Analyze This Inductor

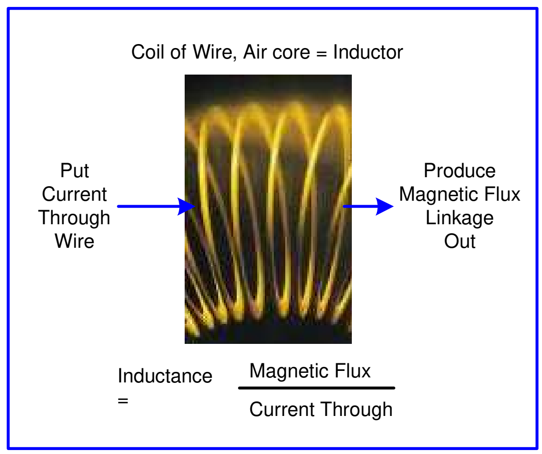
Recent advances in switching power supplies and the telecommunications industry have resulted in requirements for inductors with high frequency characteristics and low loss. In this light, the testing of inductors is also moving to higher frequencies. Let’s take a look at inductor measurements in general and some application specific features that today’s impedance meters must have to fully characterize an inductor.

- DCR Measurements of winding resistance of coils
- Voltage Leveling (effective in measuring piezo capacitors)
- Measuring Voltage & Current through DUT in inductor measurements
- Constant Source Impedance in inductor measurements

There are a number of parameters that characterize an inductor. The most commonly measured parameters are inductance (L) and quality factor (Q). In addition, dc resistance (DCR) can also be a useful parameter as well. In this article we will discuss each of these parameters as well as typical issues that can arise when measuring each parameter.

What is an inductor?

An inductor is a coiled conductor. It is a device for storing energy in a magnetic field (which is the opposite of a capacitor that is a device for storing energy in an electric field). An inductor consists of a wire wrapped around a core material. Air is the simplest inductor core material it is constant, yet for physical efficiency, magnetic materials such as iron and ferrites are commonly used. The core material of the inductor, its’ length and number of turns directly affect the inductor’s ability to carry current.



Inductor measurements can be made in series or parallel mode, but remember they are frequency dependent. In the case of a large inductance, the reactance at a given frequency is relatively large; parallel resistance becomes more significant than series. Parallel equivalent circuit should be used for a large inductance. For low valued inductors, the reactance is also low so the series resistance is more significant. Therefore, a series equivalent circuit is the better measurement mode. For very small inductance values, a higher measurement frequency will yield better accuracy.

Real Inductor Measurements: Complex and Imaginary Science

Inductance is a basic electrical property of any coil. The unit of inductance is the Henry. The inductance of a coil depends on the number of turns, diameter of the coils, the length of the coil and the nature of the core. By definition the inductance is the ratio of the total magnetic flux linkage (Λ) to the current (I) through the inductor or coil. A mouthful but the main point is that total magnetic flux linkage is dependant upon permeability (μ) of the medium (core material). This means inductance is directly proportional to permeability. Permeability is a measure of how penetrable a material is. How porous or pregnable that material is to a magnetic field. Most inductance standards have an air or non-magnetic core making their induction characteristics predictable since the permeability of air is constant. Permeability however is not a constant for ferrous media and herein lies the problem. Permeability varies based upon the material and the flux density. <$L=\Lambda/I = \mu N^2r^2/2R$>. The material does not change but the flux density varies based upon the amount of current flowing through the coil.

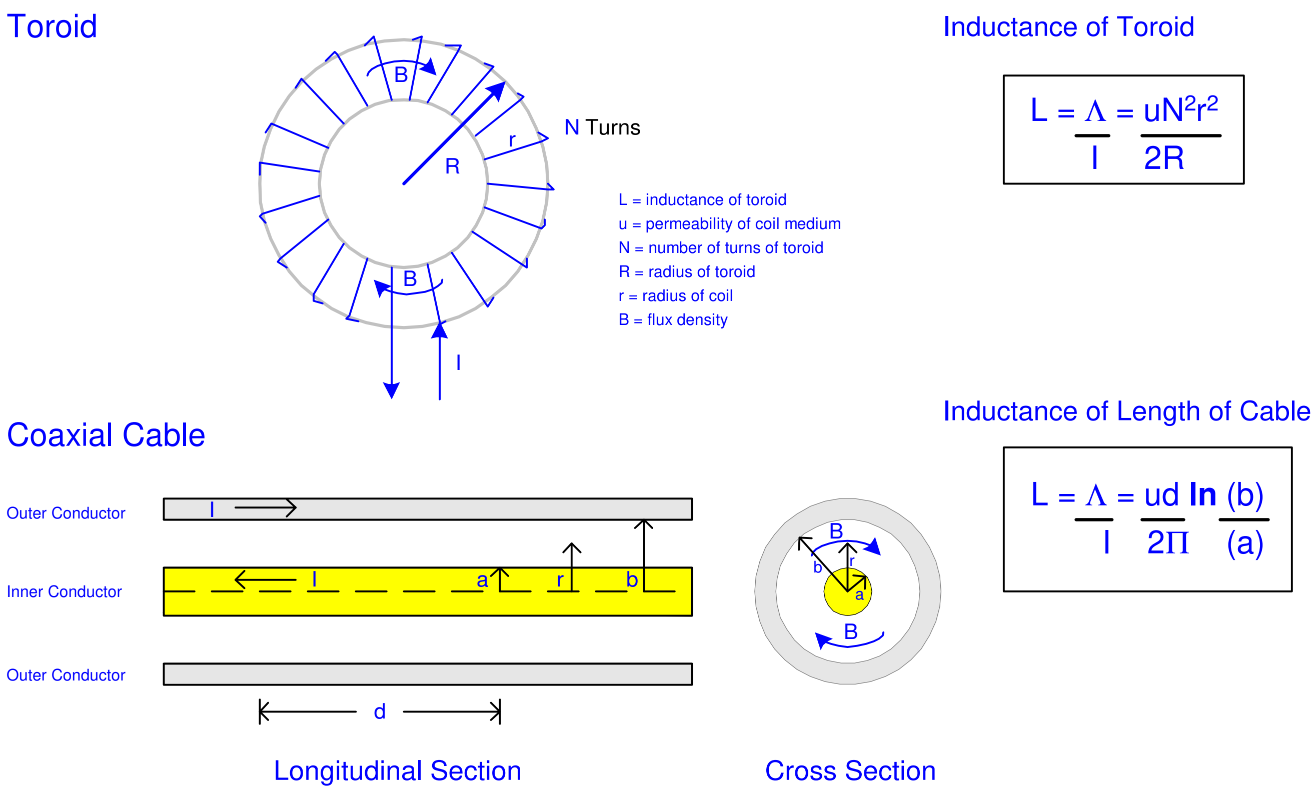
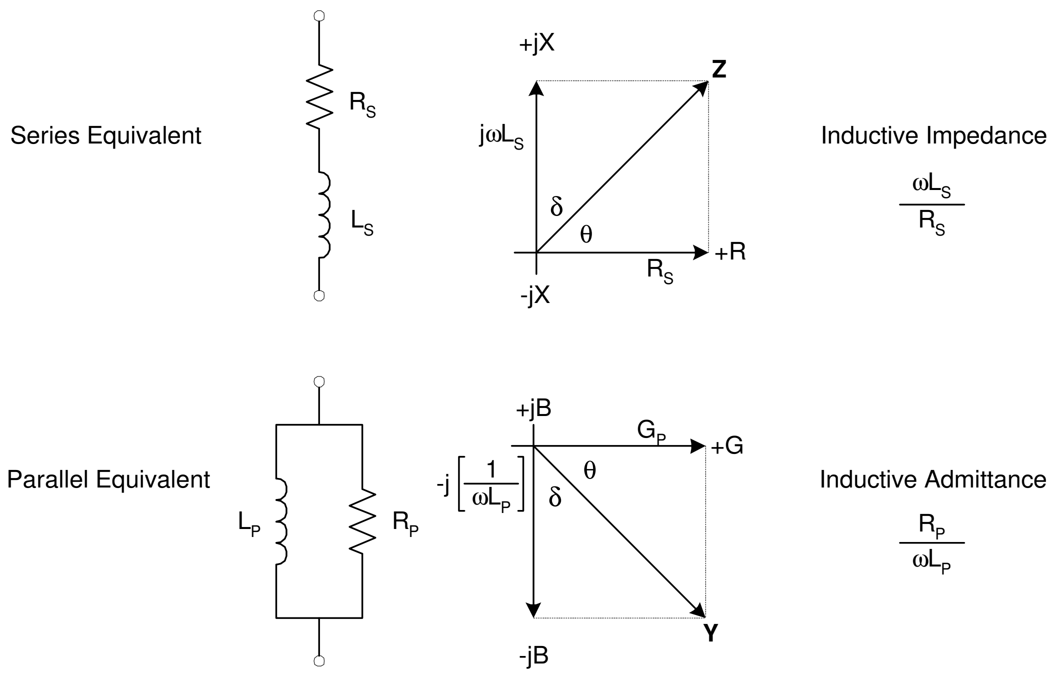


Figure 1: Toroid & coaxial cable inductance formulas

Quality factor & DC Bias

Quality Factor (**Q**) is another important characteristic of an inductor. The Q is the ratio of Reactance to Resistance and therefore is unit less. It is the measure of how 'pure' or 'real' an inductor is (i.e. the inductor contains only reactance). The higher the Q of an inductor the fewer losses there are in the inductor. The Dissipation Factor (D) the total loss within a component 1/Q. The total loss (D) of a coil is f Copper Loss, Eddy-Current Loss and Hysteretic Loss.



Quality Factor Equation $Q = \frac{1}{D} = \frac{\omega L_S}{R_S} = \frac{R_P}{\omega L_P}$

Figure 2: Quality factor equation

Reality check: Use of DC bias

Okay so what does this all mean? In order to get an accurate inductance measurement the inductor must be tested under actual conditions for current flowing through the coil. This cannot always be done with the typical ac source and a standard LCR meter as the typical source in an LCR meter is normally only capable of supplying small amounts of current. This level of current is not satisfactory for testing most inductors used in power supplies. Rather than using a larger ac current source, inductors are usually tested with a combination of dc current and ac current. Dc bias current provides a way of biasing the inductor to normal operating conditions where the inductance can be measured with a normal LCR meter. The bottom line is that the measured inductance is dependent on the current flowing through the inductor.

DCR, voltage leveling & source impedance

DC resistance measurements

Measuring the DCR or winding resistance of a coil of wire confirms that the correct gauge of wire, tension and connection were used during the manufacturing process. The amount of opposition or reactance a wire has is directly proportional to the frequency of the current variation. That is why dc resistance is measured rather than ACR. At low frequencies, the dc resistance of the winding is equivalent to the copper loss of the wire. Knowing a value of the wire's copper loss can provide a more accurate evaluation of the total loss (D_F) of the device under test (DUT).

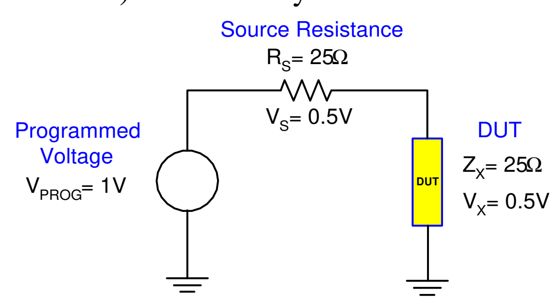
Level that voltage

Since the voltage across the inductor changes with impedance of the inductor and the impedance of the inductor changes with current, a typical LCR meter designed for measurements on capacitive and resistive devices can cause the inductance to appear to drift. The actual inductance is not drifting but is caused by the voltage across the inductor not being constant so the current is not constant. A voltage leveling circuit would monitor the voltage across the inductor and continually adjust the programmed source voltage in order to keep the voltage across the inductor constant.

Since it is possible to apply large values of current and voltage to an inductor, CAUTION must be taken when the current through an inductive circuit is suddenly interrupted because a voltage transient then occurs across the open circuit. Put another way, if the current could be instantly switched off, then the voltage would in theory become infinite. This does not occur because the high voltage develops an arc across the switch as contact is broken, keeping di/dt from becoming infinite. This does not however prevent the voltage from increasing to potentially lethal levels. If a person breaks the contact without the proper protection, the inductor induces a high voltage, forcing the current through the person.

A constant source

The current flowing through the inductor from the ac source in the LCR meter must be held constant. If not, the inductance measurements will change. This change is generally a function of the LCR meter's open circuit programmed test voltage. The programmed voltage in an LCR meter is obtained under an open circuit condition. A source resistance (Rs, internal to the meter) is effectively connected in series with the ac output and there is a voltage drop across this resistor. When a test device is connected, the voltage applied depends on the value of the source resistor (Rs) and the impedance value of the device. The source impedance is normally between 5Ω and 100kΩ. Figure 3 illustrates the effect of source resistance. The programmed voltage is 1V but the voltage to the test device is 0.5V, which means the voltage across the DUT is always less than the programmed voltage.



` **Figure 3: Constant source resistance**

Add up your losses

Copper Loss at low frequencies is equivalent to the dc resistance of the winding. Copper loss is inversely proportional to frequency. Which means as frequency increases, the copper loss decreases. Copper loss is typically measured using an inductance analyzer with dc resistance (DCR) measurement capability rather than an ac signal.

Eddy-Current Loss in iron and copper are due to currents flowing within the copper or core cased by induction. The result of eddy-currents is a loss due to heating within the inductors copper or core. Eddy-current losses are directly proportional to frequency.

Hysteretic Loss is proportional to the area enclosed by the hysteresis loop and to the rate at which this loop is transversed (frequency). It is a function of signal level and increases with frequency. Hysteretic loss is however independent of frequency. The dependence upon signal level does mean that for accurate measurements it is important to measure at known signal levels.

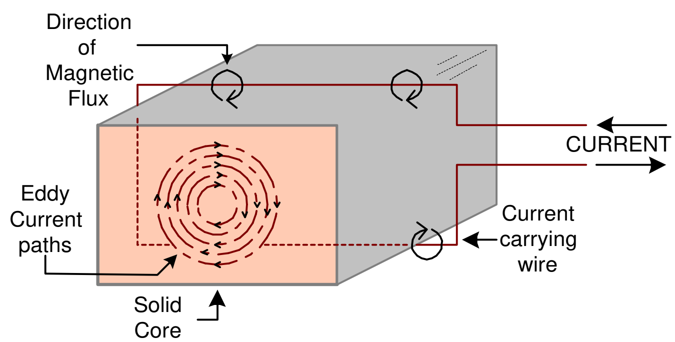


Figure 4: Eddy Currents induced in a solid iron core

Does your LCR Instrumentation fully characterize inductance? Can you monitor the ac & dc voltage and current to the DUT in real time operating conditions? Can you level the voltage across the DUT to ensure a constant voltage? Can you program the source impedance across the DUT to hold the current constant? Can you accurately measure the winding (dc) resistance of coils? Can you simulate actual inductor operating conditions with a dc bias current? Are you using an impedance meter designed primarily for capacitance measurements? LCR Instrumentation designed for multiple parameter measurement is not always the most precise in terms of inductor characterization. The IET 1910 Inductance Analyzer offers a host of unique features that put it at the front line of inductance testing.

- Measures the current through & voltage across the inductor
- Voltage leveling
- Constant source resistance.
- Dc resistance measurements
- Dc bias current