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Dimensional Resonance in Ferrite Materials

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Brief

The frequency response of ferrite materials changes greatly depending on core size. Here, we get an intuition for the implications of this effect. We will also be taking a look at proposed way of predicting this behavior in different core materials.

Bio

Michael Arasim

Lead Product Manager

Fair-Rite Products Corp.

Michael Arasim is the Lead Product Manager at Fair-Rite Products Corp. Michael has been with Fair-Rite for over 12 years and has previously served as Electrical Lab Team Leader. In his previous role, Michael was responsible for overseeing all electrical lab activities. This included setting test procedures/specifications, characterizing materials, making process improvements, and supporting production efforts across Fair-Rite's different facilities. In his current role Michael is responsible for overseeing development projects, marketing efforts, and providing application support across Fair-Rite's product types.

Getting an Intuition for Dimensional Resonance

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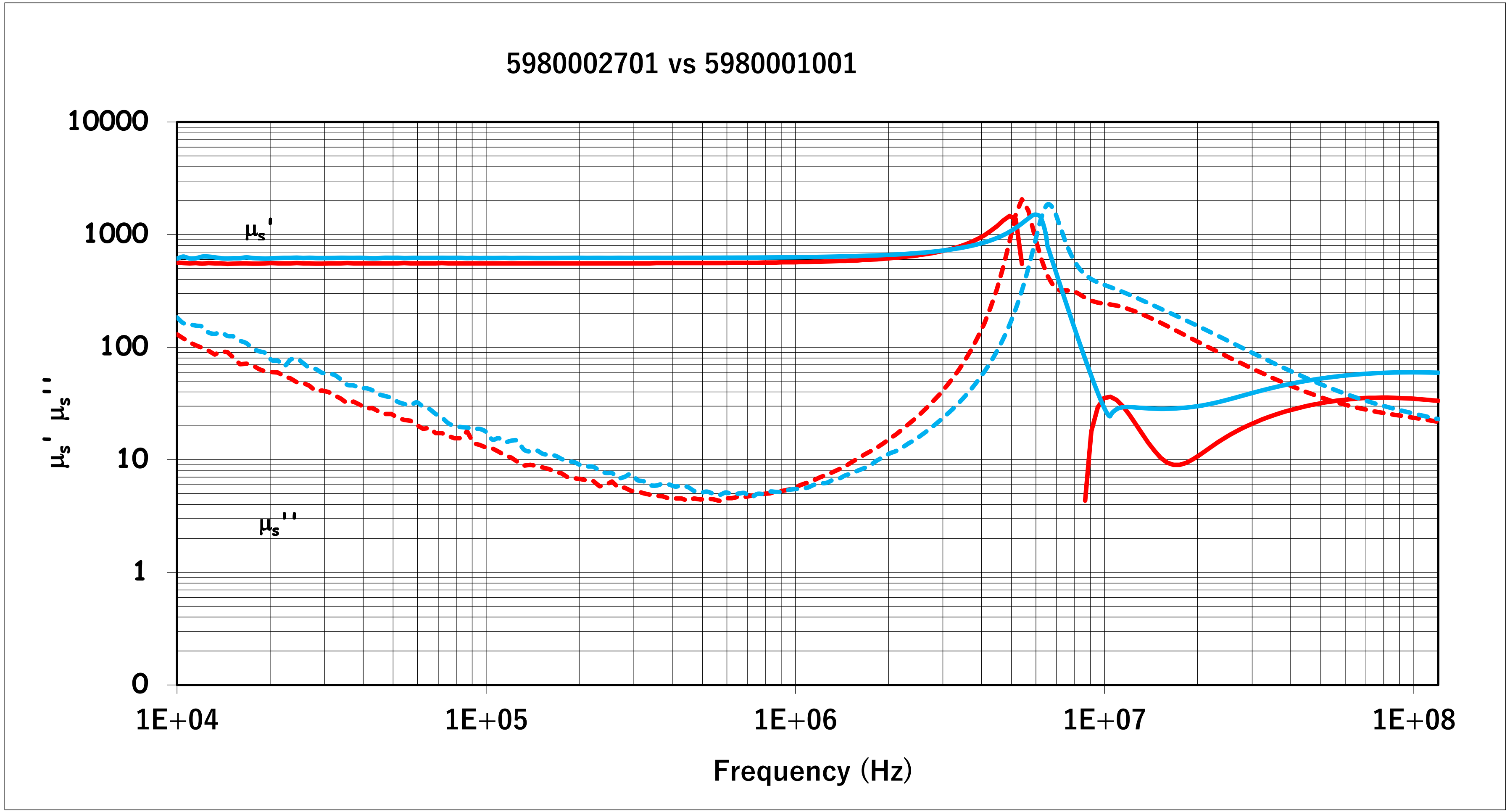
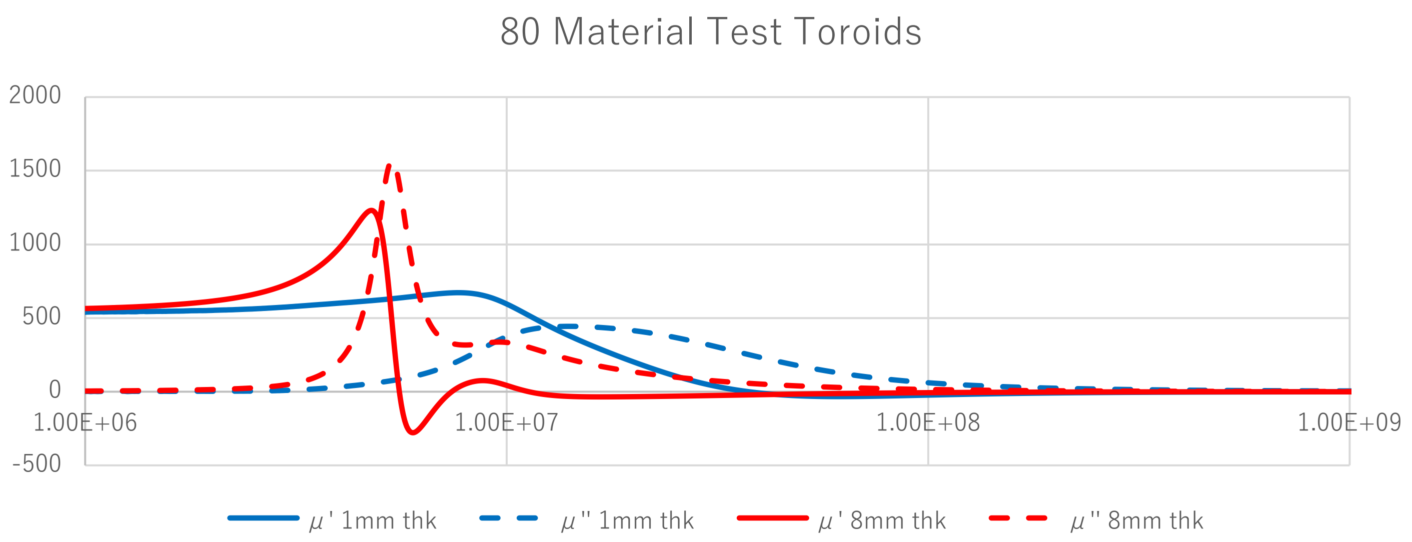
Dimensional Resonance

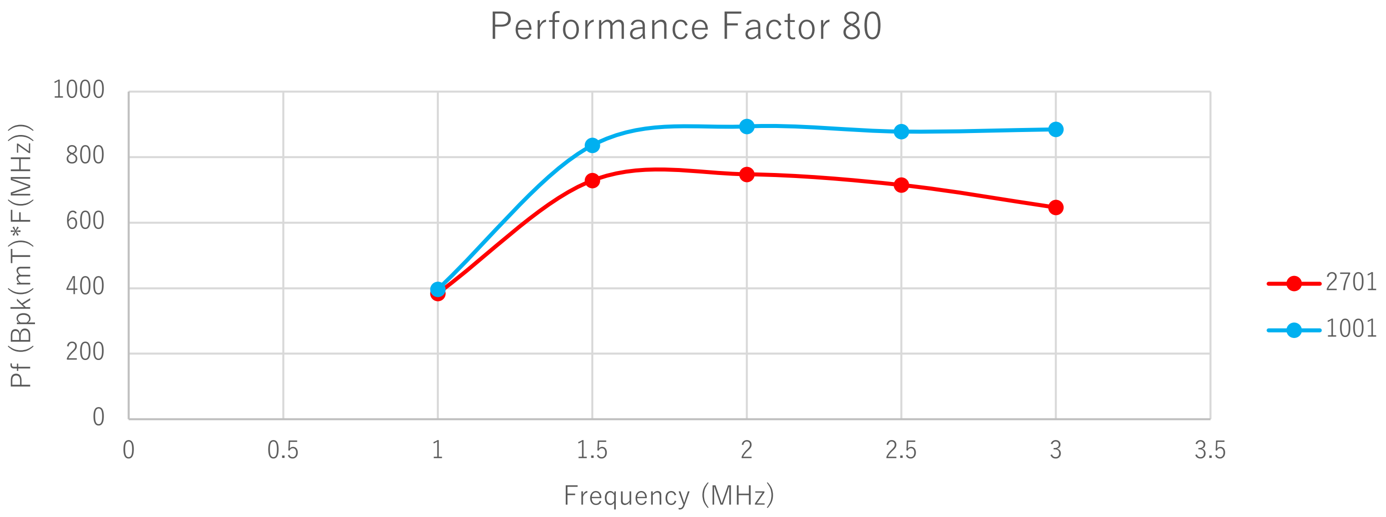
This chart shows the complex permeability of two different sized cores constructed from identical material. The core in blue (1001) has a cross-sectional area of 36.9mm^2. The red trace (2701) has a cross-sectional area of 80mm^2.



Can We Predict It?

One can get an intuition for how much dimensions will affect the performance of a material/part combo without diving too deep into the material datasheets or attempting simulations





Average Part?

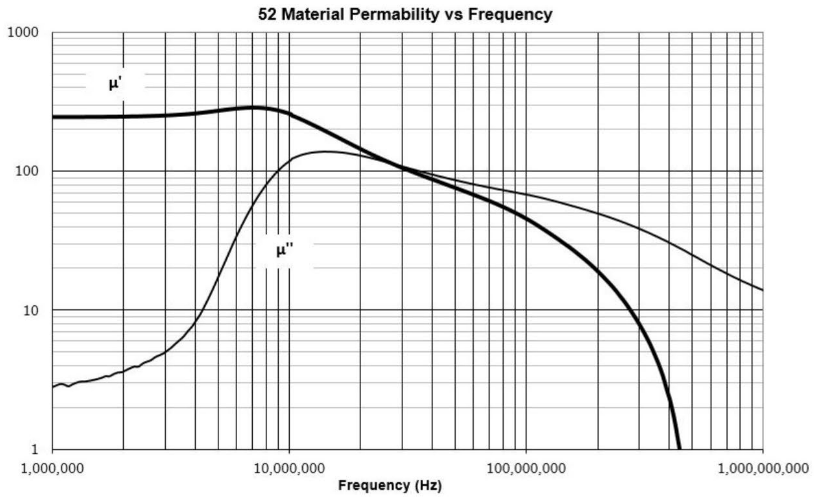
Most material manufacturers will list the size part that was used to produce the performance curves. We can consider this a medium sized part.

Curie Temperature	°C	T_c	>250
Resistivity	ohm-cm	ρ	$1{\times}10^9$

**** Characteristic curves are measured on standard Toroids (18/10/6 mm) at 25°C and 10 kHz unless otherwise indicated. Impedance characteristics are measured on standard shield beads (3.5/1.3/6.0 mm) unless otherwise indicated.

Material Safety Data Sheet (MSDS)

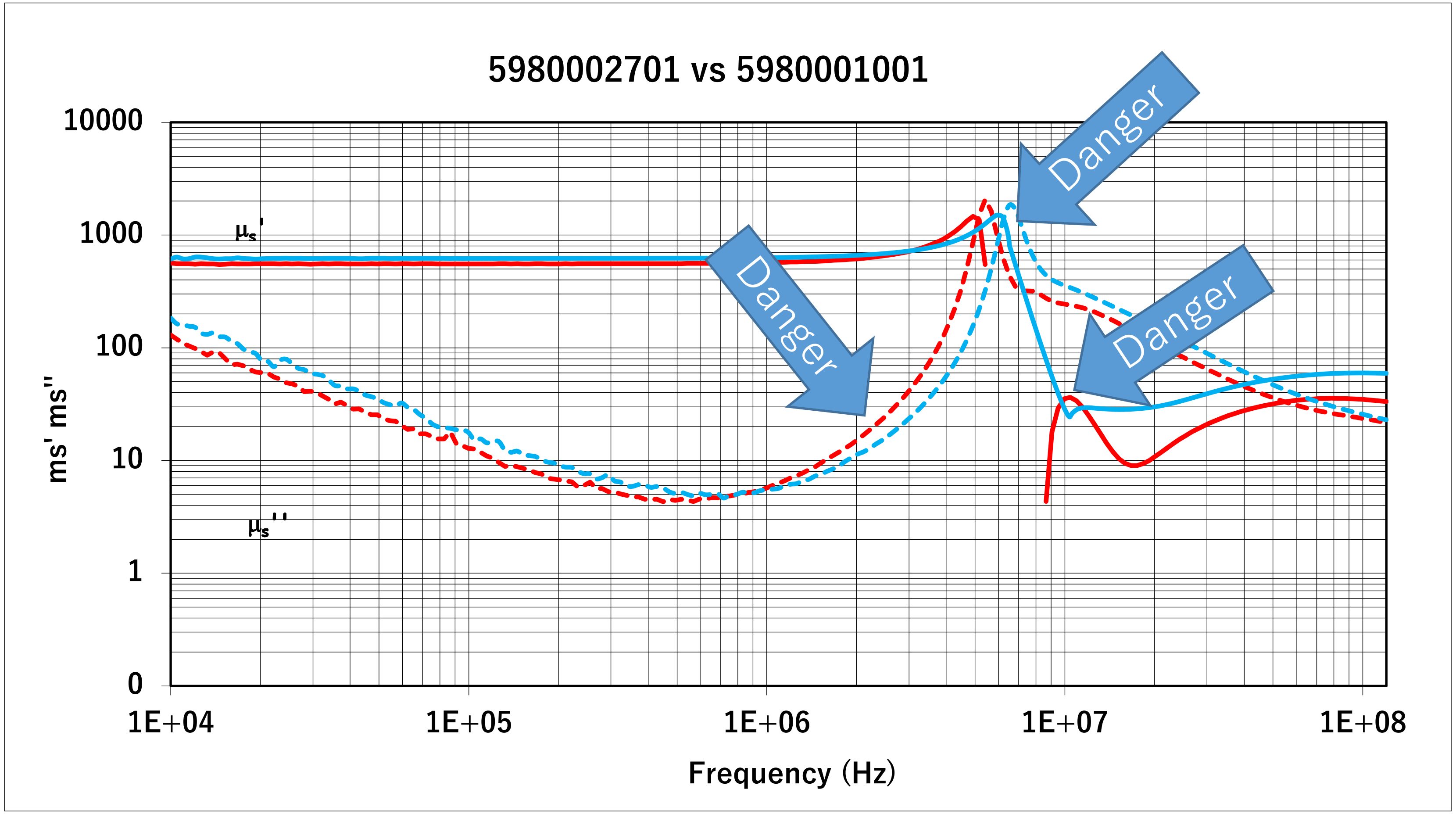
Click here to download Complex Permeability vs. Frequency (CSV)



Performance Envelope of a Material

How flat is the frequency response of the material?

Am I operating near sharp peaks or valleys in regards to the complex permeability of the material?



What Material?

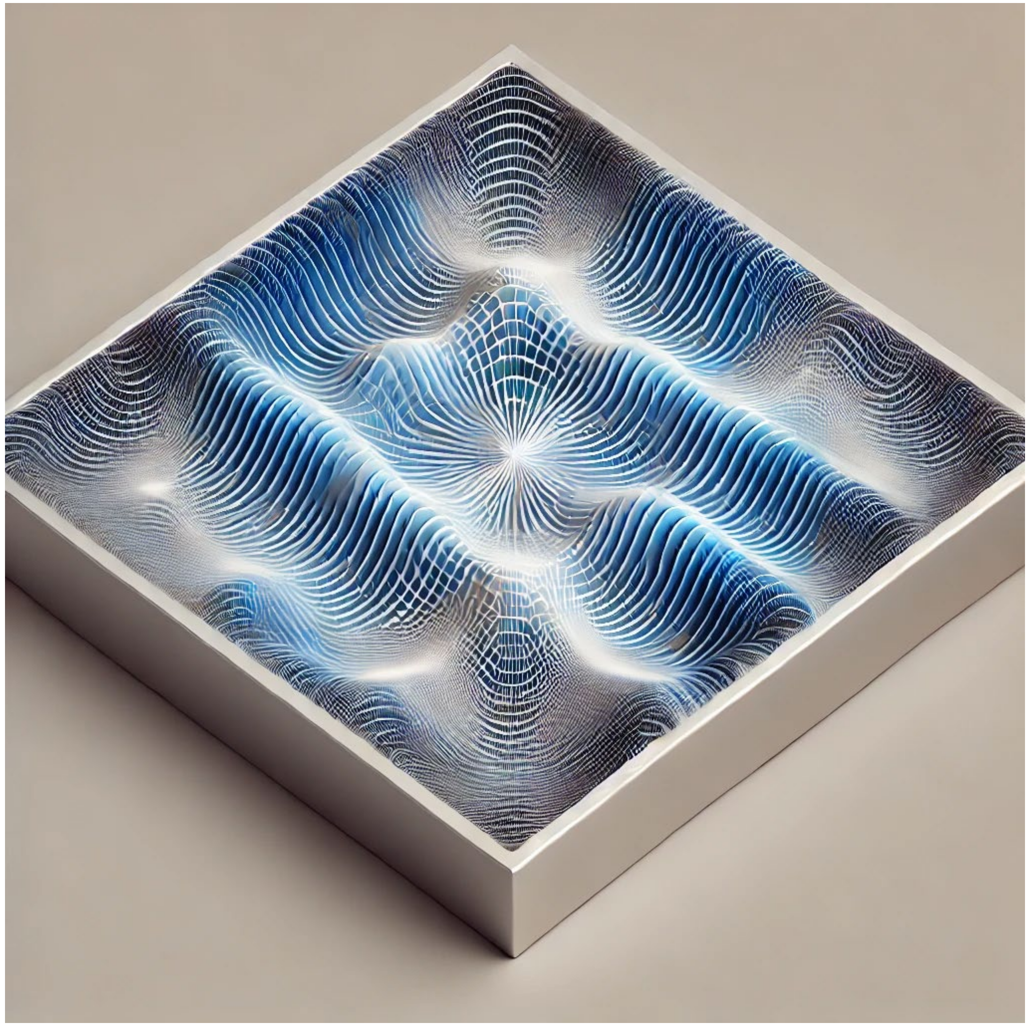
In general, MnZn materials are going to experience more variation in material due to dimensional variation. Part of this is due to the frequencies where MnZn materials are used relative to NiZn materials. Even among MnZn materials, there is a large spread in variation. While not a 100% accurate way to predict, lower DCR materials will tend to be more sensitive to core size.

Property	Unit	Symbol	61	52	51	44	46	43	15	31	20	77	78	73	75	76
Material Type			NiZn	NiZn	NiZn	NiZn	MgZn	NiZn	NiZn	MnZn	NiZn	MnZn	NiZn	MnZn	MnZn	MnZn
Initial Permeability @ B <10 gauss		µ	125	250	350	500	500	800	1500	1500	2000	2000	2300	2500	5000	10000
Flux Density	gauss	B	2500	4200	3500	3000	2550	3500	2700	3600	3300	5100	4800	4200	4800	4000
	mT		250	420	350	300	250	350	270	360	330	510	480	420	480	400
@ Field Strength	oersted	H	15	10	10	10	10	10	5	5	10	5	5	5	5	5
	A/m		1200	800	800	800	800	800	800	400	800	400	400	400	400	400
Residual Flux Density	gauss	Br	1000	2900	2300	1100	1680	2200	1800	2600	1980	1800	1500	1100	1000	1800
	mT		100	290	230	110	168	220	180	260	198	180	150	110	100	180
Coercive Force	oersted	Hc	1.2	0.6	0.6	0.45	0.53	0.36	0.2	0.34	0.14	0.25	0.2	0.18	0.11	0.12
	A/m		96	48	48	36	32	36	16	27	12	20	16	16	9	10
Loss Factor	10^{-6}	tan δ/µ	90	45	30	150	60	100	15	20	35	15	3	10	15	15
@ Frequency	MHz		10	1	1	1	0.1	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.025
Temperature Coefficient of Initial Permeability (20 – 70°C)	%/°C	T.C.	0.1	0.8	1.3	1.6	0.85	1.25	1.1	1.3	2.0	1.2	1	0.5	1	0.5
Curie Temperature	°C	Tc	>300	>250	>170	>160	>140	>130	>105	>130	>110	>200	>200	>160	>140	>120
Resistivity	ohm-cm	p	10^{8}	10^{9}	10^{9}	10^{9}	10^{8}	10^{5}	10^{8}	3000	10^{7}	100	200	100	300	50
Application Area	**EMI suppression**															
Recommended Frequency Range	MHz		200-2000	50-1000	50-500	25-300	25-300	25-300	10-300	1-300	1-300	<10	<10	<50	<20	<5

What if We Want to Do Some Math?

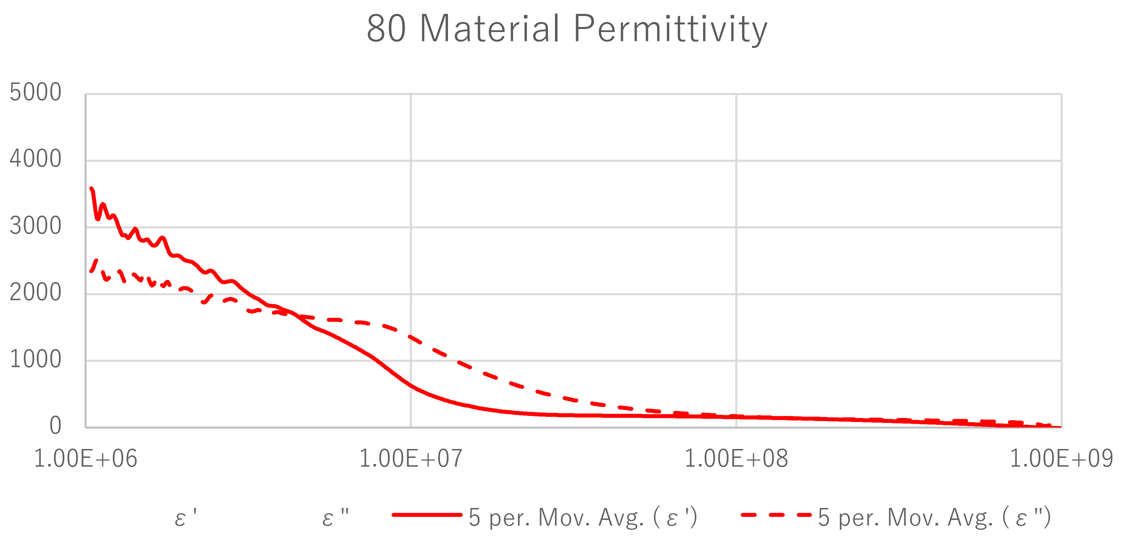
Core Dimensions Relative to Wavelength

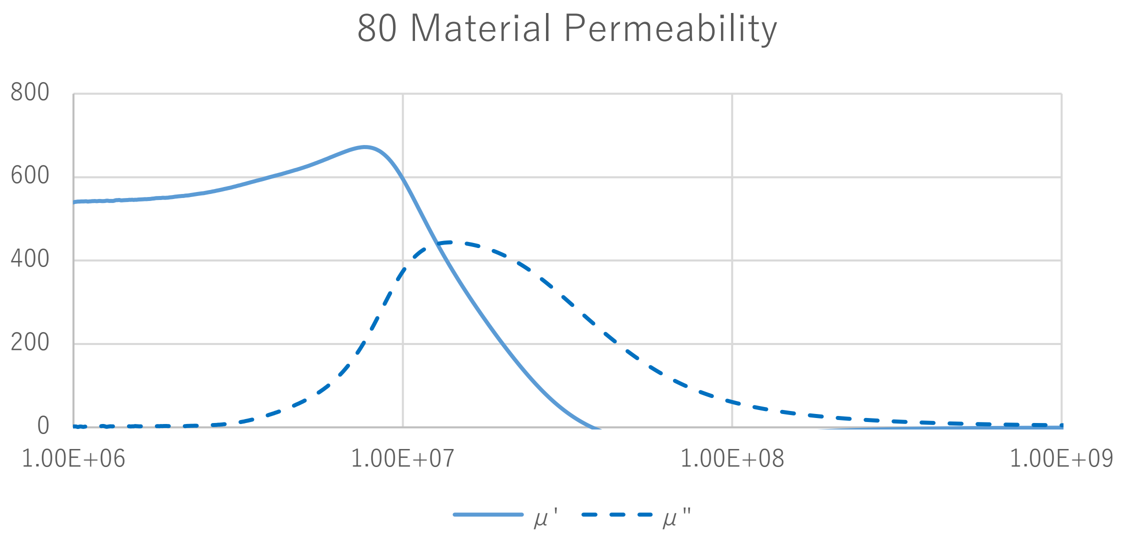
Ferrite cores (even large ones) are generally small. At the frequencies ferrites are used, the wavelengths are very large relative to their cross section. But, are they really?



Effective Wavelength in Ferrite

The magnetic and dielectric properties of a ferrite material will modify the propagation speed of the wave travelling through it.





Effective Wavelength in Ferrite

A toroid was picked (5980002701 in this case). This toroid was then machined in several different "composite" iterations consisting of several pieces that add up to the core parameters and dimensions of the original core.

$$WL_{eff} = \frac{c/\sqrt{\mu' - j\mu"} \cdot \sqrt{\varepsilon' - j\varepsilon"}}{f}$$

$where:$

$c = speed\ of\ light\ (m/s)$

$f = frequency\ (Hz)$

$WL_{eff} = Effevtive\ wavelength\ (m)$

$\mu = Permeability\ of\ material$

$\varepsilon = Permittivity\ of\ material$

Effective Wavelength in Ferrite

Two methods were used to evaluate the predicted wavelength in the core vs real life observations. The first is simply looking at the minimum cross section dimension. The second is taking the magnetic path length into account with Lmin.

$$L_{eff} = \sqrt{L_{min} \cdot L_e}$$

$$where:$$

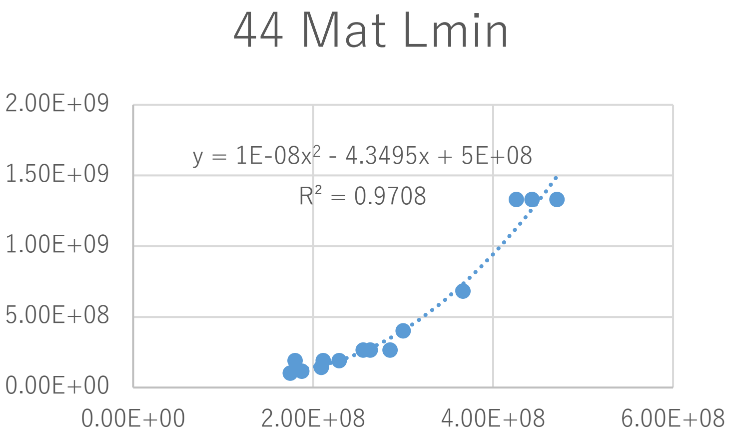
$$L_{eff} = \text{Figure of merrit}$$

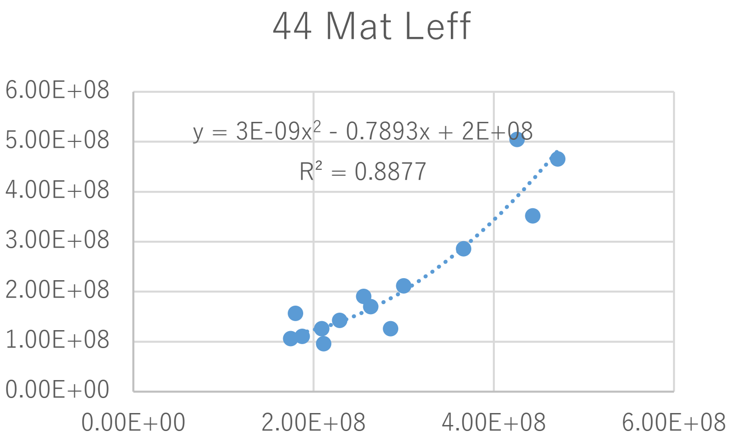
$$L_{min} = \text{Min cross} - \text{sectional length}$$

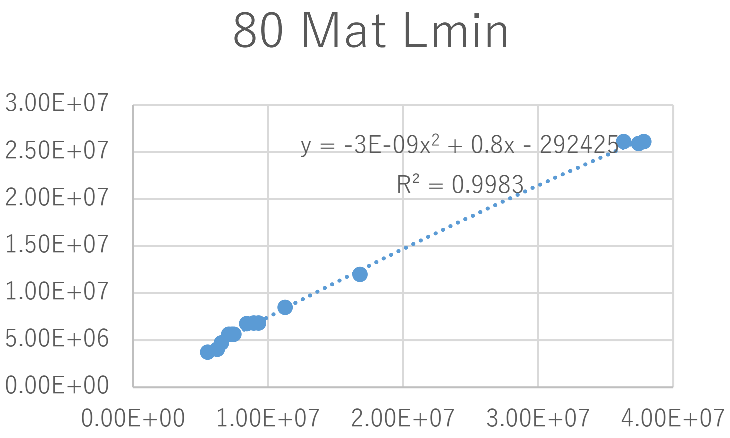
$$L_e = Magnetic\ path\ length$$

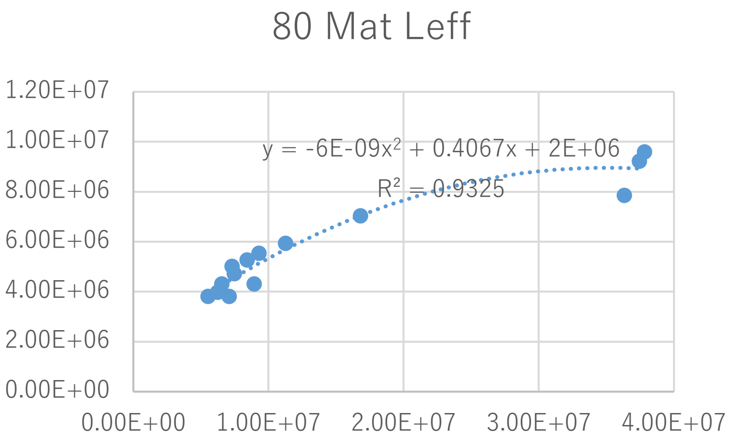
The Results

The strongest correlation was seen between the 1/8 calculated wavelength and the min cross-sectional dimension. The ¼ calculated wavelength and Leff figure of merit had weaker correlation.



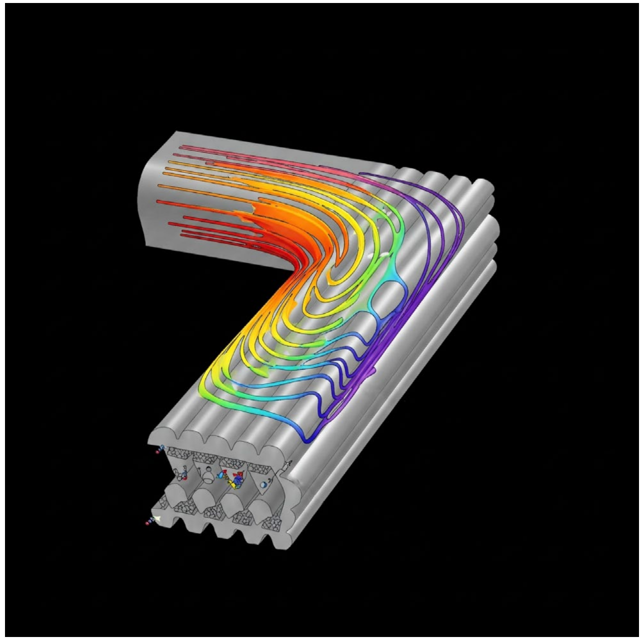


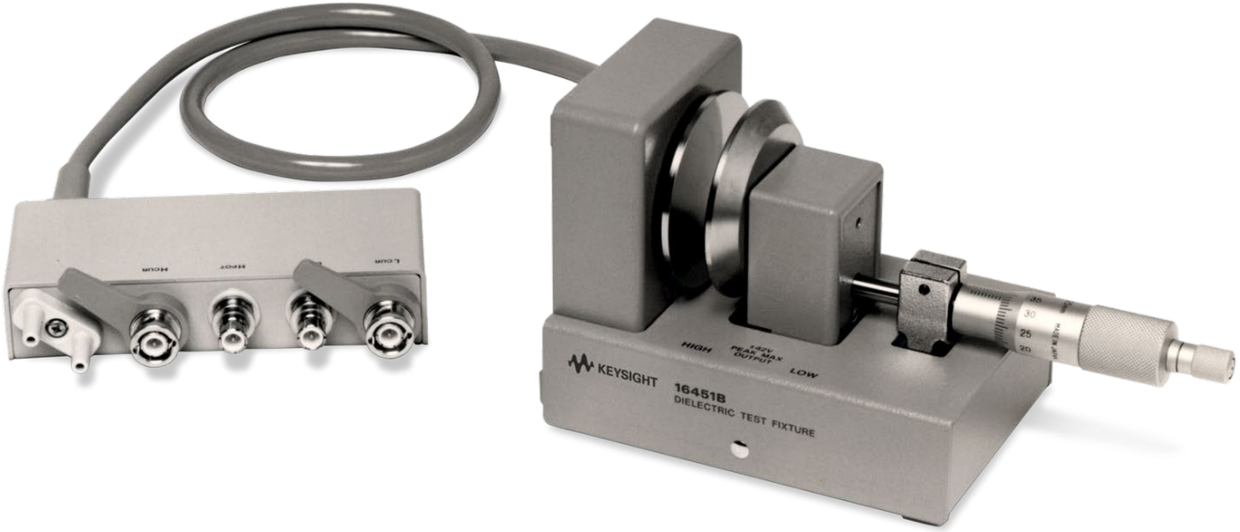




What's Next?

- Looking at Lmin relative to the calculated wavelength is a good start though, more complex mechanisms appear to be at play
- Effect of Le needs further investigation
- Curve fitting by material may be a good interim solution
- Need to figure out what happens to the rest of the curve
- More complete dielectric data is needed





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Thank You!

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