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## Application Note

### Measuring Biased Inductors with the GenRad Digibridge

This note is intended for those who have the need to make measurements on DC-biased inductors with the GenRad Digibridge. The object is to make these measurements accurate and safe. All safety precautions should be used, including those suggested below.

#### **WARNING**

**Inductors carrying current may contain lethal energy.**

**Dangerous voltages are generated if connections are broken while the current is flowing.**

**Always set all power sources to zero output before making or breaking connections.**

**Limit supply voltages to 60V or less.**

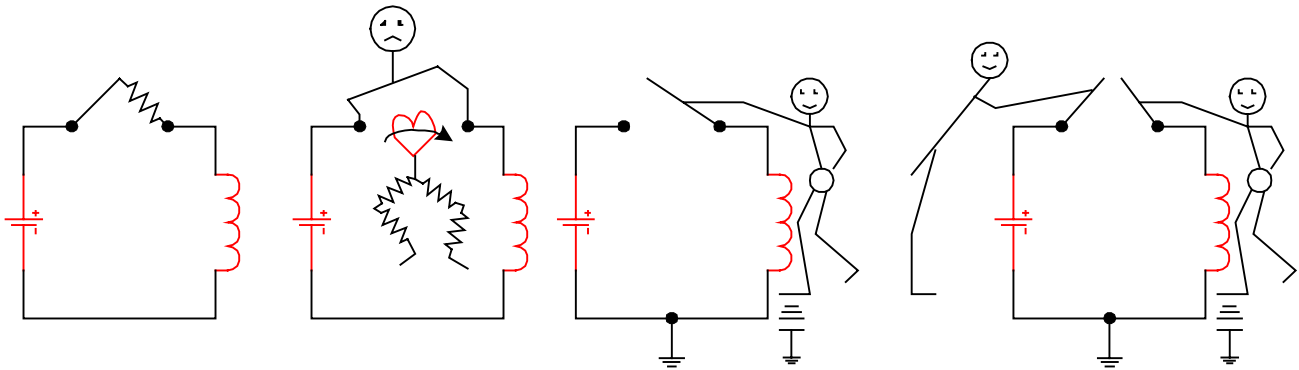
**Use redundant safety measures to greatly reduce the shock hazard to the operator and avoid damage to the measuring instrumentation.**

#### **What is so Dangerous about Inductors?**

The voltage across an inductor is proportional to its inductance and the rate-of-change of the current through it:  $E = L di/dt$ . If the current could be instantly switched off, the voltage would, in theory, become infinite. This does not happen in practice because the high voltage develops an arc across the switch as the contact is broken, keeping  $di/dt$  from becoming infinite. The voltage can, however, get very high. One might say that an inductor doesn't like to have its current changed and will develop a very high voltage in an effort to keep it flowing.

If a person breaks the contact without the proper protection, the inductor induces a high voltage, forcing the current through him. The current flows from arm to arm, through the heart, and can easily be lethal. This hazard is all the more dangerous because it is unexpected - there were no high voltages present before he broke the connections. A person doesn't have to be across the broken connection to receive a dangerous shock, for the current may flow through ground. Therefore, breaking the circuit with one hand is not necessarily safe and the common safety precaution of one hand in the pocket may not work. Moreover, even if someone else at some distance away remotely performs the switching of the circuit, the person touching the inductor could still receive a lethal shock. A disconnection might also be the result of a component or wiring failure that could happen at anytime. Figure 1 illustrates the breaking of the contact across the inductor.

## Inductor Circuit



**Figure 1: Breaking the contact across an inductor**

The energy of an inductor is equal to  $\frac{1}{2} LI^2$  and the danger increases as the energy increases. Safety standards do not cover the shock hazard from inductors, so that no value of energy can be considered safe. Even low energy levels, which may not in themselves be dangerous, can cause an involuntary physical reaction that can cause dangerous accidents. One should always assume the worse could happen and use utmost caution. One should use **redundant** safety measures, because any single protective device could fail and any safety procedure could be forgotten or even ignored.

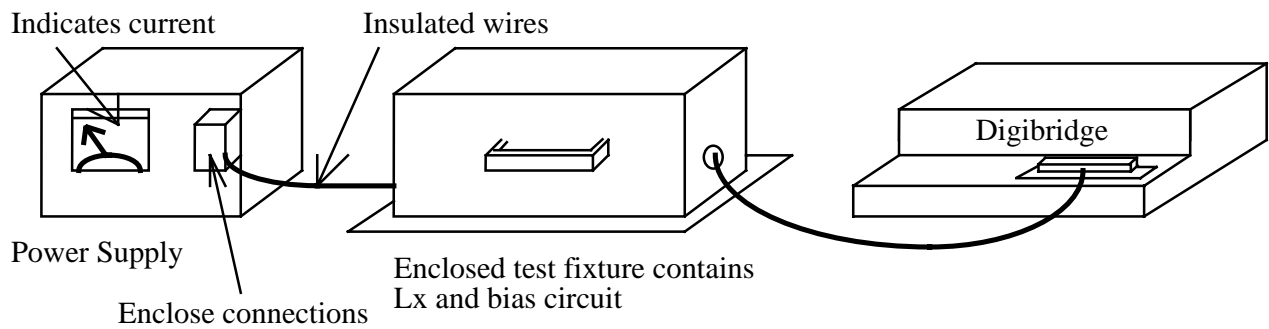
### Suggested Safety Precautions

To avoid shock hazard, we recommend all the following equipment and procedures:  
(Not to exclude those precautions the user already has in place)

1. Instruct the operator of the possible dangers.
2. Enclose the inductor in an insulated box with an interlock switch so that the current cannot flow when the box is open (See Figure 2).
3. Use redundant switching (See Figure 2).
4. Use some method of connecting the inductor that keeps the operator from directly touching the conducting connections.
5. Have some means of indicating that the current is indeed zero and instruct the operator not to touch anything in the box if the current is not zero.
6. Make sure the floor and work surface are dry and non-conductive.
7. Inspect and check the test setup regularly to make sure that the safety mechanisms function properly.

## Inductor Measurement Setup

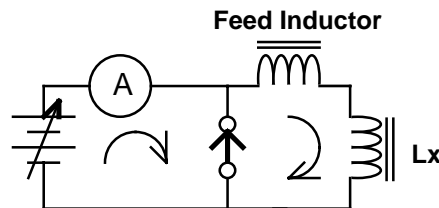
A measurement system should look something like that sketched in Figure 2.



**Figure 2: Example Inductor Test Setup**

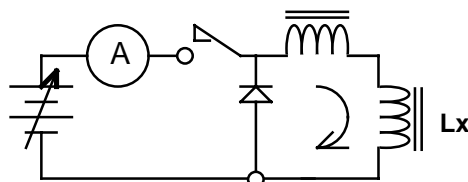
A switch should be activated when the box cover is closed. One way to do this is to use a push-button switch that is depressed by a protrusion from the cover. All connections into the box should be well insulated and the connections to the power supply and the Digibridge should be enclosed and secured. The power-supply meter should be set to indicate current. The box should contain the inductor to be tested and all other inductors and other components of the bias circuit.

Avoid the high induced voltage by shorting the inductors carrying current with a switch rather than leaving them open (Figure 3). However, this method has a disadvantage: the ammeter will indicate high current whether the switch is open or closed and thus cannot be used as an additional safety indication.



**Figure 3: Use a switch to short inductors**

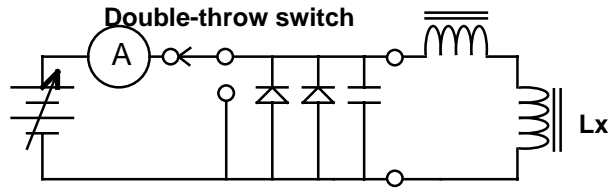
An alternative method is to open the circuit, but use a rectifier to carry the transient discharge current (Figure 4). This should be a power rectifier with a current rating higher than the bias current used. Paralleling two rectifiers would give added safety in case of failure.



**Figure 4: Use a rectifier to pass transient current**

## Bias Method

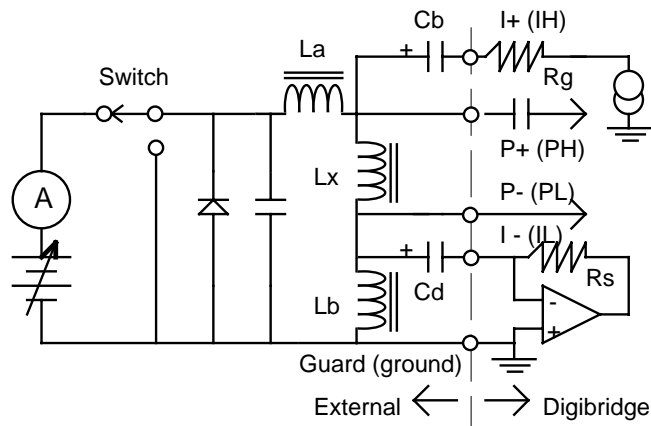
The suggested circuit (Figure 5) combines both methods, using a double-throw switch and rectifiers. A small 1000-pF capacitor is added to avoid high-speed transients.



**Figure 5: Recommended switching circuit**

### Bias Method

The recommended method for supplying DC bias current to inductors while their inductances are being measured on a Digibridge is referred to as a **Guarded Feed**. This method allows high bias currents with little error as shown in the circuit in Figure 6. An impedance source feeds DC bias current to the "unknown" inductor,  $L_x$ , while blocking the AC signal to avoid excessive loading by the bias source. An "ideal" inductor of high value would be the best feed impedance because it would have high impedance at AC but zero DC resistance. Ideal inductors are shown in Figure 6 but, of course, practical inductors have finite DC resistance and limited inductance.



**Figure 6: Guarded Feed Circuit**

#### Requirements:

$$C_b > \frac{1}{\omega R_g}$$

$$L_a \geq L_x$$

$$L_b \geq L_x$$

$$C_d \frac{1}{\omega^2 L_b}$$

## Bias Method (Continued)

The Digibridge is capable of making measurements with considerable loading admittance from either end of the unknown to the guard (ground) connection. The guarded-feed method takes advantage of this guarding capability. Neither feed inductor is directly in parallel with  $L_x$ , common with other measurement methods, therefore there is no shunting error introduced. Also, with this method the power supply is grounded so that common-mode hum is not a problem.

There still are some sources of error, however, which require some necessary precautions. The capacitor  $C_b$  must be adequately large ( $C_b > 1/2\pi f R_g$ ) and the feed inductor  $L_a$  should be approximately equal to  $L_x$  or larger to avoid a reduction in signal level that would give poorer accuracy due to noise.

The input of the inverting op amp is shunted by  $L_b$ , the second feed inductor. This causes an error of  $R_s/K\omega L_b \times 100\%$  where  $K$  is the magnitude of the op-amp gain at the test frequency. Table 2 lists typical values of gain for the Digibridge instruments at several test frequencies (the gain is inversely proportional to frequency). Usually, this error is negligible if  $L_b$  is roughly equal to, or larger than,  $L_x$ .

**Table 1: Maximum Digibridge Bias Current**

<b>1659, 92, 89, &amp; 93 Digibridge</b>		
<b>Range</b>	<b><math>R_s</math></b>	<b>I max</b>
1	25 $\Omega$	70 mA
2	400 $\Omega$	10 mA
3	6.4 k $\Omega$	700 $\mu$ A
4	102.4 k $\Omega$	40 $\mu$ A

**Table 2: Approximate Gain\* of Inverting Amplifier**

<b>Frequency</b>	<b>1659</b>	<b>1692</b>	<b>1689,93</b>
120 Hz	80,000	80,000	80,000
240 Hz	-	-	40,000
1 kHz	10,000	10,000	10,000
10 kHz	1,000	1,000	1,000
100 kHz	-	100	100

\* Magnitude,  $|K|$  usually proportional to  $1/f$

## Bias Method (Continued)

A blocking capacitor,  $C_d$ , is required in the I- connection to keep the DC out of  $R_s$  and the inverting amplifier. The reactance of this capacitor should be much lower than that of  $L_b$  so that the AC signal current will flow in  $R_s$  and be accurately measured thus  $C_d > 100/\omega^2 L_b$ . It is usually easy to find an electrolytic capacitor of suitable value. If it is too large, however, it will take excessive time to charge.

Because both  $L_a$  and  $L_b$  may be more-or-less equal to  $L_x$ , this method is convenient if several similar inductors are to be measured, as would be the case in production or inspection situations. Even when similar inductors aren't available, the feed impedances required for this method, active or passive, are much lower than any other method because they only have to be of the same order as the impedance of  $L_x$  and not substantially larger. Feed resistors rather than inductors are practical in some cases.

For complete product specifications on the Digibridge Line of LCR meters or any of IET's products, visit us at <http://www.ietlabs.com/digibridges.html> Do you have an application specific testing need? Call us at 1800-899-8436 or email engineering at [sales@ietlabs.com](mailto:sales@ietlabs.com) and we'll work with you on a custom solution. Put IET to the test because we're committed to solving your testing requirements.