GENERAL RADIO COMPANY

engineering department

INSTRUMENT NOTES

IN-101 1964

CAPACITANCE AND INDUCTANCE MEASUREMENTS FROM 20 TO 100 KC WITH THE TYPE 1650-A IMPEDANCE BRIDGE

One of General Radio's most popular instruments is the TYPE 1650-A Impedance Bridge. The TYPE 1650-A is essentially five bridges built into a single, neat, portable package, with its own generator and detector for dc and 1-kc ac measurements of capacitance, resistance, and inductance. An external generator can be connected to the bridge for measurements at frequencies other than 1 kc. The specifications for the TYPE 1650-A claim 1% accuracy up to 20 kc for inductance and capacitance measurements, and up to 5 kc for resistance measurements.

Because the bridge circuits were carefully designed to minimize stray capacitances and inductances, it was reasonable to assume that the bridge would perform well at frequencies above the nominal 20-kc limit. For several reasons, such higher-frequency performance was not incorporated in the instrument specifications. Among these reasons were a desire to keep the basic accuracy statements as simple as possible, a realization that higher-frequency test procedures in the calibration laboratory would add to the cost of the instrument, and the belief that the great majority of users would be interested in 1-kc measurements only.

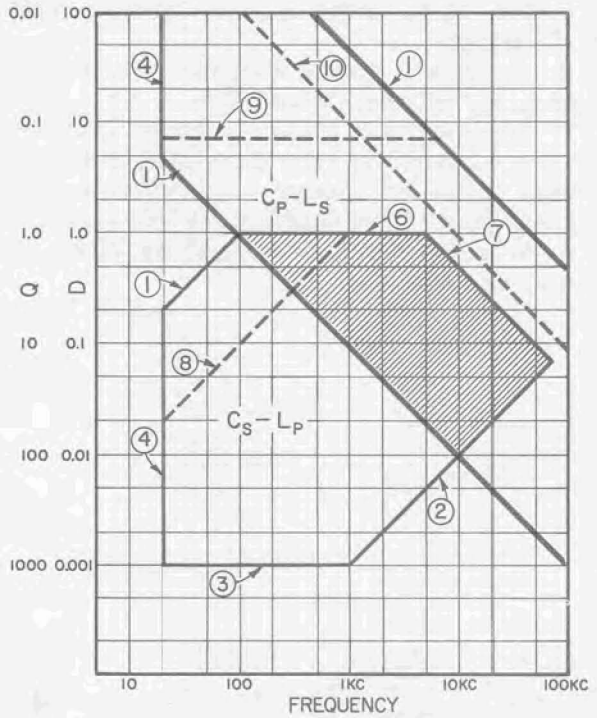

Figure 1. C and L accuracy ranges as a function of D and Q frequency.

Since the introduction of the TYPE 1650-A, however, the experience of many of our customers and our own further tests indicate that this bridge can be used up to 100 kc with only a slight sacrifice in accuracy. Moreover, there is a growing interest in C and L measurements in the 100-kc region. The following detailed account of the accuracy of the TYPE 1650-A is given, not as an addition to bridge specifications, but as a guide for those wondering what accuracy they might reasonably expect at frequencies from 20 to 100 kc.

Figure 1 is a modification of Figure 14 in the instruction manual for the bridge. Up to 20 kc, the numbered lines show the limits of D and Q within which the basic 1% C and L accuracy is possible. Above 20 kc, the lines set forth the DQ ranges over which the accuracies given in this article apply. The various numbered lines are:

1. the end of the DQ rheostat range (no C or L error),
2. the first division on LOW D or HIGH Q scales (no C or L error),
3. the limit imposed by the D of the standard capacitor (no C or L error),
4. the 20-cps low-frequency limit imposed by meter response (no C or L error),
6. the error in C or L caused by capacitance across the series combination of the standard capacitor and the DQ rheostat,
7. the error in C_s or L_p caused by inductance in the DQ rheostat,
8. the end of the LOW D and HIGH Q scales (no error),
9. the limit of 1% C and L accuracy, even with *Orthonull*, because of sliding null,
10. another limit caused by inductance in the DQ rheostat. Above this line there may be an additional C_p and L_s error of +1%.

(Limit number 5 was the nominal 20-kc limit given in the instrument specifications.)

Of the above limits, only numbers 6, 7, 9, and 10 are actual limits of C and L accuracy. The others are mechanical limits, limits of readability, D and Q limits, and the limit of meter response. Limits 6 and 7, furthermore, restrict the C_s-L_p range but are well within the range of the C_p-L_s bridge. Also, the C_p-L_s bridge limits (shown in red) come into a more useful DQ range at frequencies approaching 100 kc. The C_p-L_s bridge is inherently more accurate than the C_s-L_p bridge to begin with (its lead inductance is less), and it permits better D and Q balances. The first rule in achieving maximum accuracy at higher frequencies, then, is to measure *parallel* capacitance and *series* inductance (usually the preferred measurements anyway).

Above 50 kc, the point of balance on the CRL dial becomes important, C and L accuracy decreasing at higher CRL settings. The added error is caused by a phase-angle-compensating capacitor tapped onto the CRL potentiometer at about the 3.3 dial setting. From 3.3 up, the percent error increases linearly with CRL dial setting, and at 100 kc there is an added 4.5-percent C_p error at 10 on the CRL dial. However, proper use of the CRL MULTIPLIER switch makes it possible to balance almost any component on the lower half of the CRL dial, where accuracy is best.

At frequencies above 20 kc, limits other than those shown in Figure 1 restrict the accuracy attainable with the bridge. We can state these limits in terms of a percent error, which must be added to the basic one-percent accuracy of the bridge. The added error introduced above 20 kc is *always negative*, and the net effect of the two errors will probably be negative. This is shown in the following table of C_p-L_s accuracy at CRL dial settings between 0.4 and 4.

Frequency	Basic Bridge Accuracy*	Limits of Error Added Above 20 kc	Net Accuracy Limits*
50 kc	±1%	+0, −1%	+1%, −2%
100 kc	±1%	+0, −2.5%	+1%, −3.5%

* below line 10 in Figure 1.

Since the sense of the probable error is known, a correction can be applied to increase accuracy further. For instance, the average of the "net accuracy limits" shown above is −1.25% at 100 kc. For maximum accuracy, then, the user should *add* 1.25% to the value indicated on the bridge. If such correction is made, the accuracy may then be expressed symmetrically as ±1.5% at 50 kc and ±2.25% at 100 kc.

Above line 10 in Figure 1, a further 1% should be added to the *plus* net accuracy limit.

DQ ACCURACY

Above 20 kc, the C_p-L_s bridge is decidedly superior to the C_s-L_p bridge for measurements of D and Q. The accuracy with which D (or $1/Q$) can be measured by the C_p-L_s bridge is:

$$\pm 5\% \ \pm 0.0005 \ f_{kc}$$

AMPLIFIER SENSITIVITY

The amplifier sensitivity decreases rapidly with increasing frequency, and an external detector may be necessary, depending upon the bridge generator voltage level. When a TYPE 1210-C Unit RC Oscillator (20 cps to 500 kc) is used as the generator, the sensitivity of the internal detector is just good enough for a 1% balance precision at 100 kc.

CORRECTION FOR RESIDUAL AND LEAD IMPEDANCES

For maximum accuracy, the corrections for residual and lead impedances, as given in Table 5 of the instruction manual, must be applied. Those corrections that include ω as a factor must be considered carefully at higher frequencies.

SUMMARY

Here are the points to remember in measurements above 20 kc:

1. The C_p-L_s bridge is more accurate than the C_s-L_p bridge.
2. Accuracy is greater with the CRL dial at a low setting, say between 0.4 and 4.
3. While the basic 1% C or L bridge accuracy may be plus or minus, the error introduced above 20 kc is always minus. For greater accuracy between 50 and 100 kc, add a 1% correction to the indicated value.
4. When measuring D or Q above 20 kc, always use the C_p-L_s bridge.

— F. T. VAN VEEN

GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS, USA

Printed in U.S.A.