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Wind Up the Best

Minntronix Technical Note

Inductance measurement using real-world inductance bridges

– or –

What you ‘set’ may not be what you ‘get’

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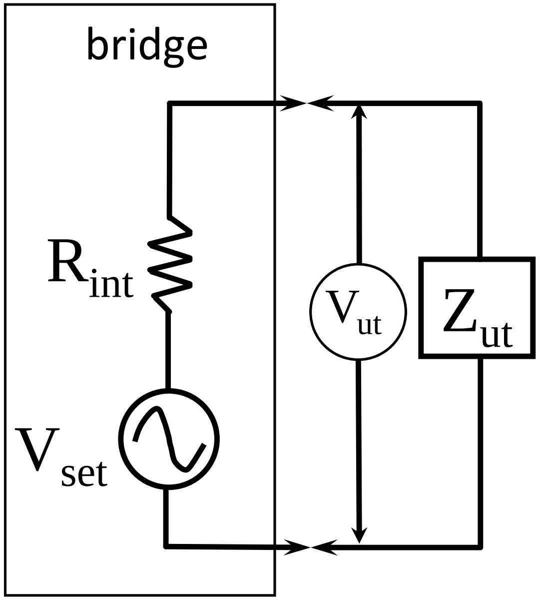
The Problems:

- Setting the drive level on many inductance bridges doesn’t always guarantee that the level you set will be the same as what is applied to the part under test.
- Most if not all core materials (except for “air”) exhibit changes in their permeability at different drive levels.
- When tested near its saturation point the inductance of a winding may vary widely causing some bridges to provide erroneous readings or no reading at all.

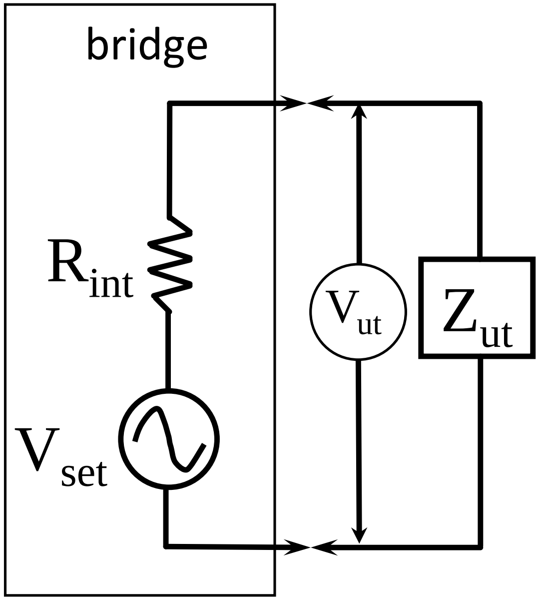
Part 1: How inductance bridges work



Like any oscillator or amplifier all inductance bridges have an internal driving impedance, shown here as R_{int}.

The amount of voltage that will appear across the inductor under test, shown here as V_{ut} and Z_{ut} depend on the relative values of R_{int} and Z_{ut}. When $Z_{ut} >> R_{int}$ the voltage across Z_{ut} will be almost the same as V_{set}.

Part 1: How inductance bridges work



When $Z_{ut} = R_{int}$ the voltage across Z_{ut} will be half of V_{set}.

When $Z_{ut} << R_{int}$ then the voltage appearing across Z_{ut} will be much less than V_{set}.

The value of V_{ut} is based on the voltage splitting principle:

$$V_{ut} = \frac{V_{set} \cdot Z_{ut}}{R_{int} + Z_{ut}}$$

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A Real-World Example

The first step: verify the internal impedance of the inductance bridge

Determining the internal impedance and applied drive voltage capabilities of the Wayne Kerr WK3260B based on empirical measurements.

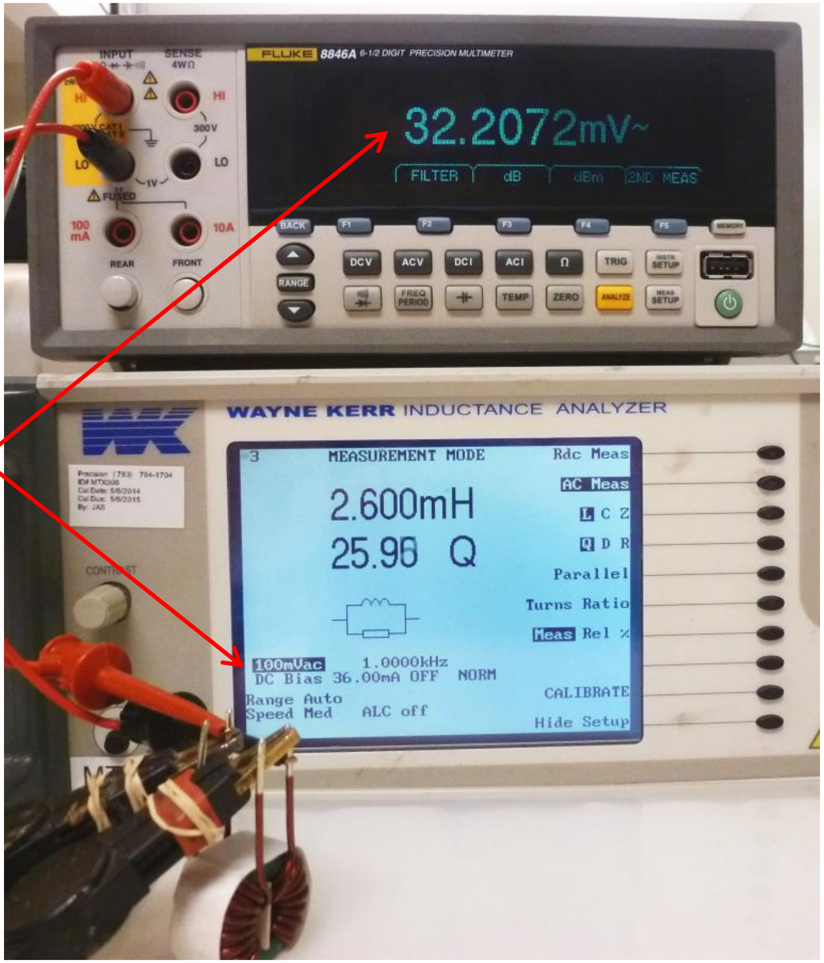
DJL	6-Dec-14				
ALC=off	f=1kHz	Zut = 50 ohm max variable resistor load			
Vset	Vm	Zut	Iut (calc)	Zint (ohms)	Pout (mW)
0.1	0.0202	12.140	0.001664	47.96	0.034
0.1	0.0295	20.000	0.001477	47.73	0.044
0.1	0.0343	24.880	0.001378	47.68	0.047
0.1	0.0511	49.590	0.001031	47.40	0.053
1.0	0.0943	5.049	0.018673	48.50	1.760
1.0	0.1998	12.122	0.016482	48.55	3.293
1.0	0.2919	20.000	0.014595	48.52	4.260
1.0	0.3388	24.865	0.013626	48.53	4.616
1.0	0.5050	49.590	0.010184	48.61	5.143
			Average:	48.16	ohms

A real-world example

The second step: measure an impedance, verify the results

A 2.6mH with Q=26 at 1kHz can be effectively treated as a nearly pure reactance of j$2\pi fL = j2\pi(1000)2.6m$ or j16.33Ω. With V_{set} = 100mV the voltage being applied to the inductor becomes:

$$V_{ut} = \frac{V_{set}\cdot Z_{ut}}{R_{int}+Z_{ut}} = \frac{100mV\cdot j16.33\Omega}{48+j16.33\Omega} = 32.2mV^*$$

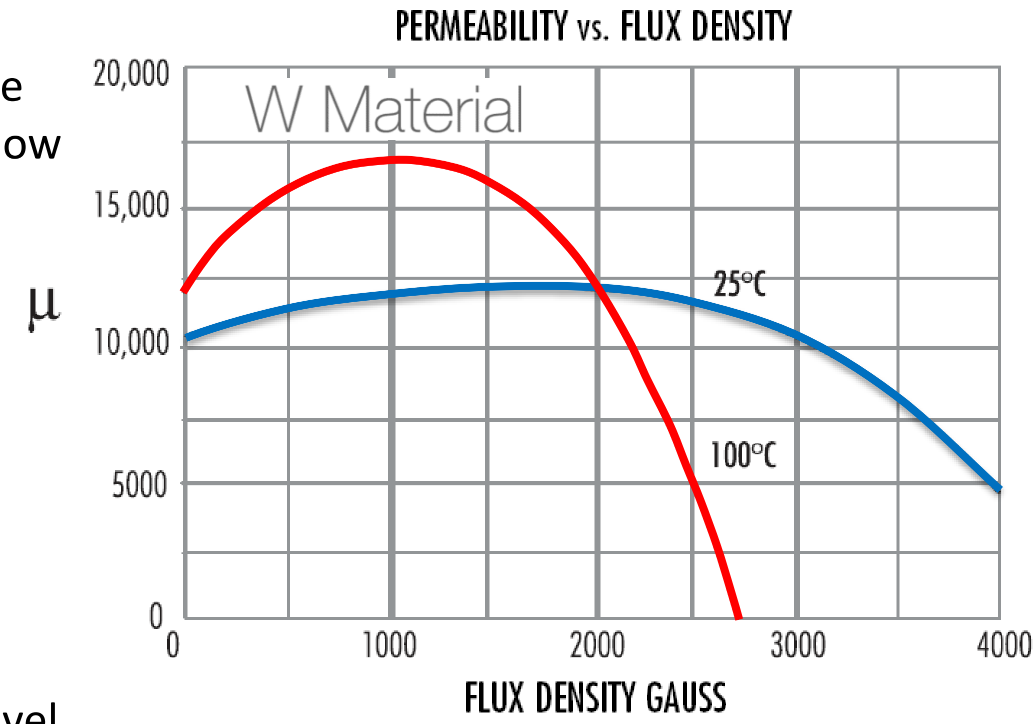


We can see in this case that setting a voltage of 100mV nets around a third of that to the inductor under test.

*Complex math operators are required to obtain correct results.

Part 2: How drive level affects inductance

The permeability versus flux density curve of a typical high-perm (10K u) ferrite, in this case Mag Inc "W" material, shows how permeability can be a strong function of drive level when driven near saturation.



Mag Inc lists B_{sat} for their "W" as 4300 gauss. At room temperature the permeability rises from 100% at low drive levels to 125% at around 1500 gauss then drops off as drive level increases toward saturation.

The effect is more pronounced at elevated temperatures.

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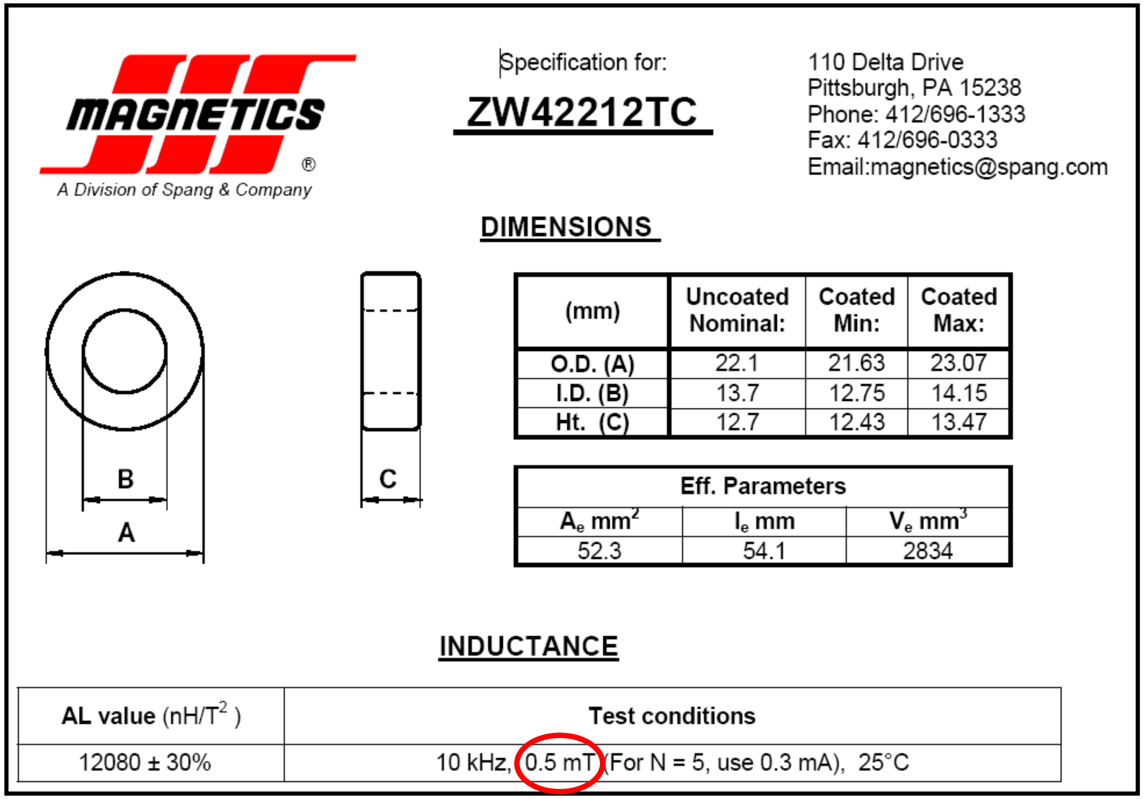
Part 2: How drive level affects inductance

Core manufacturers usually specify relatively low drive levels for their test condition. This slide shows a core spec to be tested at 5 gauss (0.5mT).

It is for this reason that we transformer manufacturers are reluctant to specify inductance limits that are based strictly on the AL value and its tolerance without first checking the core's test specs. The next slide shows why…



MAGNETICS ®
A Division of Spang & Company

Specification for:

ZW42212TC

110 Delta Drive
Pittsburgh, PA 15238
Phone: 412/696-1333
Fax: 412/696-0333
Email:magnetics@spang.com

DIMENSIONS

(mm)	Uncoated Nominal:	Coated Min:	Coated Max:
O.D. (A)	22.1	21.63	23.07
I.D. (B)	13.7	12.75	14.15
Ht. (C)	12.7	12.43	13.47

Eff. Parameters		
A_e mm^2	l_e mm	V_e mm^3
52.3	54.1	2834

INDUCTANCE

AL value (nH/T^2)	Test conditions
12080 ± 30%	10 kHz, 0.5 mT (For N = 5, use 0.3 mA), 25°C

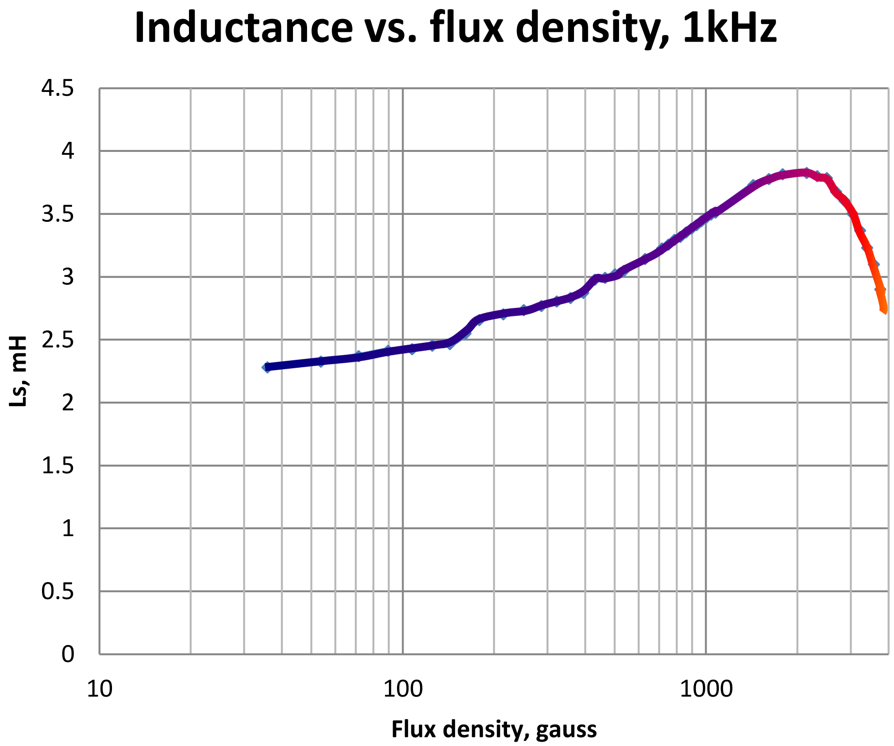
Part 2: How drive level affects inductance

Here are actual measurements taken on a toroidal inductor, the core of which is similar in size to the one shown on the previous slide. We can readily see the effect of increasing drive level on inductance as it rises then falls off sharply after saturation.

For reference, flux density B is related to drive level voltage by:

$$B_m = \frac{V \cdot 10^8}{4.44 \cdot n \cdot A_c \cdot f}$$

Where B_m is the flux density in gauss, V is applied voltage, n is the number of turns on the core, A_c is the core area in cm^2 and f is frequency in Hertz. Also: recall that $L \propto \mu$.



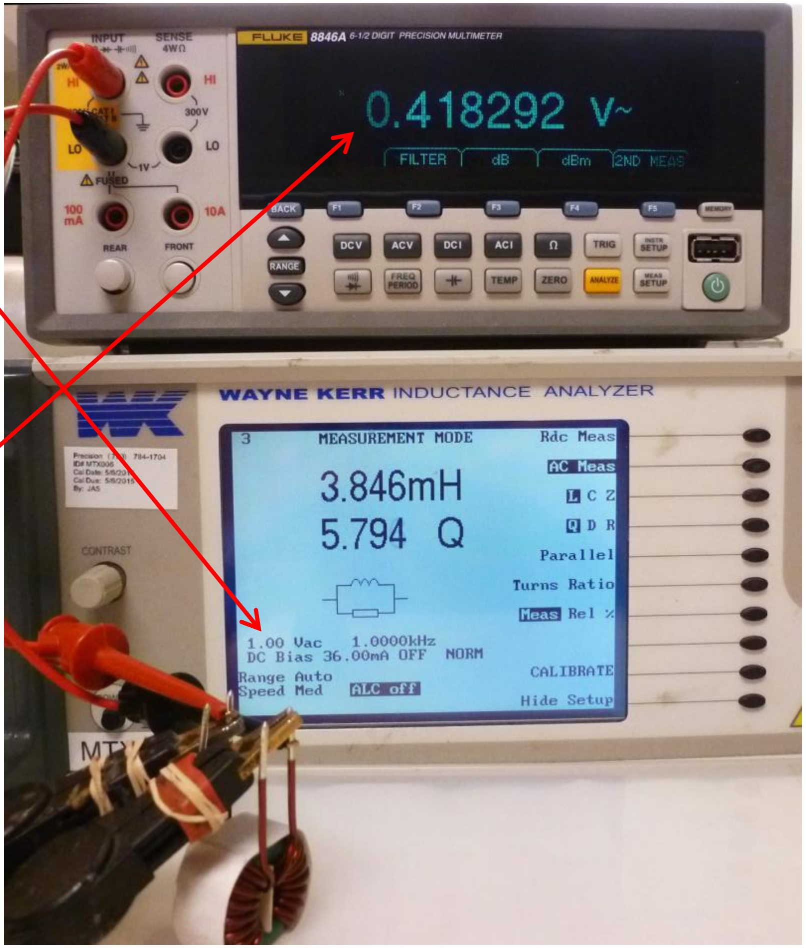
A real-world example

The second step, continued: measure an impedance, verify the results

Returning to our example, with V_{set} = 1.0V the inductor now reads 3.846mH with Q=5.794 resulting in an impedance of 3.983 + j23.42Ω. The voltage being applied to the inductor becomes:

$$V_{ut} = \frac{V_{set} \cdot Z_{ut}}{R_{int} + Z_{ut}} = \frac{1V \cdot (3.983 + j24.42)\Omega}{48 + 3.983 + j24.42\Omega} = 0.417V$$

Since the inductance increased due to higher permeability the voltage splitting factor also increased resulting in a higher proportion of drive level across the inductor.

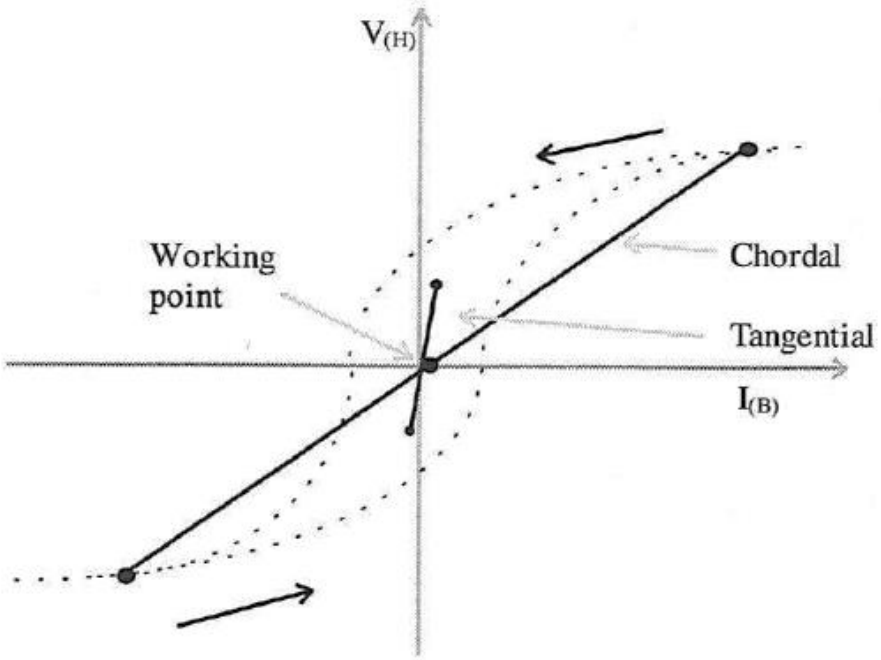


A real-world example

So why won't my inductance bridge provide a reading?

Borrowing (shamelessly) from a Wayne-Kerr equipment manual shows how the operating point of an inductor being subjected to high drive levels is effectively taking an average of the core's permeability.

If the inductance bridge tries to 'set' the voltage at a given value based on an impedance that is changing it may never be able to settle on a consistent reading. This 'hunting' process slows down production testing which is why most production engineers avoid using ALC except when absolutely necessary.



A real-world example

What to do about it?

Probably the easiest solution is to choose a higher test frequency. Decade multiples are popular and available on most inductance bridges. If 1kHz is too low to provide proper results consider increasing the test frequency to 10kHz or even 100kHz. This technique is commonly used when choosing an appropriate test frequency for leakage inductance, which thankfully doesn't involve the nonlinearities of the core material but does involve the measurement of a relatively low impedance. Going back to our initial example, the 2.6mH at 10kHz instead of 1kHz now provides a reactance of $j2\pi f L = j2\pi(10000)2.6m$ or j163.3Ω. With V_{set} = 100mV the voltage being applied to the inductor now becomes:

$$V_{ut} = \frac{V_{set} \cdot Z_{ut}}{R_{int} + Z_{ut}} = \frac{100mV \cdot j163.3\Omega}{48 + j163.3\Omega} = 95.9mV$$

Which is much closer to the desired 100mV value for V_{set}, especially when compared to 32.2mV we obtained previously.

References:

www.waynekerrtest.com – source for background on inductance bridges

http://www.eeweb.com/tools/calculator - Complex Math Calculator

Also: Complex Calc, Android App by Renat Notfullin