Pitfalls with inductance measurements

Inductance is fundamental to all designs

- Inductance is a fundamental characteristic of magnetic components
- Inductance seems straight forward, however due to non-linearities of the materials and large variety of applications there are many different definitions of inductance
- Calculating inductance during the design phase is crucial, however, there are many effects to consider
- Measuring inductance is important to verify designs, but designers have to take care to ensure they measure the right type of inductance and use the correct operating point

Calculating inductances

- Designers use AL values provided either in datasheets or calculated from magnetic dimensions to determine inductance

$$L = N^2 x\ AL$$

- For AL value given in datasheets the value is only valid for the measurement conditions stated. It can be different for other conditions
- For AL value calculated from magnetic dimensions, one has to consider the various effects that can change the AL value

Inductance ∝ Material Permeability

- Easy to assume a material with twice the permeability will have twice the inductance/AL for the same core but this is not true
- Stray inductance can contribute to overall inductance
- Cores are made to an AL spec not to a permeability spec

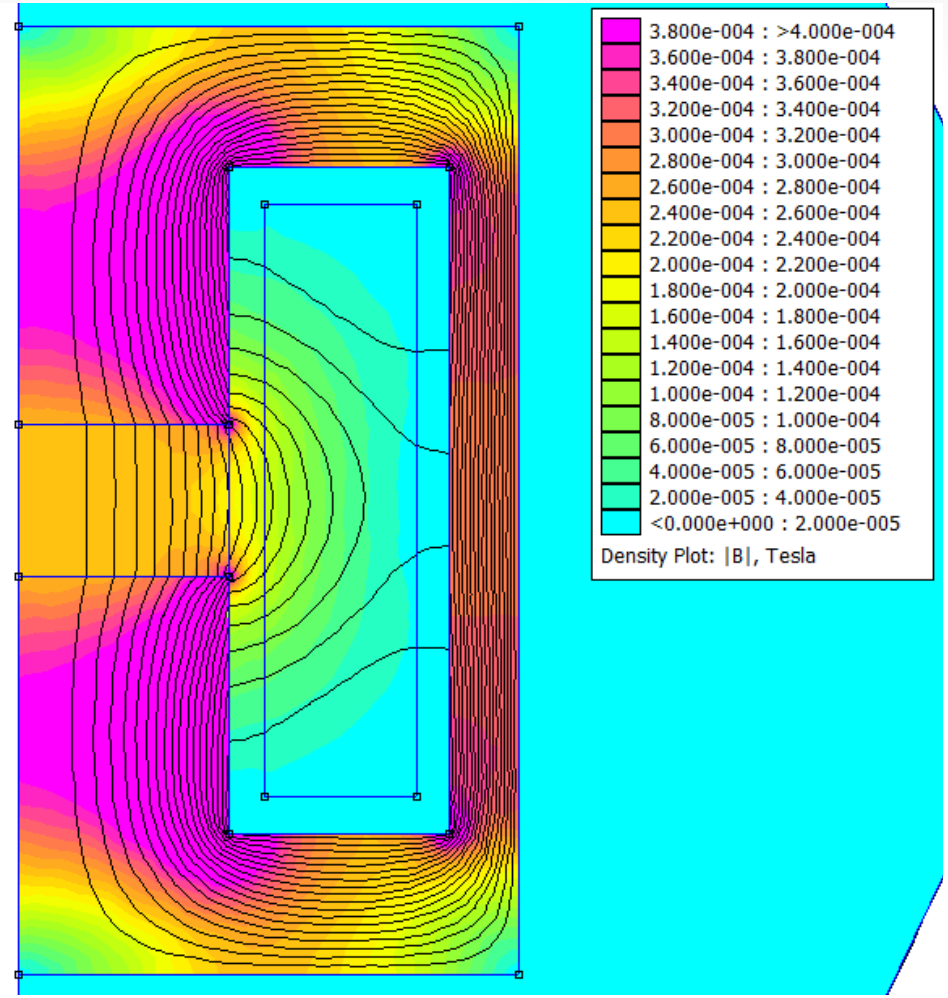
Material	#1	#2	#3	#4
Relative Perm	10	33	75	100
Change in Perm compared to #1	-	x3.3	X7.5	x10
1 inch toroid AL	13.5nH/t^2	40nH/t^2	93nH/t^2	125nH/t^2
Change in AL compared to #1	-	x2.96	X6.88	X9.26

Air Gap length ∝/Inductance

- In high permeability gapped cores, inductance does not change linearly with air gap length
- There is a significant field outside the air gap that increases the inductance
- Correction factor:

$$X_f = 1 + \frac{l_g}{A_e} \ln\left(\frac{2w}{l_g}\right)$$

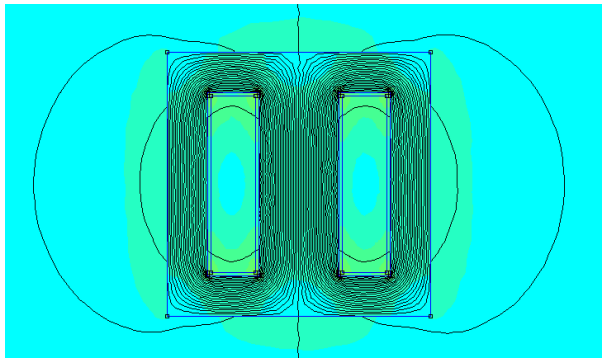
- Use manufacturer curve fit, correction factor or use magnetic simulation

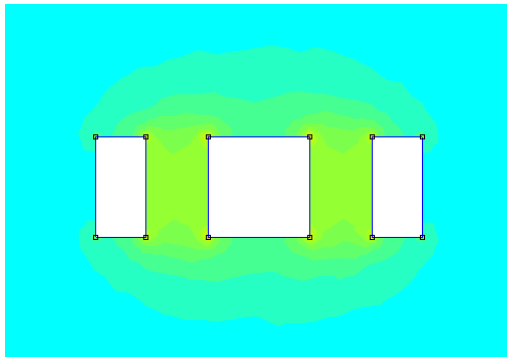


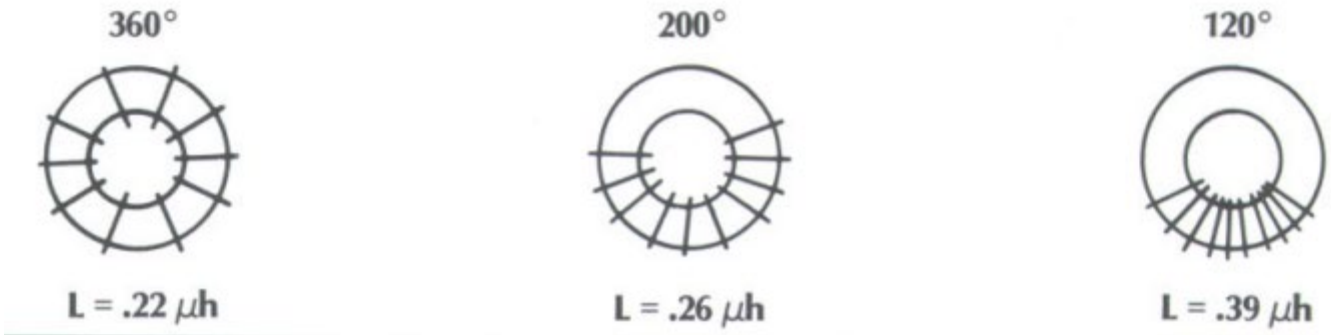
2 cores ≠ 2x inductance
More winding ≈ lower AL

- Inductance does not scale linearly with number of stacked cores. This is due to the loss of stray inductance around the individual cores
- Higher winding fills on toroid or E cores reduces the stray field, decreasing the AL value. Inductance depends on turn number and winding fill.

$$AL = \Lambda_{core} + \Lambda_{winding} + \Lambda_{air,sides} + \Lambda_{air,front/back}$$







Measuring inductances

- When measuring AL or inductance for quality control or verification purposes the exact same operating conditions as specified have to be used, otherwise AL can vary even if the core is not defective
- The AL value given in the manufacturer datasheet might not be the AL value that is relevant for a specific design or construction. AL specification for wound inductors should be based on actual design not just on the magnetic core material

Inductance		
	μ_i(reference)	10
	A_L value (nominal)	13.5 nH/N²
	Test Winding	N=100, #26 AWG
	Frequency	10 kHz
	Voltage on Agilent 4284A	0.29 V
	A_L tolerance	±5%

Different type of inductance – need to measure the correct one

- Due to the non-linearity of magnetic materials there can be different effective inductances depending on the application
  - Differential Inductance - small signal value, important for filters

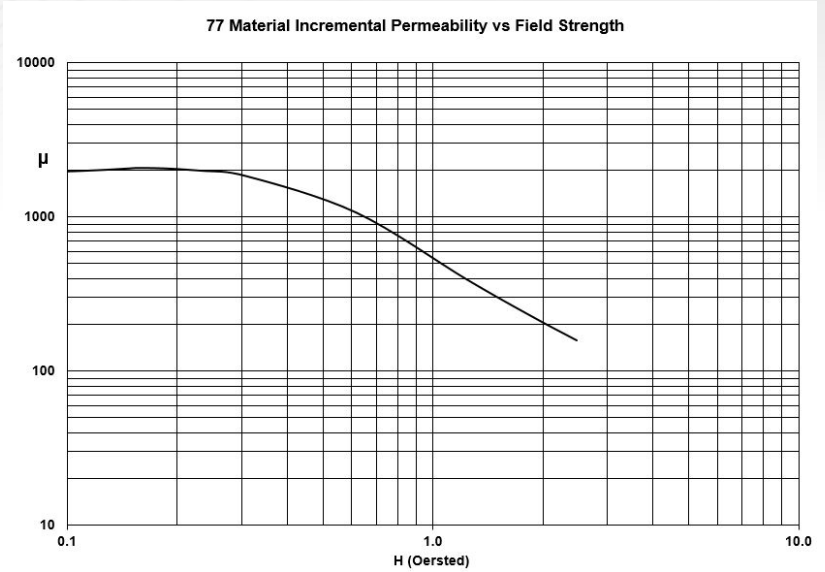
$$L_d(i) = \frac{d\Psi}{di} = \frac{V}{\frac{di}{dt}}$$

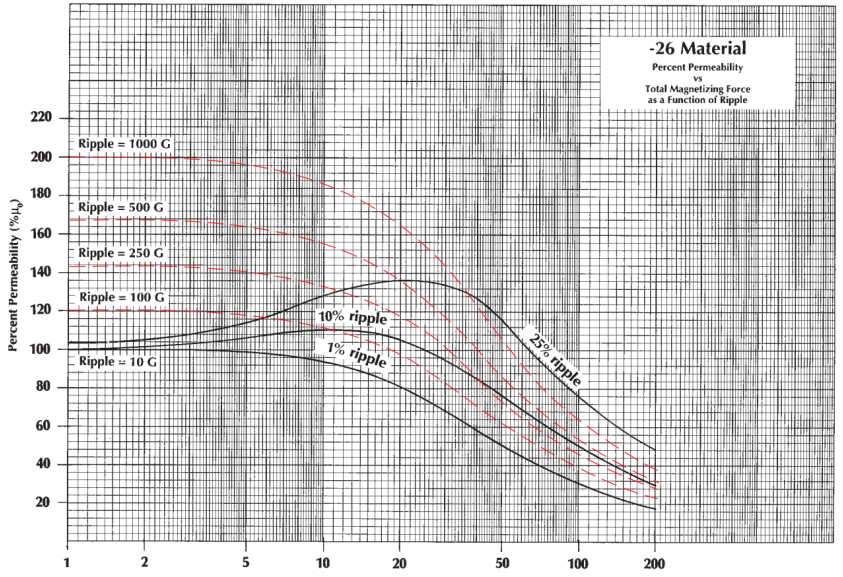
  - Amplitude inductance - large signal, important for resonant inductors

$$L_a(I_p) = \frac{\Psi_p}{I_p}$$

Differential inductance changes with bias

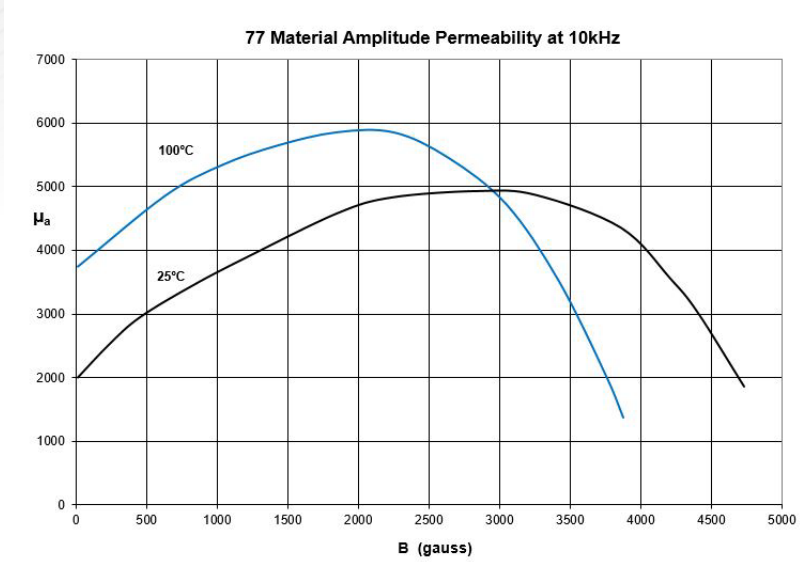
- A DC Bias current will change the differential inductance depending on field strength. Ungapped ferrites are especially sensitive to this
- Operating frequency will change inductance
- A large signal excitation can impact the effective inductance of a superimposed small signal

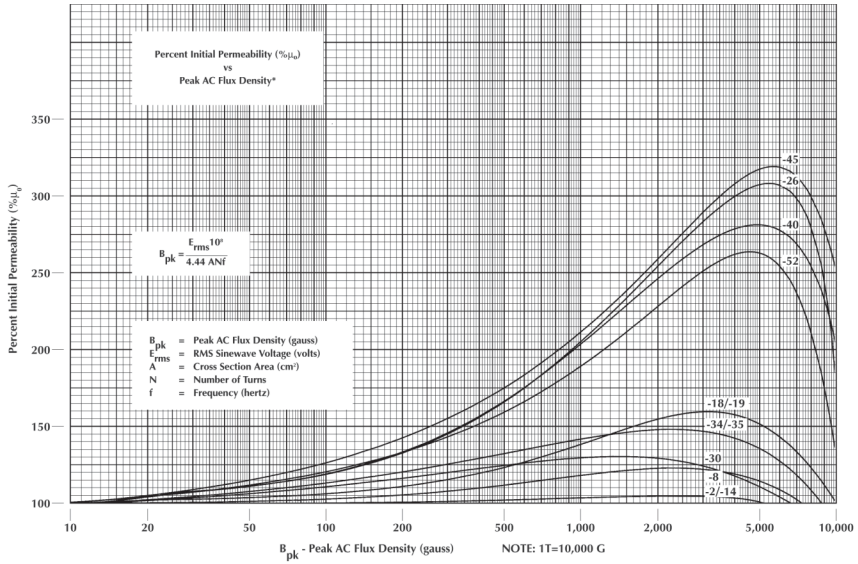




Amplitude inductance changes with excitation

- Different drive strengths during testing will change the effective amplitude inductance of the core under test
- Ungapped ferrites and some powdered iron materials as especially affected by this
- Inductance can up to 3x larger than expected if excitation is high





MICROMETALS
POWDER CORE SOLUTIONS

Conclusion

- During design, don’t assume inductance is linear with number of stacked cores, gap length or permeability. Verify with measurements
- For quality control measurements, use exact same conditions as stated in the manufacturer’s datasheet
- For verification of finished wound inductors, determine nominal inductance or AL from tests, do not base it on core datasheet value
- Be mindful what inductance is actually being measured. Is it a small signal inductance or a large signal inductance
- For ungapped ferrites and some powdered iron, ensure small drive levels to achieve a peak flux density of 10gauss/1mT, otherwise inductance will be higher than expected

Thank You