INDUCTANCE Meter

By I. QUEEN

THE subject of capacitance-measurement has been discussed in recent issues of *Radio-Craft*. It has been shown that such measurements are not at all difficult for the serviceman and experimenter to make. The measurement of coil constants is slightly more complicated due to the fact that some coils possess appreciable self-capacitance.

Fig. 1 shows what occurs when a tuning coil has a comparatively large self-capacitance. It has then in reality a large condenser in shunt with its actual inductance. If the latter requires a given condenser to tune through a range of frequencies, it is quite possible that the self-capacitance is already a good portion of that required. It will then be difficult or impossible to correctly design the tuning circuit other than by cut-and-try.

A knowledge of the actual inductance of a coil is important when tracking is to be done. It is desired that all coils must be very approximately of the same true inductance and self-capacitance. Coil measurements are also of importance where the ultra-high frequencies are involved. Here the physical constants may mean little, since the difference between a coil of 3 turns and one of 3½ turns may prove surprising! Any slight change in shape or spacing of the turns may throw the tuning circuit into another band altogether.

Some measuring device to find whether the desired inductance is higher or lower than desired would save much time in making final adjustments.

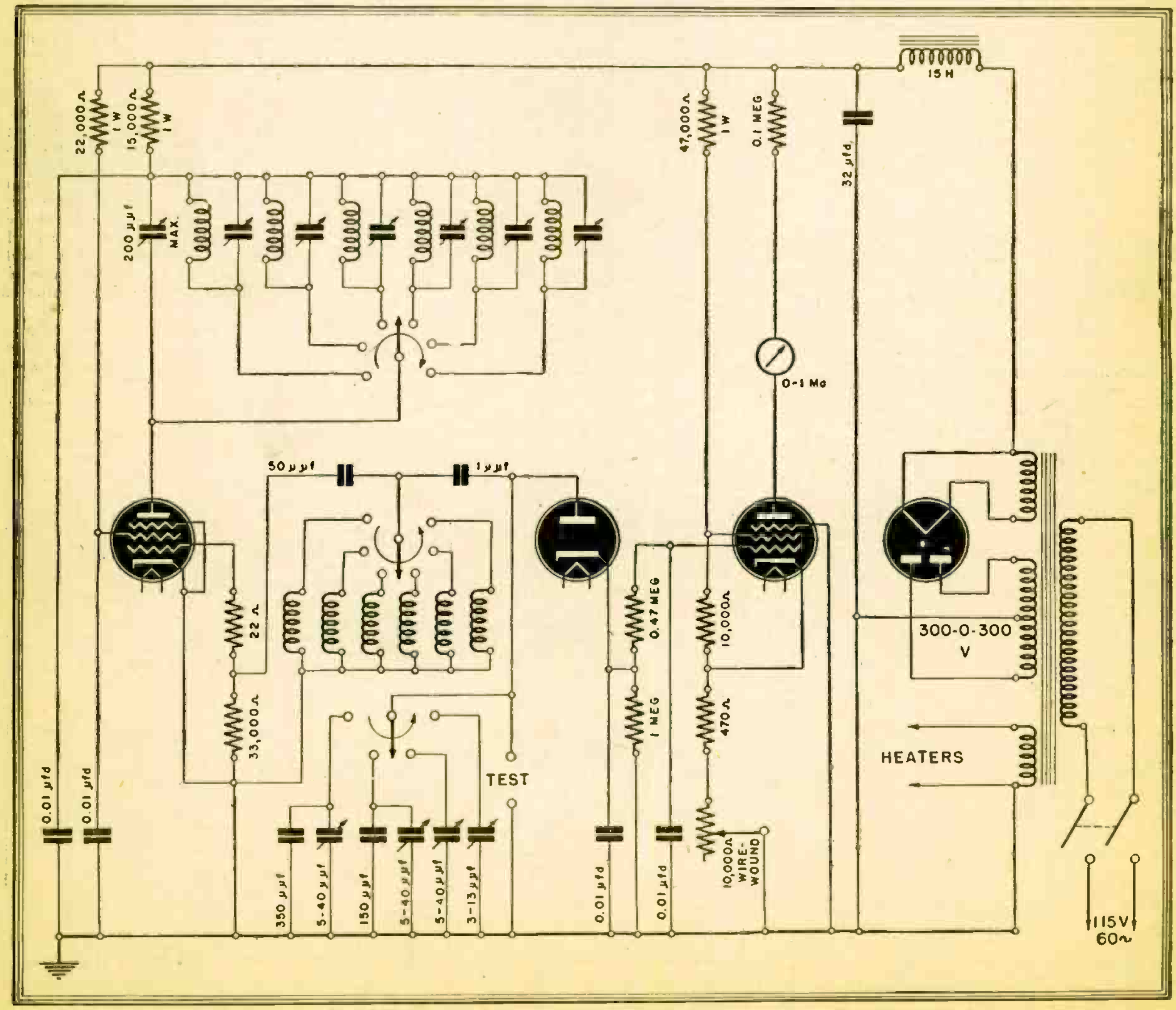
The measuring instrument should be quick and easy to use, cover a wide range of values and be simple to construct. The range of from 1 to 1000 microhenries would cover the broadcast band as well as the ultra-high. For example, a coil of 1000 microhenries will resonate at 500 Kc. when shunted by 100 mmf.

Two general methods are available for the measurement of small values of inductance; the bridge and the resonant methods. The first is difficult to construct for high-frequency operation due to shielding requirements. It is often used at low frequencies, however, and this eliminates the effects of self-capacitance.

On the other hand, at low frequencies, the ratio of resistance to reactance becomes large, and as the bridge user is well aware, much manipulation is necessary since both components must be balanced for a correct null.

The resonant method gives a quick indication and may be used at the frequency at which the coil will probably be used. Unfortunately, the use of but a single frequency does not take into account the effect of self-capacitance. The measurement will therefore show a lower inductance than is actually the case.

The instrument to be described here



Schematic of the inductance meter, including electronic voltmeter for indicating the point of resonance on which measurements are based.

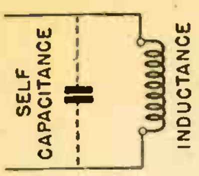


FIG.1

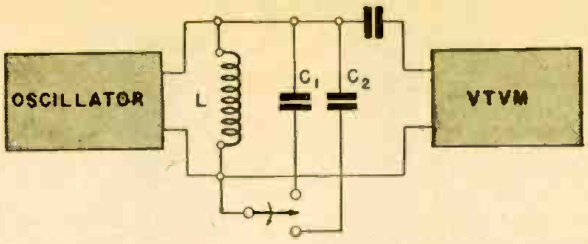


FIG.2

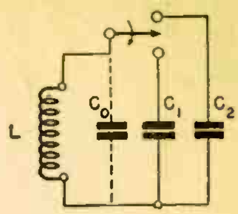


FIG.3

Fig. 1—A coil carries a concealed capacity. Fig. 2—Block diagram of the inductance meter. Fig. 3—Measurements are very simply made.

makes use of *two* frequencies, whereby the effect of self-capacitance is compensated for and the true inductance indicated. Besides, we are in a position to find the self-capacitance should it be required. The device is for laboratory use, and was recently very completely described in *Wireless World* (London). Its construction is well within the means of the serviceman and should find ready application in his workshop.

A block diagram of the instrument is shown in Fig. 2. An all-wave signal generator is tuned by means of a calibrated variable condenser to the resonant frequency of the unknown coil and a known fixed condenser. Resonance will be indicated on the VTVM (which need not be calibrated). Now the coil is switched to another fixed condenser and again resonance is established on the generator. The difference between the two readings obtained on the calibrated condenser of the oscillator is the true inductance of the coil with its self-capacitance accounted for. (The VTVM consists of a diode rectifier and a triode with a 0-1 ma. meter in its plate circuit.)

THEORY OF THE METHOD

We will first develop the required theory so that the reader will not only be in a better position to construct and use the instrument, but he will be able to make any changes in the design to suit his own requirements.

In Fig. 3 the procedure used in taking a measurement is shown. L is the coil to be measured, C_0 its self-capacitance, and C_1, C_2 are two known fixed condensers. First we switch in C_1 and tune the oscillator to resonance. The well-known frequency formula is $f = \frac{1}{2\pi\sqrt{LC}}$

The above formula shows that for a given frequency the product of L × C is constant. Since the frequency of the oscillator and that of the tuned circuit are equal we may write $L\ (C_1 + C_0) = L_2X$ where L_2 is the oscillator coil inductance and X is the oscillator condenser capacitance. L and L_2 must be in the same units. Likewise for C_1, C_0 and X.

Switching now to C_2 and tuning for resonance again, we may write $L\ (C_2 + C_0) = L_2Y$ where Y is the new oscillator capacitance value. Subtracting from the first formula we easily obtain

$$L\ (C_1 - C_2) = L_2\ (X - Y)$$

$$\text{or } L = \frac{L_2\ (X - Y)}{C_1 - C_2}$$

For convenience we make $C_1 = 2C_2$ and the formula becomes $L = \frac{L_2}{C_2}\ (X - Y)$. *The inductance is then proportional to the difference of the capacitance readings.*

For complete ease of operation we might make $L_2 = C_2$. If the oscillator condenser is directly calibrated in capacitance units, the unknown coil is simply the difference as read on the dial. It is also possible to make L_2/C_2 equal to, say 1/50, in which case the calibrations on the condenser may be 1/50 that of the actual capacitance value. Small numbers on the dial may be much more easily handled, of course, so that the latter procedure will be followed.

The oscillator condenser used in this particular instrument is of the straight-line capacitance type (semi-circular plates) having a range of 50-250 mmf. As mentioned in the previous paragraph we may calibrate it in units from 1-5 if L_2/C_2 equals 1/50. Straight-line capacity condensers were widely used in old-time receivers and are probably readily available. The calibration may be done in accordance with the recent capacitance-measuring articles in *Radio-Craft*. Because of the straight-line capacitance characteristic the calibration will be linear and only a few known points are required. Fig. 4 shows a good arrangement of the final form. The point "1" corresponds to 50 mmf. and the "5" on scale A corresponds to 250 mmf.

For highest accuracy, the calibration could be done after the condenser has been wired into the circuit so that all stray capacitances are accounted for.

Scale B on the condenser is used to extend the available range. When the first scale is in use

$$\frac{L_2}{C_2} = \frac{1}{50}$$

and for the second scale we make

$$\frac{L_2}{C_2} = \frac{1}{10}$$

so that a multiplying factor of 5 is obtained. The values of C_1 and C_2 are fixed at 40 and 20 MMF respectively. This fixes the oscillator coils at values of .4 and 2. microhenries respectively, for scales "A" and "B."

We know that at point "1" on scale A the capacitance is 50 MMF and that the coil has a value of .4 microhenry. Using the well-known frequency formula we find that we should obtain a frequency of 35.6 Mc. at point "1" on scale A. Now with the same coil and a capacitance of 250 MMF (point "5") a frequency of 15.9 Mc. should be obtained.

This gives us several methods for correctly designing the all-wave oscillator. We may calibrate the straight-line condenser (including associated wiring) and then wind the coil to cover the required frequencies at both ends of the dial. Or we may first wind the coil to specified value (.4 microhenry) and then find the proper point on the condenser to bring in the correct frequency. The tuned plate coil determines the oscillator frequency, the grid coil being untuned.

Scale B is used when our oscillator coil is 2 microhenries (multiplying factor of 5). Calculating the frequencies at each end of the dial now we obtain 15.9 and 7.12 Mc, respectively.

Multiplying factors carry the range higher as shown in the table Fig. 5. For instance, an oscillator coil of 4 microhenries being 10 times larger than the original for the A scale multiplies this scale by 10. To multiply by 100, however, it is found that the oscillator coils become large and may exhibit large self-capacitances compared to C_1 and C_2. For this reason, C_1 and C_2 are made 400 and 200 MMF. for this range. With C_2 made 10 times larger, L_2 must be made 1000 times larger to obtain a multiplying factor of 100. The table eliminates the need for calculating the constants for the different ranges.

Note the convenient arrangement for scales C and D. C is the band-changing switch for the six coils used. D switches in the two sets of C_1 and C_2 as described.

In obtaining the values for each C_1 and C_2 the following procedure is followed, (Fig. 4). In order to take into account the various stray wiring capacitances, each of these condensers is in reality a small fixed condenser in shunt with a small trimmer which is varied until the required value is reached.

In setting up the instrument the following procedure is a good one. The variable oscillator condenser may be calibrated (with coil disconnected) at 50, 100, 150, 200, 250 MMF, giving points 1, 2, 3, 4, 5. The smaller divisions are marked off with equal spacing. Now C1 and C2 are adjusted to proper values. Stray capacitances are taken into account by measuring them after they are properly connected into the circuit. As mentioned before C1 and C2 are 40 and 20 MMF respectively, except for the two

(Continued on page 702)

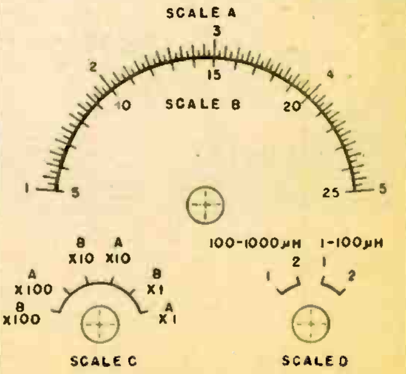


FIG.4

Fig. 4—The inductance meter's panel layout.

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INDUCTANCE METER

(Continued from page 665)

higher multiplying ranges when we switch in the 400 and 200 MMF condensers. Scale D takes care of this change.

The oscillator coils are preferably permeability tuned and may be shunted by a very small trimmer to equalize the possible small change of capacitance when switching from one coil to another. At point "1" the trimmer is adjusted for proper frequency (in table) and at point "5" the inductance is adjusted.

Range (μH)	Scale C switch position	Oscillator Inductance (μH)	Frequency (Mcs) at scale A position: 1	5
1 to	A x 1	0.4	35.6	15.9
10	B x 1	2.0	15.9	7.12
10 to	A x 10	4.0	11.25	5.03
100	B x 10	20.0	5.03	2.25
100 to	A x 100	400.0	1.125	0.503
1000	B x 100	2000.0	0.503	0.225

Fig. 5—Calibration table for the oscillator.

To make a measurement, the unknown coil is placed across the "test" terminals. Switch "D" is set to position 1 on the proper scale depending upon estimated inductance of the unknown. Scale C dial is now left at A x 1 and the oscillator dial rotated throughout its range. We do the same at B x 1 and so on until resonance is indicated on the VTVM. The condenser reading is noted. If scale C indicates B x 10, for instance, and we find B points to 15.6, we would note 156. Now scale D switch is set to 2 and again we find resonance. This time, say we obtain maximum when scale D is on A x 10 and A points to 2.3 units. The unknown has an inductance of 156—23 or 133 microhenries. As the resonant point is approached, sensitivity may be reduced, by varying the resistor in the VTVM cathode circuit.

L (μH)	No. Turns	Coil Diam.	Coil Length
.4	4¾	1"	1"
2	11	1"	1"
4	11	1½"	1"
20	23	1½"	1"
400	130	2"	2½"
2000	260	2"	2½"

COIL DATA—Fig. 6

The self-capacitance of the coil which is necessary information when designing a circuit to cover a definite tuning range is found as follows: Recalling the two earlier formulae $L(C_1 + C_0) = L_1X$ and $L(C_2 + C_0) = L_2Y$ we may divide to obtain

$$\frac{C_1 + C_0}{C_2 + C_0} = \frac{X}{Y}$$

Simplifying, $C_1Y + C_0Y = XC_2 + XC_0$ or

$$C_0 = \frac{XC_2 - YC_1}{Y - X}$$

which becomes

$$C_0 = \frac{C_2(2Y - X)}{(X - Y)}.$$

This can be easily calculated when C_2 and the two condenser readings X and Y are known. The value of C_2 depends upon scale D setting.

A 6J7 may be used for the oscillator and vacuum-tube voltmeter tubes, with one section of a 6H6 for the diode. The plate requirements are small so that any convenient power rectifier may be used. Coil data is given in Fig. 6. As an alternative to permeability-tuned coils the smaller coils may be self-supporting, being wound with heavy wire, while the very large coils may be wound with fine wire such that each coil length requirement may be met.

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