the current Io, this current nevertheless flows through them, and voltages are developed across both L and C. The voltages across each can be many times higher than the generator voltage Eg, but the two are opposite in polarity because of the opposite types of reactance. A very high impedance voltmeter connected across C will at resonance indicate Ec, whose magnitude will be equal to (Xo.Io), the product of the reactance and the current.

From the foregoing Eg is at resonance proportional to (Io.r), while Ec is at the same time proportional to (Io.Xo); hence by taking the ratio between the two (Ec/Eg), the common factor Io can be cancelled to leave Xo/r. This may be seen from expression (4) to be equivalent to the Q-factor of the circuit. In other words the Q-factor may be found simply by taking the ratio between the capacitor voltage and the generator voltage, at resonance.

Although it may be seen to be basically quite simple and straightforward, Q-factor measurement is in practice subject to two quite significant sources of error. One arises because the idealised test circuit of figure 1 cannot be realised in a practical instrument: it is in general not possible to achieve an RF generator with zero source impedance, as assumed in figure 1, or to provide an infinitely high impedance metering circuit for the measurement of Ec.

The second source of error is perhaps more subtle, arising because all practical inductors have inherent self-capacitance. The effect of such self-capacitance is to provide, in "hidden" form, part of the capacitance necessary to resonate with the inductor at the measurement frequency. Hence the external capacitor C will no longer represent the total capacitance of the resonant circuit, and the validity of the measurement will suffer because Ec will no longer represent an accurate indication of (Xo.Io).

As will be explained shortly, the errors due to instrument limitations can be fairly accurately calculated and where they are significant corrections can be made. However, due to the distributed nature of inductor self-capacitance it is not really feasible to make valid corrections for the second source of error. As a result Q-factor measurements, even when performed on the most pretentious instruments, can only be relied upon to have an accuracy of between ±5% and ±10%. Q-factor is therefore best regarded in practice as a useful parameter indicating the relative "performance" of inductors and resonant circuits, rather than as an absolute figure.

Although the Q-meter cannot really make a valid correction for the effect of inductor self-capacitance upon the indicated Q-factor reading, it does permit a useful measurement to be made of the self-capacitance if this is considered as a hypothetical lumped shunt capacitor. To determine the value of this equivalent capacitor, measurements are made at two different frequencies, and the values of the external capacitor C required to achieve resonance in each case noted. The equivalent shunt capacitance is then calculated by comparing the ratio of the actual capacitance values to the theoretical ratio corresponding to the frequency ratio between the two frequencies used.

Hence if Cs represents the equivalent shunt capacitance of the inductor self-capacitance, and C1 and C2 the external capacitor values required to resonate at frequencies F1 and F2, the value of Cs may be found by the expression

$$Cs = \frac{C2 - (F1/F2)^2.C1}{(F1/F2)^2 - 1} \quad . . . (6)$$

If frequency F1 is chosen to be exactly twice F2, the calculation is considerably reduced, as expression (6) then simplifies to

$$Cs = \frac{C1 - 4.C2}{3} \quad . . . (7)$$

There are a number of ways of measuring Q-factor which are alternatives to that shown in figure 1, and these are sometimes used. However, the two most commonly used of these alternative methods pose in many cases rather severe calibration requirements. One, the so-called Incremental Frequency method, requires an RF generator having high resolution and accuracy in frequency calibration; the other or Incremental Capacitance method requires high resolution and accuracy in the calibration of the resonating capacitor. The only exceptions to these requirements is in the case of measurement of very low-Q inductors.

The Incremental Frequency method of Q-factor measurement is based upon the relationship between Q-factor and the "sharpness" of the dip or peak of impedance in the vicinity of resonance. It happens that for resonant circuits with a Q greater than 10 the frequency difference by which one may detune—in either direction — from resonance, before the depth of the impedance dip or peak has fallen by 3dB, is equal to a fraction 1/2Q of the resonant frequency. This is illustrated in figure 2.

It may be seen that if the two frequencies at which the dip or peak has fallen by 3dB are designated F1 and F2, then the difference between them — often called the "3dB bandwidth" — is equal to the simple ratio Fo/Q. The Q-factor can therefore be found by noting Fo, F1 and F2, and using the expression

$$Q = \frac{Fo}{F1 - F2} \quad . . . (8)$$

With high-Q circuits all three of these frequencies will be very close together, and this explains why an RF generator with high frequency resolution is required.

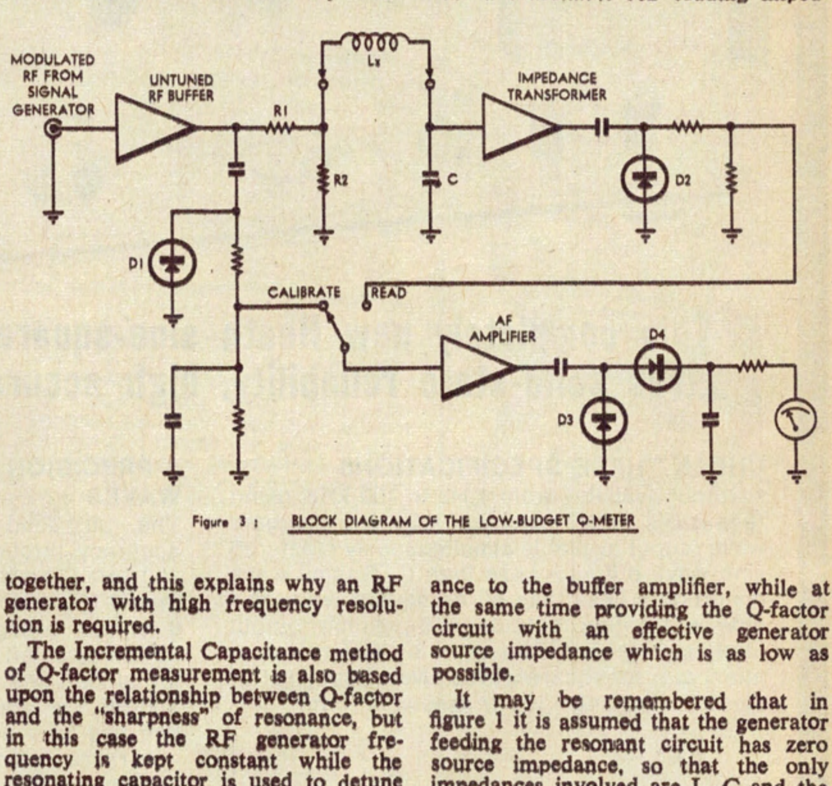


Figure 3: BLOCK DIAGRAM OF THE LOW-BUDGET Q-METER

The Incremental Capacitance method of Q-factor measurement is also based upon the relationship between Q-factor and the "sharpness" of resonance, but in this case the RF generator frequency is kept constant while the resonating capacitor is used to detune the resonant circuit itself to the points where the depth of the dip or peak has fallen by 3dB. Here if Co is the value of the capacitor at resonance, and C1 and C2 the values for the 3dB down points, then Q is given by

$$Q = \frac{Co}{C1 - C2} \quad . . . (9)$$

Here again as the Q to be measured increases, the three capacitance values become closer together, explaining why this method generally requires the resonating capacitor to be calibrated with high resolution and accuracy. In this case there is also the complication that the self-capacitance of the inductor should strictly be taken into account; for this reason the Incremental Capacitance method tends to be less accurate than the Incremental Frequency method.

The block diagram of the practical Q-meter to be described in this article is shown in figure 3, and it may be seen to differ in a number of ways from the basic arrangement of figure 1.

Perhaps the most obvious difference is that the instrument contains no RF signal generator of its own. Rather, it is designed to accept the RF output of an external generator or oscillator. This has been done purely for reasons of economy, and is based on the quite reasonable assumption that a conventional RF signal generator or oscillator will normally be available in any situation in which a Q-meter will be required. It may be noticed that the input RF to the instrument must be modulated, again a very reasonable requirement, and the reason for this will be explained shortly.

The modulated RF input to the instrument is amplified by an untuned wideband RF buffer, and then introduced to the Q-factor resonant measuring circuit by means of a resistive voltage divider formed by R1 and R2. The purpose of the divider is to provide a reasonable AC loading impedance to the buffer amplifier, while at the same time providing the Q-factor circuit with an effective generator source impedance which is as low as possible.

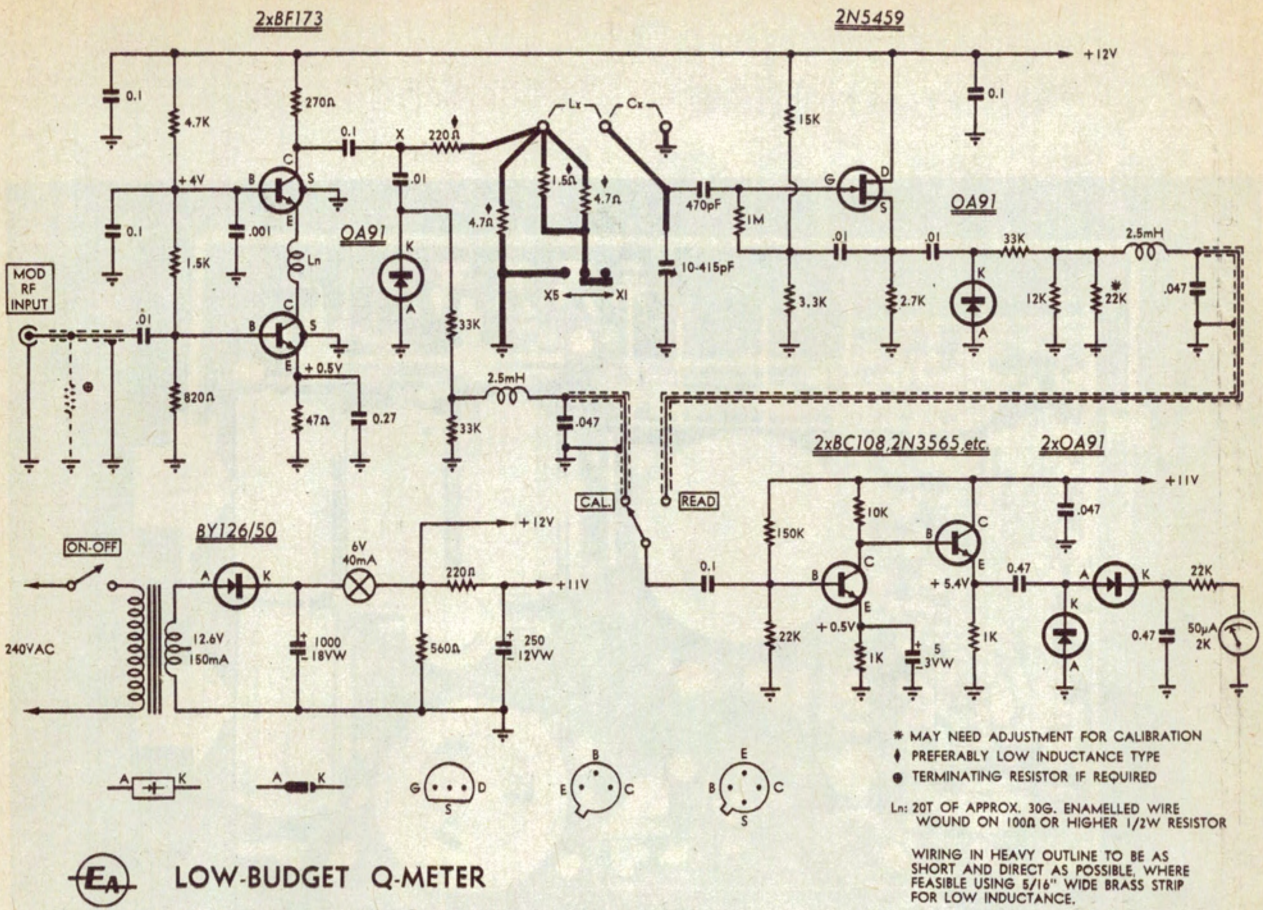
It may be remembered that in figure 1 it is assumed that the generator feeding the resonant circuit has zero source impedance, so that the only impedances involved are L, C and the hypothetical loss resistance r. This is, of course, an idealised situation, as in practice any normal generator will have a finite source impedance, even though the value can be made extremely low.

The error arising from this practical requirement can be calculated, and it transpires that to correct for the effect of generator source impedance (considered as a pure resistance), the following expression may be used:

$$Q = \frac{Xo.Qind}{Xo - Rs.Qind} \quad . . . (10)$$

Here Q represents the corrected Q-factor, Qind the indicated Q-factor (the Q actually measured), and Rs the effective generator resistance. Xo, as before, is the resonant reactance of the circuit.

From this expression it may be seen that the error caused by finite generator resistance depends upon the relative magnitude of Xo and (Rs. Qind), increasing as these two quan-



* MAY NEED ADJUSTMENT FOR CALIBRATION
♦ PREFERABLY LOW INDUCTANCE TYPE
● TERMINATING RESISTOR IF REQUIRED

Ln: 20T OF APPROX. 30G. ENAMELLED WIRE WOUND ON 100Ω OR HIGHER 1/2W RESISTOR

WIRING IN HEAVY OUTLINE TO BE AS SHORT AND DIRECT AS POSSIBLE, WHERE FEASIBLE USING 5/16" WIDE BRASS STRIP FOR LOW INDUCTANCE.

EA LOW-BUDGET Q-METER

The complete circuit for the practical Q-meter described on these pages. It is used in conjunction with a normal RF generator.

tities become comparable. Hence the greatest error and most need to make a correction occurs when Xo is relatively low (low L/C ratio, and/or low frequencies), and when either Rs or Qind or both are high. In general, provided that Rs is fairly low, corrections are not normally required unless Xo is very low while at the same time Qind is high.

In the block diagram of figure 3, Rs would be found by calculating the resistance of the parallel combination of R2 and (R1 + Rbo), where Rbo is the output resistance of the buffer amplifier. In the final circuit two values of Rs exist, because two values of R2 are used to provide two Q-factor measuring ranges. The values of Rs have been calculated, and will be given later in the article to enable the constructor to make measurement corrections when and if this is desired.

The measurement of generator voltage Eg and capacitor voltage Ec are facilitated in the practical instrument by means of two shunt-connected diode detectors, shown in figure 3 as D1 and D2. Detector D1 is connected not across R2, but across the buffer amplifier output; this is done because the signal level across R2 is too low for practical measurement. Allowance is made for the division in the R1-R2 voltage divider in interpreting the output of this detector, the assumption being made that the divider ratio is independent of frequency. This is a reasonable assumption if non-inductive resistors are used for R1 and R2.

Detector D2 is not connected across the adjustable resonating capacitor C directly, but instead via an impedance transforming stage which is designed to provide a very high loading impedance. This ensures that the measurement does not introduce a further source of error, by lowering the effective leakage resistance of C.

Although the DC output signals produced by the two detectors are proportional to the signal voltage Eg and Ec upon which the Q-factor measurement is based, these signals are quite low in magnitude and are not directly suitable for connection to a meter movement. Because stable DC amplification involves rather complex circuitry, however, this step is not taken. Rather, in the interests of simplicity and economy, use is made of the fact that if the RF signal fed to the instrument is modulated, both detectors will have an AF or audio output signal derived from the modulation, and that the ratio between the two audio signals will again be proportional to the Q-factor.

By this use of the modulating signal for measurement rather than the carrier-proportional DC output of the detectors, the metering section of the instrument is simplified to a straightforward AF amplifier followed by a voltage-doubling meter rectifier using diodes D3 and D4. While it is true that this approach also introduces yet another potential source of error (!) due to the reduction of effective bandwidth of the resonant circuit with increasing Q-factor, the magnitude of this error will be quite small, amounting to only 3dB even for a low measurement frequency of 200KHz and a relatively high Q-factor of 250 (assuming 400Hz modulation).

It may seem strange that the two positions of the metering switch are labelled "calibrate" and "read." The reasoning behind this is based upon the fact that, because Q-factor is equal to the ratio of Ec/Eg, holding Eg constant will make Ec directly proportional to Q-factor. Hence the instrument may be arranged so that, by adjusting the external RF generator output to produce a preset "CAL" reading when measuring Eg, the Ec measurement may be read off a meter scale directly in terms of Q-factor. This simplifies the use of the instrument considerably.

Using the block diagram of figure 3 as a guide, it should not be difficult to identify the main sections of the new Q-meter as shown in the main circuit diagram.

It may be seen that the untuned RF buffer amplifier comprises two type BF173 high-frequency NPN silicon planar transistors connected in a cascode configuration. While simple, the amplifier has useful power gain, a fairly high input impedance and a response which is only about 6dB down at 30MHz. A neutralising inductor Ln is connected between the collector of the input device and the emitter of the output device to ensure stability.

The resistive voltage divider feeding the resonant circuit of the instrument employs a 220 ohm resistor in the series position corresponding to R1 in figure 3. For the lower or "X1" basic Q-factor measuring range provided by the instrument, the lower resistor R2 has a value of 4.7 ohms. Additional 1.5 ohm and 4.7 ohm resistors are connected in parallel with this resistor by a slider switch; this has the effect of increasing the divider ratio by five times, providing the higher or "X5" measuring range.

The effective generator resistance seen by the resonant circuit for the two measuring ranges is 4.6 ohms and 0.92 ohms for the X1 and X5 ranges respectively, and these figures may be used for Rs if the measurements made by the instrument are to be corrected using expression (10). In general such corrections will normally only be necessary when measuring low-value inductors at medium-to-low frequencies on the X1 range.

The resonating capacitor used in the instrument is a standard miniature single-gang 10-415pF variable unit. The connections between the capacitor, the inductor connection terminals and the injection divider resistors are kept as short as possible, and where feasible are made using 5/16in brass strip for rigidity and low inductance

An earthed third test terminal is provided on the instrument to permit measurement of small capacitors by the method of substitution. This simply involves the use of a convenient inductor resonating at a convenient frequency with the adjustable resonating capacitor when the latter is set near to its maximum value of 400pF. The capacitor dial reading is noted, and then the unknown capacitor connected in parallel with the internal capacitor via the appropriate terminals. The new, lower, setting of the adjustable capacitor to restore resonance then indicates the value of the unknown capacitor, by subtraction from the first reading. Capacitors up to approximately 375pF may be measured in this way.

The impedance transformer stage employs a type 2N5459 (MPF105) N-channel JFET, which is connected as a source-follower. The gate biasing network is bootstrapped back to the source, ensuring that the stage has a very high input impedance for low loading of the tuning capacitor. The response of the stage is within about 1dB to approximately 30MHz, so that it introduces negligible error.

The diode detector used to measure Eg for the "cal" function of the instrument is a standard shunt circuit using an OA91 or similar germanium diode. Series and shunt 33K resistors are used for isolation and DC return, and a 2.5mH RFC and .047uF capacitor for RF filtering.

The detector used to measure Ec for the "read" function is identical to the first with the exception that the DC return resistance is used to form a calibration divider. The divider can be adjusted in a simple manner to compensate for the less-than-unity gain of the impedance transformer stage and for detector differences, and this operation will be described later.

The AF amplifier employs two BC108, 2N3565 or similar NPN planar silicon transistors. The first is connected as a standard common-emitter amplifier stage, and the second as an emitter-follower providing impedance matching to the meter rectifier circuit. The meter used is a modest-cost 3-inch rectangular type of Japanese manufacture, designated type VP-2A and having a sensitivity of 50uA with 2K internal resistance.

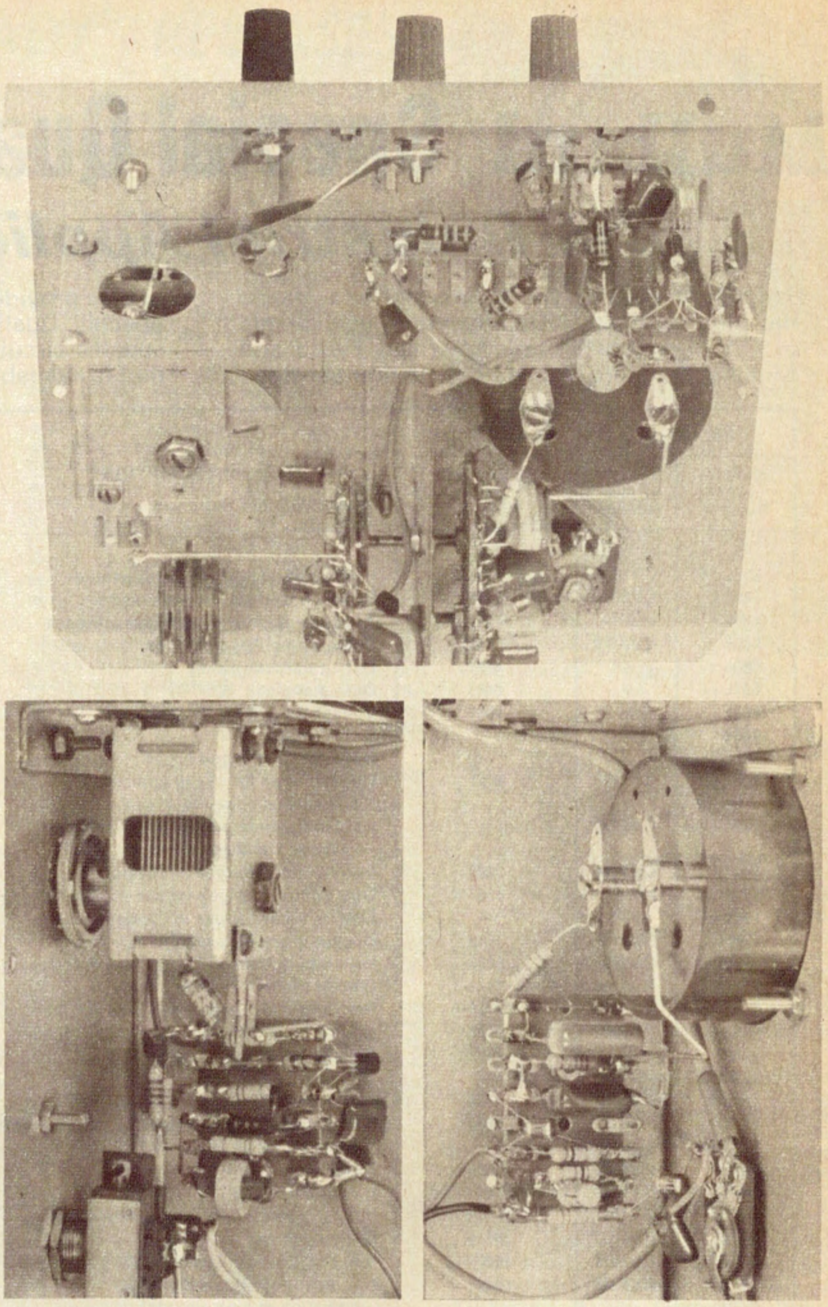
Power supply for the instrument is derived from the AC mains via a simple half-wave rectifier using a silicon diode type BY126/50 or similar, and a miniature 12.6V/150mA step-down transformer. A small 6V 40mA incandescent bezel lamp is connected in series with the rectifier output, serving as both pilot lamp and dropping resistor.

As may be seen from the photographs, the Q-meter is constructed in a standard 6½in x 7in x 7¼in sloping-front utility box. The box is used with the wrap-over part of the front panel at the top of the case, this allowing all of the functional circuitry of the instrument to be mounted compactly and rigidly on the rear of the panel.

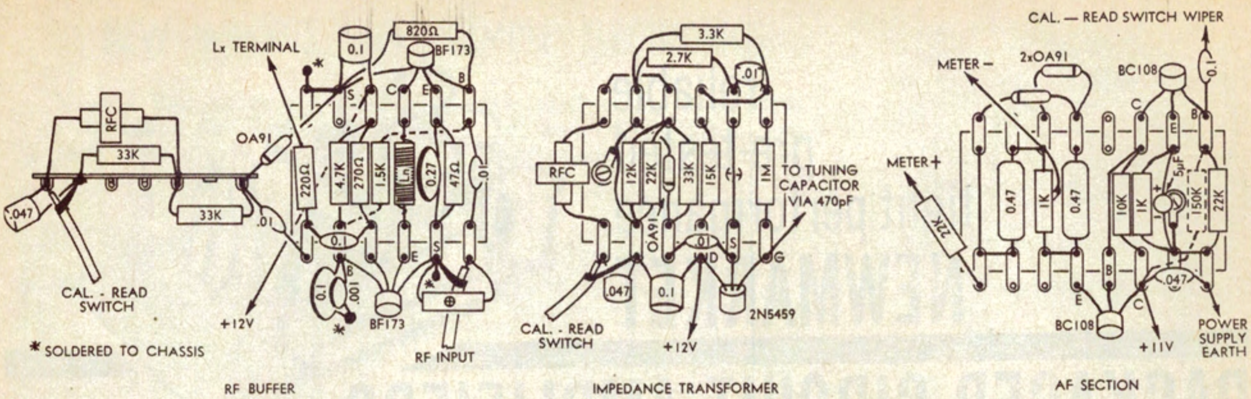
The three test terminals are mounted on the wrap-over section itself, with the two active terminals mounted on a small acrylic plate for low capacitance to chassis. Side by side on the upper portion of the front panel are the Q-factor meter and the resonating capacitor tuning dial, with the X1-X5 slider switch immediately above the meter. Beneath the meter is the "Cal-Read" function switch, while the pilot bezel and mains switch are mounted adjacent to this and beneath the capacitor dial.

The capacitor dial is provided with three scales, the outer and principal of which is calibrated directly in terms of capacitance: 25-400pF. The remaining scales are calculated from this scale, and are provided to enable rapid and convenient determination of resonant reactance and the inductance of unknown coils.

The innermost scale is calibrated in terms of "X.f," and may be used to find resonant reactance (in ohms) simply by dividing by the resonant frequency in Hertz. The scale was pro-



Three views of the rear of the front panel of the instrument, showing respectively the RF buffer and generator detector (top), the JFET impedance transformer and resonating capacitor (lower left), and the AF circuitry.



Above are three diagrams showing the wiring of the main sections of the instrument, to aid constructors in duplicating the layout of the prototype.

duced by calculation from the relationship

$$X.f = \frac{1}{2\pi C} \quad \ldots (11)$$

and is calibrated in units of (Ω.Hz x 10^8).

The central scale is calibrated in terms of "L.f²," and may be used to find the value of an unknown inductor (in Henries) by dividing by the square of the resonant frequency in Hertz. This scale was also produced by calculation, in this case using the relationship

$$L.Fo^2 = \frac{1}{4\pi^2 C} \quad \ldots (12)$$

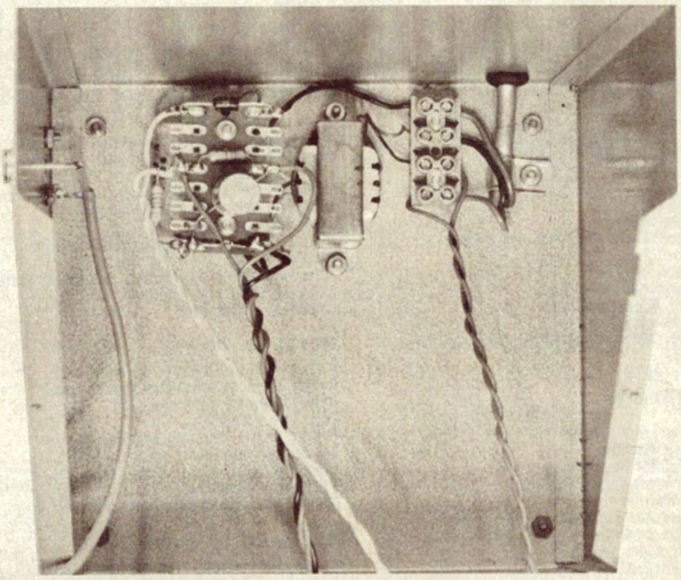
and is accordingly calibrated in units of (H.Hz² x 10^8).

Because of stray capacitance and wiring inductance variations, the capacitor scales of each instrument should ideally be calibrated individually. However, the scales produced for the prototype will probably be sufficiently close for many practical purposes, providing constructors use the same type of variable capacitor (Roblan type RMG-1, 10-415pF) and copy the prototype layout. Photographic copies of the original dial scales will be made available via the Information Service.

Also available will be copies of the meter face, which has a non-linear Q-factor scale reading 20-100 with a reference —3dB mark (for bandwidth and Incremental Frequency Q-factor measurements, if desired), together with a calibration scale showing "Cal" and "Cal X2" settings. (The last-named setting allows the effective generator input Eg to be set to half its normal value, thus effectively doubling the range of each of the normal Q-factor ranges.)

Inside the instrument, most of the RF circuitry is supported by a horizontal metal shield plate mounted behind the front panel between the slider switch and the meter. The RF buffer amplifier components are supported on a 6-lug section of miniature resistor panel mounted on the plate immediately behind the slider switch, keeping the injection divider resistor wiring as short as would be feasible. Adjacent to the output end of the buffer is the calibration detector circuitry, supported by a miniature 7-lug tagstrip.

The resonating capacitor is suspended beneath the shield plate, with the brass strip connection between the stator and the centre test terminal passing through a 7/8in clearance hole. The earthed test terminal is bonded to the shield plate via a second



A view of the interior of the rear of the case. Constructors should take special care to fit a grommet on the mains cord entry and to clamp the cord after entry to prevent strain on the connections.

brass strip, to ensure low series inductance.

The JFET impedance transformer and "read" detector, and the AF amplifier and rectifier are mounted on sections of miniature resistor panel supported on either side of a second vertical shield plate which is bolted to both the front panel and the horizontal shield, adjacent to the meter. This layout was chosen to ensure that unwanted coupling between the RF and AF circuitry was kept to a very low level.

Most of the wiring details of the impedance transformer and AF circuitry should be visible from the photographs, and from the wiring diagrams. It may be seen that the only component of the JFET section not mounted on the 6-lug section of miniature resistor panel is the 470pF input coupling capacitor, which is supported by a miniature 2-lug tagstrip mounted on the resonating capacitor frame.

The section of miniature resistor panel used to support the AF amplifier and meter rectifier circuitry is 8 lugs long, and the only components not wholly supported by the panel are the 0.1uF input coupling capacitor and the 22K meter series resistor. In each case these components are supported at one end by the panel, and at the other by the function switch and meter lug respectively.

We have prepared and present on these pages wiring diagrams of the three main circuit sections of the Q-meter, and using these in conjunction with the photographs constructors should have little difficulty in virtually duplicating the prototype instrument. The usual precautions apply when soldering in the components; particular care should be taken to avoid overheating those in the RF wiring, where the pigtails are kept short to reduce circuit losses.

Two critical points should be noted. One is that the base of the second RF buffer transistor is bypassed as directly as possible to the horizontal shield plate, using two ceramic capacitors as shown, and with their pigtails cut as short as possible. The second point is that the leads from the two detectors to the function switch must be run in shielded cable, with the shield braids earthed at the detector ends only.

As shown in one of the photographs, the power supply circuitry is mounted in the lower rear of the case. The

OPERATING THE Q-METER

Operation of the instrument is quite straightforward. The external RF generator is used to set the test frequency and to produce a full-scale reading in the "Cal" position of the function switch. With the inductor to be measured connected between the appropriate terminals, the function switch is then turned to the "Read" position and the resonating capacitor adjusted until the meter reading indicates a peak in response. The peak meter reading is then read directly in terms of the Q-factor of the inductor. Note that if the frequency must be changed in order to obtain resonance, it is necessary to return to the "Cal" position and check that the RF input has not been altered, before taking the reading.

If the reading obviously exceeds full-scale on the "X1" range, the slider switch may be moved to the "X5" position. Alternatively the function switch may be returned to the "Cal" position and the RF input reduced to the "Cal X2" setting, in which case the new reading obtained in the "Read" mode will need to be multiplied by 2. Obviously the latter alternative is only appropriate for inductors having a Q-factor between 100 and 200.

Generator source resistance error may be corrected using the values of Rs given earlier in the article, and substituting the appropriate value and that of Xo (obtained from the capacitor X.f scale) in expression (10). Similarly inductor self-capacitance may be found using expressions (6) or (7).

The lowest Q-factor reading which may be obtained on the instrument using the technique of figure 1 is 20, and this should be adequately low for most purposes. However, in situations where measurements must be made on inductors having a lower Q-factor than this, this can be done using the -3dB point provided on the meter face, and either the Incremental Frequency or Incremental Capacitance methods. But it should be noted that for inductors having a Q-factor below about 10, all of the normal methods of measurement are subject to considerable error, and have very little significance.

When the Incremental Frequency or Incremental Capacitance methods are used, the "Cal" mode and setting-up procedure are not required. The technique is simply one of switching to the "Read" mode, obtaining the resonant peak and then adjusting the RF input level for a full scale reading (100). The frequency or resonating capacitance are then altered up and down to find the -3dB points, after which the Q-factor may be calculated using expressions (8) or (9) as appropriate.

Measurement of small capacitors may be performed using a test inductor which resonates at a convenient frequency with the inbuilt resonating capacitor when the latter is set for near-maximum capacitance. Using the inductor and internal capacitor alone, the resonating capacitor is adjusted accurately for resonance and its capitance noted. Then the capacitor to be measured is connected to the appropriate terminals, whereupon the internal capacitor will have to be reset to a lower value to restore the resonant condition. The amount by which it has to be reduced will be equal to the value of the external capacitor.

The table printed above gives brief operating instructions for the instrument, and would be suitable for mounting on the rear of the case for convenient reference. If this is done it would be wise to employ a sheet of clear acrylic for protection.

mains cable is clamped upon entry and terminated in a small section of "B-B" connector, with the miniature step-down transformer adjacent. On the far side of the latter is an 8-lug section of miniature resistor panel supporting most of the minor supply components. The RF input connector is mounted at the lower rear of the left-hand side of the box as viewed from the front.

When the instrument is completed, it should be calibrated in terms of Q-factor reading. This is done in the following quite simple manner, using a modulated RF signal generator or oscillator set for 30% modulation and an output frequency of around 300—400KHz.

Using ordinary hookup wire connect a temporary link betwen the output of the RF buffer amplifier (point "X" on the circuit) and the centre test terminal. Then set the resonating capacitor for minimum capacitance, and turn the function switch to the "Cal" position. With the RF generator connected it should then be possible to adjust the RF input to produce a full scale reading on the meter; typically this will require something in the order of 80-100mV.

If the function switch is now turned to the "Read" position, the meter indication should drop to a value equivalent to "48" on the Q-factor scale. If the reading does not drop to this figure, the value of the calibrating resistor in the second detector circuit (marked with an asterisk on the main circuit diagram) should be altered to correct matters. Increasing the resistor value will increase the reading, while reducing the resistor value will have the opposite effect. When the correct reading is produced the temporary link should be removed.

The instrument can now be considered ready for use, unless of course it is desired to individually calibrate the resonating capacitor. In most cases this will probably not be possible, although constructors may be able to check the capacitance at individual points using one or more inductors of known value. ■