***Author's note:** Electronic circuits increasingly operate under high frequency and high power. Do we really understand the challenges of AC loss measurement of the magnetic components? Do we still face trouble about it or suspect the performance of the component but can't verify it? No worries, Laird™ Steward™ expertise will provide economical, fast and practical testing methods to measure AC loss under high frequency/high power conditions, freeing design engineers of worries about unexpected and excessive losses.*

One Simple and Accurate Method of Inductor AC Loss Measurement Under Dynamic Conditions

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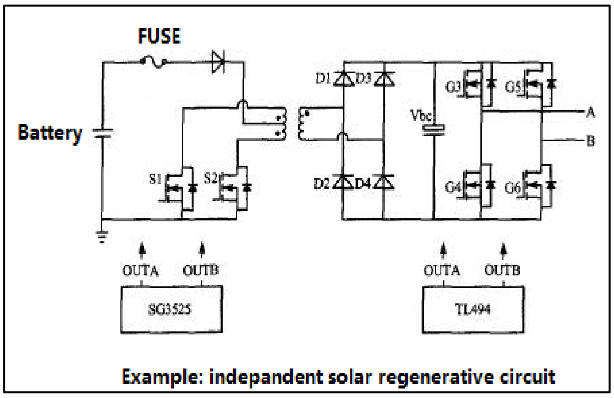
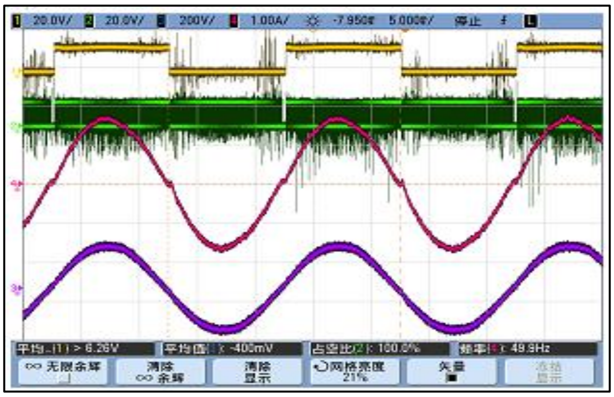
The ease to adopt higher power through new technology and topology such as SiC and GaN processors, photovoltaic power generation and the wide use of wireless power transfer-indicated power efficiency has become an important topic throughout the industry.

Magnetic components are now very commonly used in the high frequency spectrum and within decent AC current working environments (figure 1 & 2). Under this condition, coil loss not only depends on the DC resistance of the wire, but also on the high frequency AC resistance, the design of the coil and high frequency testing for verification. All become very important.

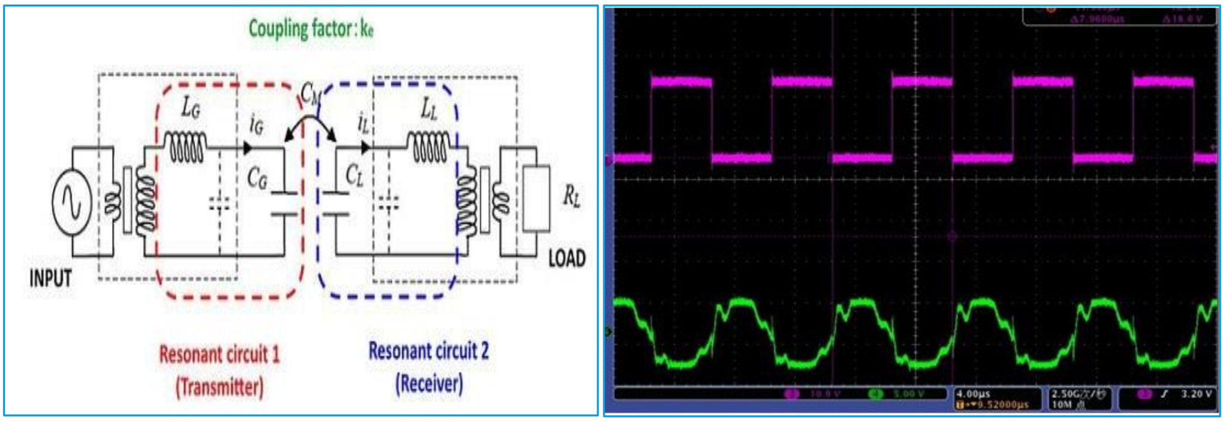
Using litz wire to reduce the AC loss has become common by design engineers, but while quantitatively evaluating thermal and electrical performance of these multi-strands litz coil designs under actual operating conditions, both computing simulation and test verification are extremely challenging. The challenges become increasingly prominent under high frequency and high-power conditions, which directly affect the success of electronic circuit design.

Figures below show adequate AC current in the system:





(Figure 1: Circuit diagram of an solar inverter and its current waveform)



(Figure 2: Circuit diagram of a wireless charging system and its current waveform）

The necessity of loss assessment under actual operating conditions: Loss Must be Tested

At present, magnetic materials loss data are measured on a standard magnetic toroid in sine wave voltage. There is still no theoretical way to conduct high frequency coil loss analysis. There is also a large gap between the simulation and the actual loss under actual operating conditions.

– The influence of BH non-linearity and magnetic anisotropy of the actual magnetic core will lead to a great difference between the core loss in DC superposition states and the manufacturer’s empirical data we used, especially in a condition close to the magnetic saturation region.

– The eddy current loss of magnetic core is closely related to the geometry of the magnetic core. The relationship between loss and the effective cross-section area of the magnetic core is in quadratic proportion. The difference between the manufacturer’s empirical data derived from a magnetic toroid shape and the actual magnetic component shape used is not taken into consideration. The general equation of eddy current loss is noted below, where R is the geometrical dimension of the product.

$$\mathbf{Pe} = 10^{-16} \cdot PI^2 \cdot F^2 \cdot Bm^2 \cdot \frac{R^2}{4p} \quad \left(\frac{W}{cm^3}\right)$$

– Magnetic permeability is several orders of magnitude lower than the electrical conductivity. In actual conditions, the magnetic flux not only flows in the magnetic core but will also leak outside the core itself. This becomes significant if there is an air gap present in the magnetic circuit. These flux leakages have a direct relationship with the coil shape and its winding processes. The coil structure used for the standard magnetic toroid is being uniformly wound 360 degrees around the magnetic toroid. This will have very low flux leakages, while the actual coils of most designs are uniformly distributed around the magnetic core. This will affect the accuracy of core loss measurement. In turn, this non-uniform magnetic flux distribution will affect the AC loss of the coil.

– The skin and proximity mechanism of coil are nonlinear with the current amplitude and excitation signal intensity. Use of an equivalent series or a parallel resistance circuit to analyze the actual loss quantitively is almost impossible.

– The Dowell’s model is based on a one-dimensional model. Most are based on a two-dimensional model. The result will be quite different from the actual three-dimensional construction. Simple coil models can use finite element analysis for use in evaluations, but finite element analyses on complex litz coils is very challenging.

Common methods for evaluating AC loss of magnetic components: Many Limitations

Take, for instance, an actual functional printed circuit board (PCB) from an electronic industry customer. The entire PCB or the magnetic element’s total efficiency can be tested. This method can trace the influence of the magnetic component, but the specific value of the losses (especially the AC loss) cannot be obtained directly. Furthermore, most magnetic component manufacturers do not always have the system level hardware from the customer to use in measurement.

Use a high frequency signal generator and programable power amplifier to generate needed excitation power to the magnetic component. Conduct real-time capture of the current and voltage waveforms. Use the period integral or lag phase arithmetically and obtain the loss value of the magnetic component.

An amplifier providing enough power amplitude is the key limitation to this specific test. There are three commonly used testing devices:

1) A high-precision analyzer such as Iwatsu SY-8217/8232 to provide power in the range of 150~300VA. This normally is insufficient for today’s needs.

2) A high frequency power generator and high bandwidth oscilloscope to capture the waveform and do mathematic calculations. Because of this method needed to analyze the phase lag angle of the waveforms, gauging the accuracy of the meter and calculation is complicated.

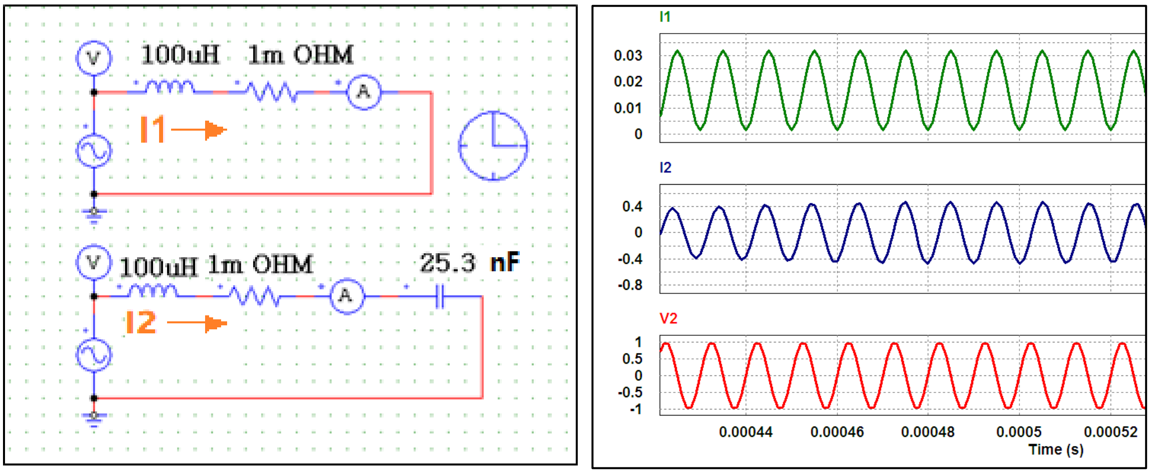
3) A high-frequency power generator with an external power meter to directly test the voltage and current. Here again the accuracy is not precise. The measurement error grows larger in the magnetic material with a phase angle close to 90 degrees.

Today’s high-power applications have surpassed 500VA easily and cause the above-mentioned methods to be limited in their ability to measure loss accurately.

Focal Point: De-risk AC loss uncertainty through a simpler and more practical test method on high power products

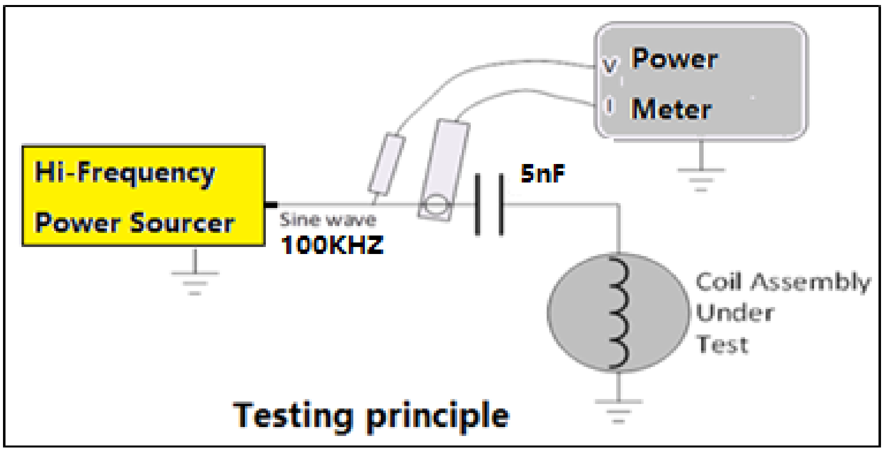
Using the difference phase angle between inductor and capacitor, 180-degree phase symmetry can be achieved under a specific frequency. This is a resonant stage with the total impedance of two components as 0. This can be realized by connecting a specified capacitor in series to the inductor. Thus, the supplied voltage or current supports only the series equivalent resistance of the magnetic element and the series equivalent resistance of the capacitor. In the case of a capacitor not being connected, the inductive reactance of the inductor and the capacitive reactance of the capacitor cannot offset each other. The total impedance is still very large so the amplitude of the inductive current will be low. This obviously cannot achieve the real inductive current under high power conditions.

Figure 3 shows the example of current amplitude to the magnetic element is increased to 0.4A with this approach compared to 0.03A before.



(Figure 3: Current amplitude using this resonant approach, I2 compared to without resonant, I1)

Figure 4 showa the schematic diagram on the set up. Table 1 is actual test data from this set up on one of the Laird Steward PFC50481k series 2kW power inductors.



(Figure 7: Schematic diagram of the test set up）

Sample rev	A
Frequency (KHz)	100
Current Ripple (A, peak)	3.5
Sourcer Voltage (V, peak)	100
AC Loss (100KHz, W)	9.2
DC Loss (100Hz, W)	2.1

s

(Table 1: Actual test result of a Laird Steward 2kW PFC50481k inductor with L = 480µH）

This test method is satisfactory for all magnetic elements, and particularly convenient to AC-AC, AC-DC power supplies such as found in inverters, charging stations, wireless charging applications, and complicated coil designs such as those using litz wire with high inductance and impedance. The test method is suited as well as an analytical tool on magnetic elements which experience heat issues. For high power/high frequency applications, start with the Laird Steward LDZ and PFC product series. Laird Steward offers this test as a service. Please contact your sales representative or field application engineer for further assistance.

Author's look back: *Laird Steward focuses on facts to describe its products and their expected performance. We develop accurate test methods from the customers' perspective to test product performance from a real application environment. Therefore, customers have grown to trust the performance and long-term reliability of our line of power inductors.*