Maintaining Impedance in Split Core Ferrites for Low-Frequency Applications

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Vice President of Fair-Rite Products Corp.

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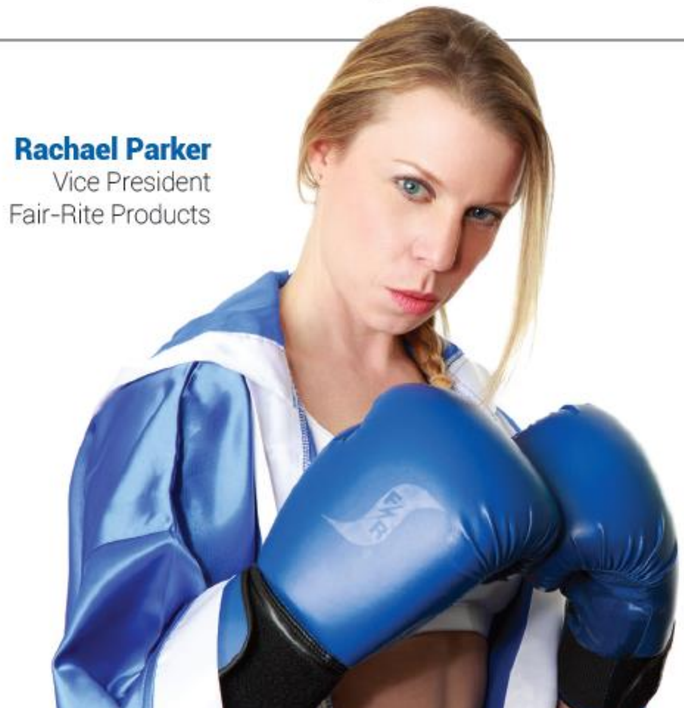
KNOCK OUT

LOW-FREQUENCY EMI

75 MATERIAL



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Joining Fair-Rite in 2014, she holds a BS in Electrical Engineering, an M.Eng in Electrical Engineering, and an MS in Engineering Management. Rachael spent her early career in product development, project leadership, and program management.

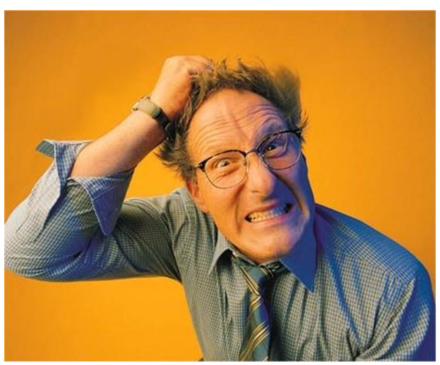
Fair-Rite Products Corp.

Your Signal Solution®

- Founded in 1952 – family owned and operated in US and China
- Providing ferrite components for the electronics industry for over **60 years**
- Wide product offering and materials for:
  - EMI Suppression
  - RFID-Antennas
  - Power/Inductive
  - Value Added Services (machining, winding, assemblies)
- Visit our new website at www.fair-rite.com

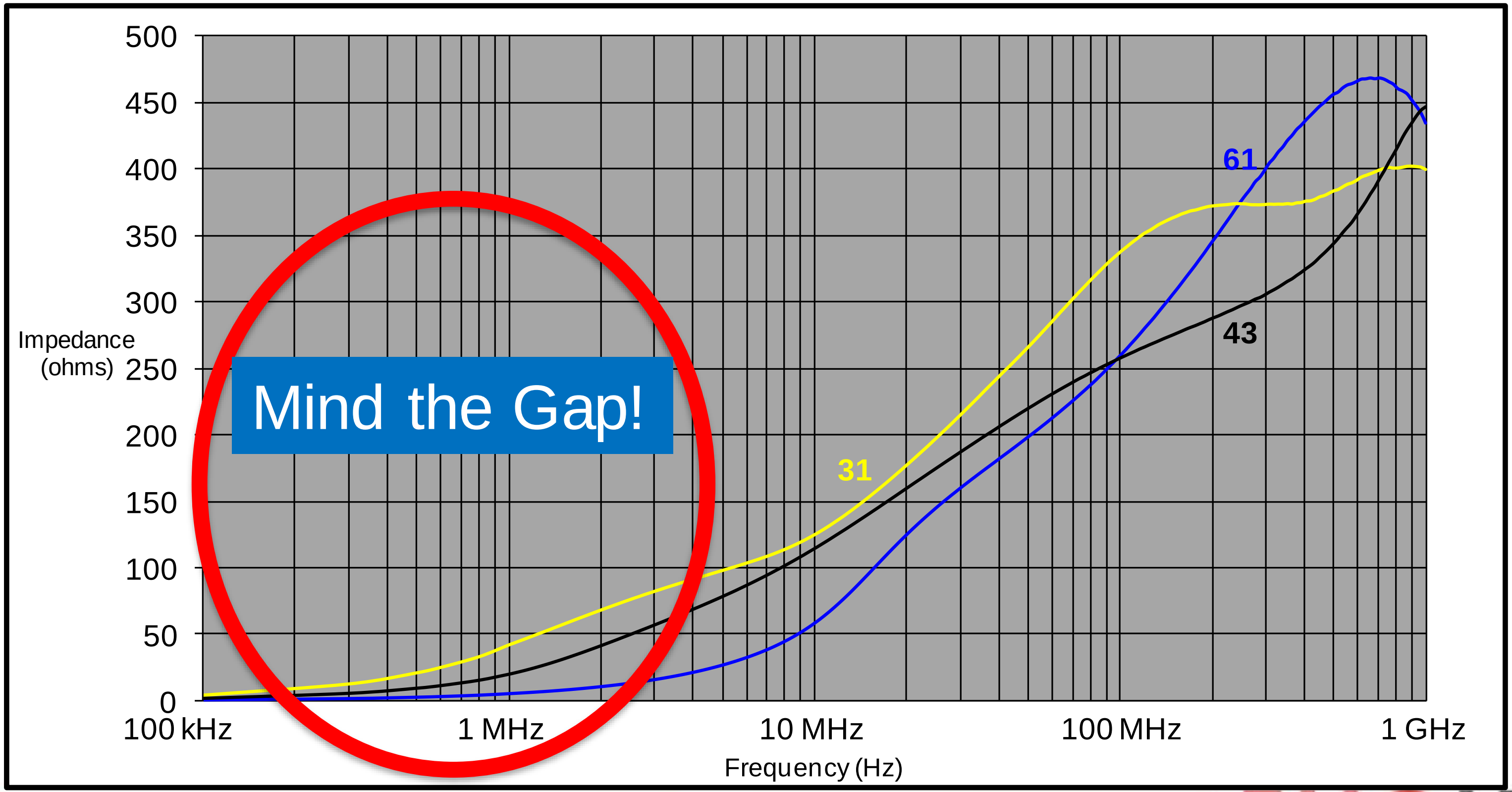
The challenge…

- So you've made it to the test lab to get your product certified – but you fail!!
  - The dreaded questions:
    - What is the fix?
    - How long will it take?
    - How much will it cost??

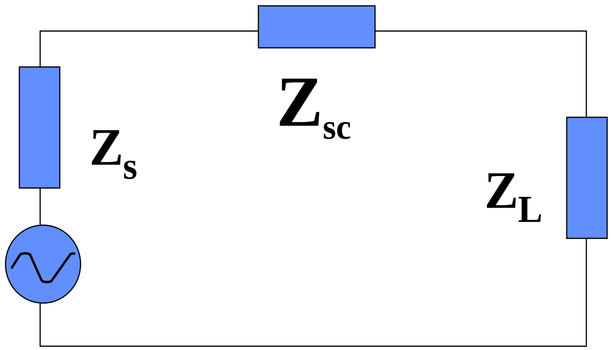


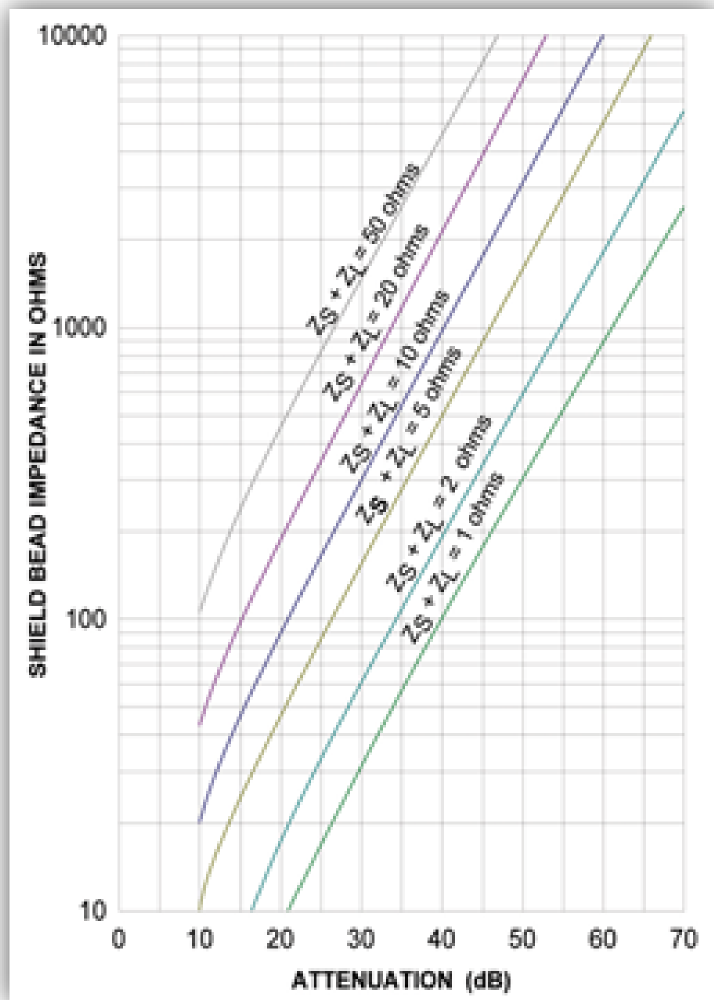
Until now…

- To solve low-frequency EMC issues, Snap-It ferrites were not a viable option



Review: How Ferrites Reduce Noise





$$Attenuation = 20 \cdot \log_{10} \frac{Z_S + Z_{SC} + Z_L}{Z_S + Z_L}$$

Z_s = Source impedance

Z_{sc} = Suppressor Core impedance

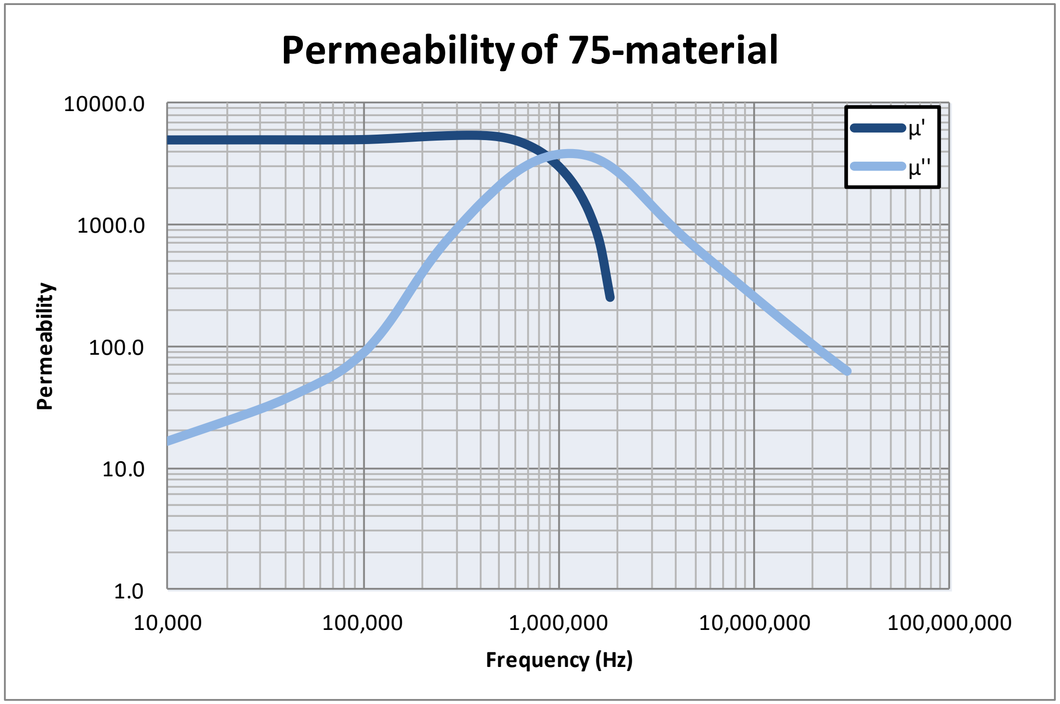
Z_L = Load impedance

Impedance Formula

$$Z = j\omega L_s + R_s = j\omega L_o(\mu' - j\mu'') \quad [\Omega]$$

L_s = series inductance
R_s = series loss resistance
L_o = air core inductance
μ = material permeability

Material permeability is a **frequency dependant** characteristic



Impedance Formula

$$Z = j\omega L_s + R_s = j\omega L_o(\mu' - j\mu'') \quad [\Omega]$$

- Generally, as the initial permeability (μ_i) **increases**, the impedance frequency range **decreases**

Material	μ_i (initial permeability)	Frequency Range
75	5000	150 kHz – 10 MHz
31	1500	1 MHz – 300 MHz
43/44	800/500	25 MHz – 300 MHz
61	125	200 MHz – 1 GHz

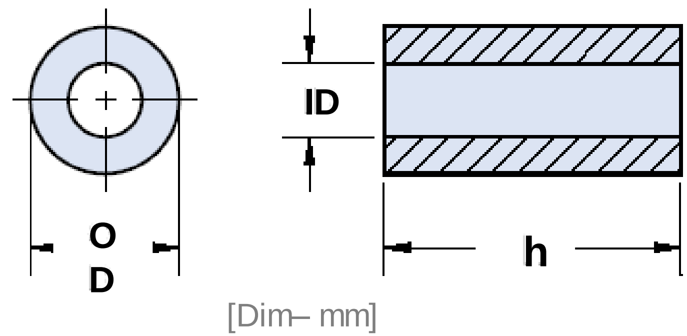
Initial permeability refers to μ when magnetization levels extremely small

Impedance Formula

$$Z = j\omega L_s + R_s = j\omega L_o(\mu' - j\mu'') \quad [\Omega]$$

L_s = series inductance
R_s = series loss resistance
L_o = air core inductance
μ = material permeability

$$L_o = \frac{\mu_0 N^2 A_e}{l_e} = \frac{\mu_0 N^2 \cdot h \cdot \ln\left(\frac{OD}{ID}\right)}{2\pi} \quad [H]$$



Ae = effective cross-sectional area
l_e = effective magnetic path length
μ_0 = permeability of free space
N = number of turns

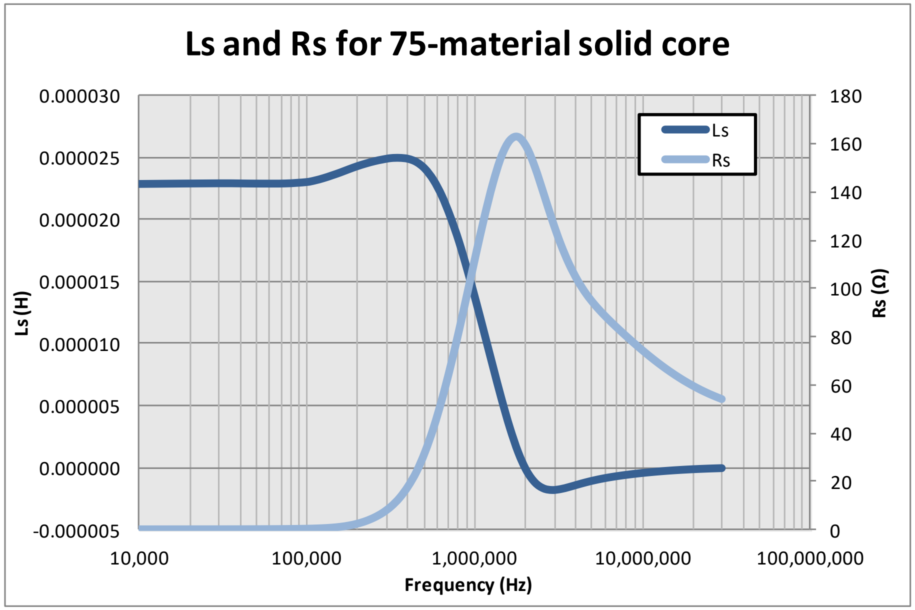
Impedance Formula

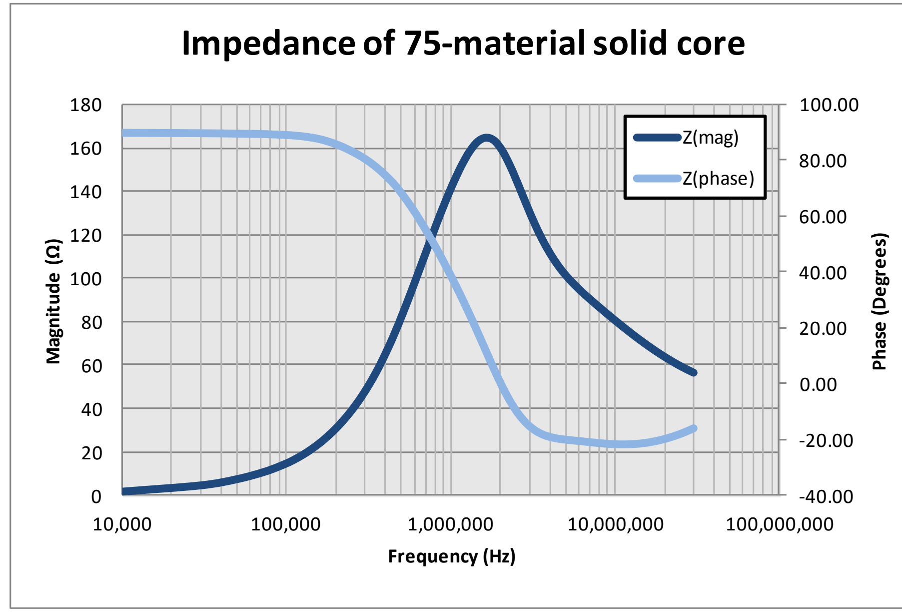
$$Z = j\omega L_s + R_s = j\omega L_o(\mu' - j\mu'') \quad [\Omega]$$

- Core performance also depends on geometric and implementation parameters as part of L_o:

Parameter	Description	As parameter is increased, Z will…
N	Number of times the cable passes through aperture the core	Increase by N^2
OD	Outer Diameter of the core	Increase linearly
ID	Inner Diameter of the core	Decrease linearly
H	Height of the core	Increase linearly

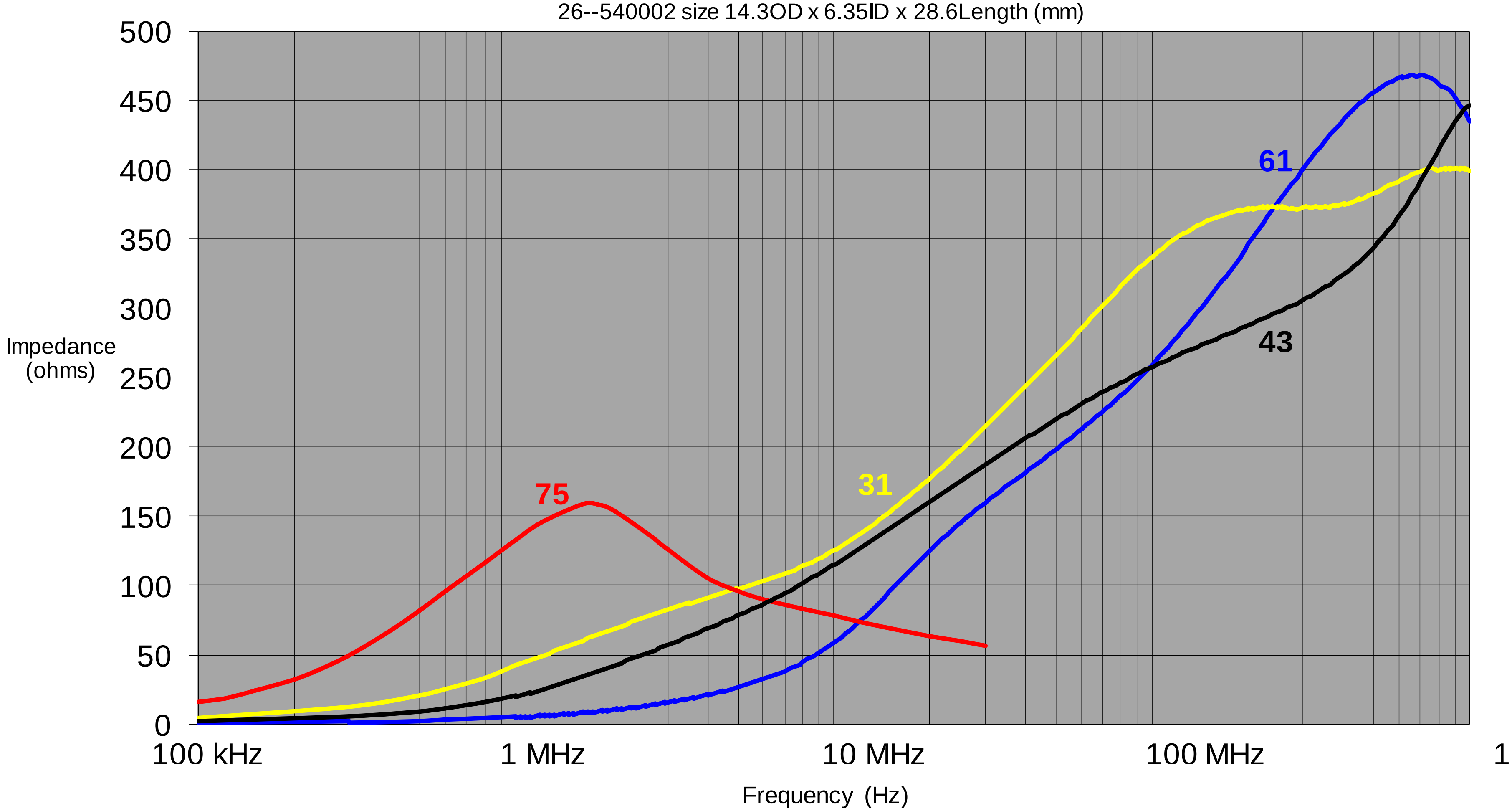
Putting it all together…





- Low frequencies → L_s is main driver of impedance.
- High frequencies (> 1MHz)→ R_s is main driver of impedance

Solid Suppression Core Comparison



Challenges

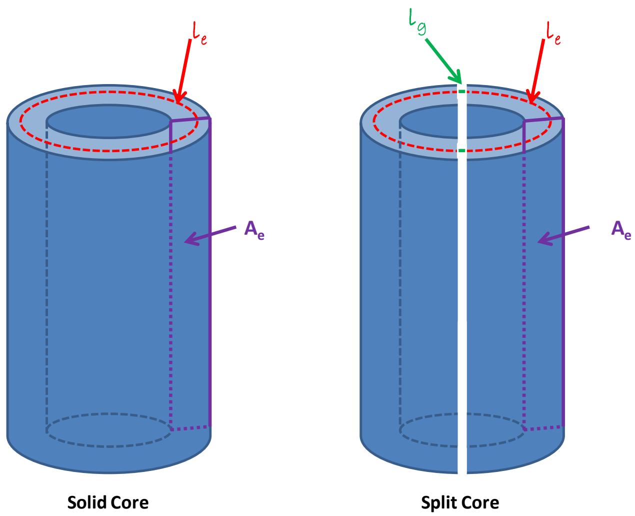
Test facilities had implementation difficulties with solid cores.

Challenges

Performance was degraded in split cores due the high permeability material (e.g., $\mu_i = 5000$)

Impedance with an Air-Gap

- Air-gap in the magnetic circuit reduces the inductance.
  - l_e needs to be considered separately.
- Core behaves as if it has reduced permeability, known as its *effective permeability.*
  - Permeability is dependant on both the magnetic path length and the air gap.



Impedance with an Air-Gap

- Assuming gap length (l_g) << magnetic path lengh (l_e)

$$Z = j\omega\left(\frac{\mu_o N^2\, h \ln\left(\frac{r_o}{r_i}\right)}{2\pi}\right)\left(\mu_e{}' - \; j\mu_e{}''\right)\ [\Omega]$$

$$\mu'_e = \frac{l_e}{\frac{l_e}{\mu'} + \ l_g}$$

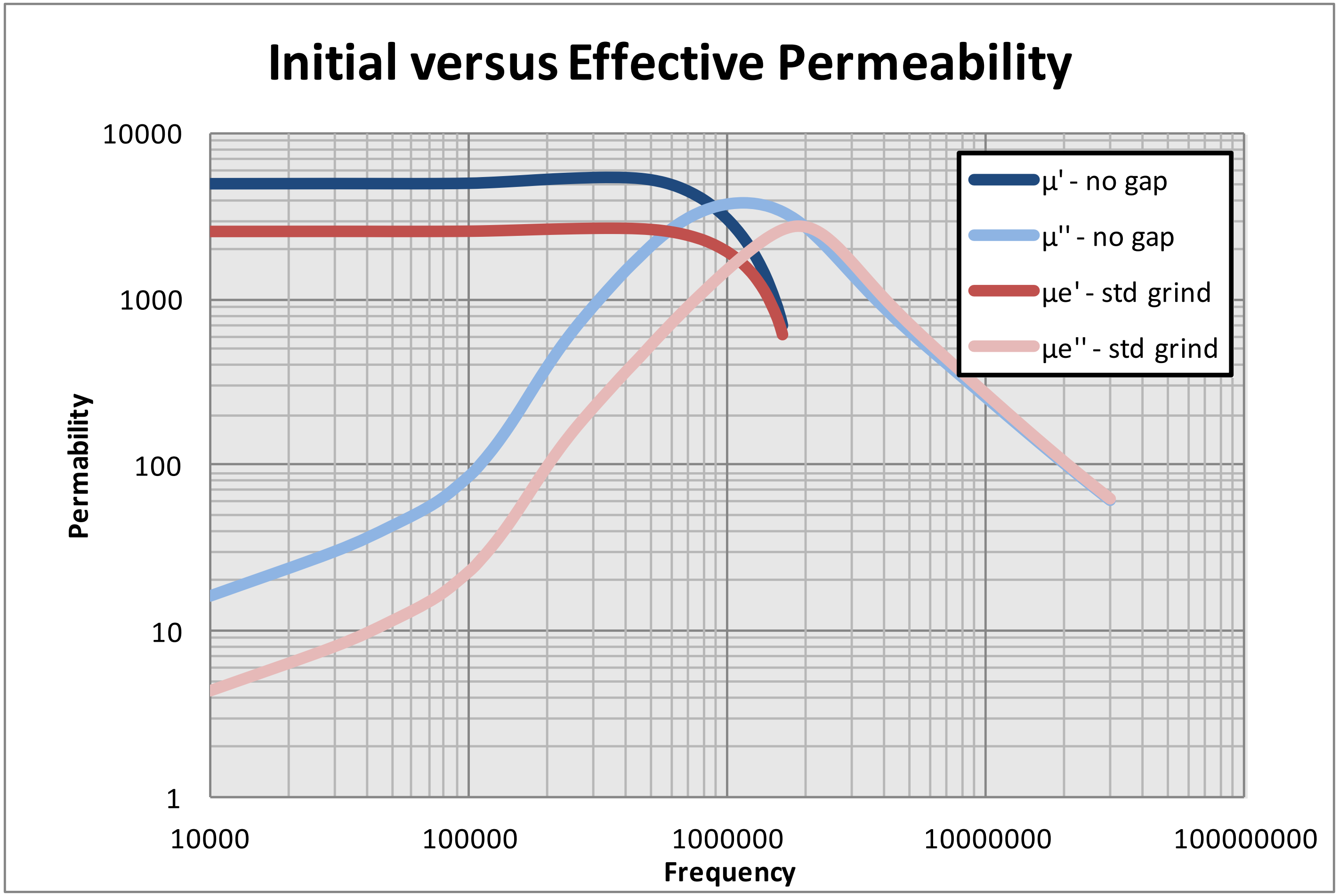
$$\mu''_e = \mu'_e \tan\,(\delta)_{\text{gapped}}$$

$$tan(\delta)_{gapped} = \frac{\tan\,(\delta)}{\mu'}\,\mu'_e$$

$$\tan(\delta) = \frac{\mu''}{\mu'}$$

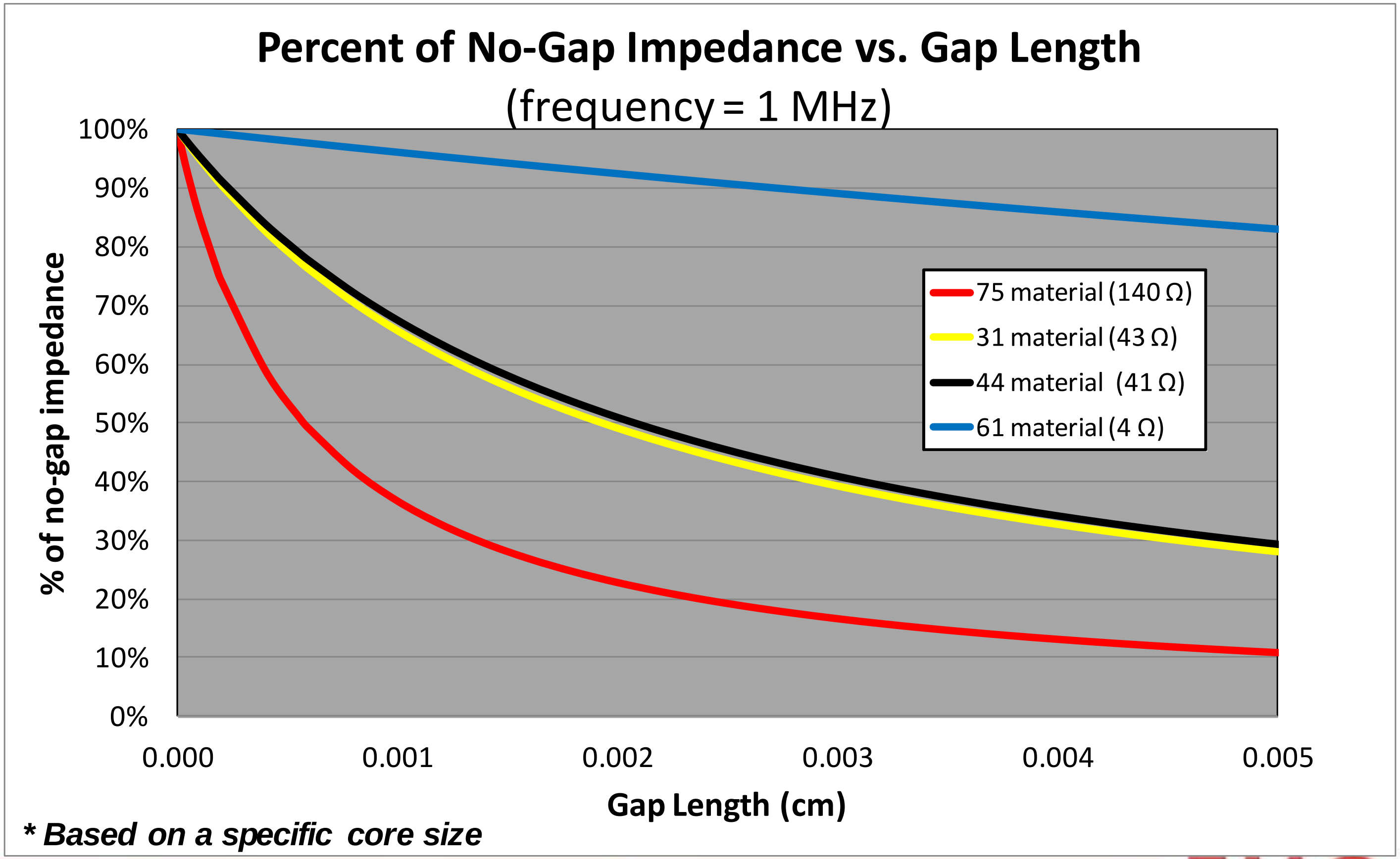
tan(δ) refers to the magnetic loss tangent and represents the inefficiency of the system based on the angle between the μ' and μ''.

Effect on Permeability

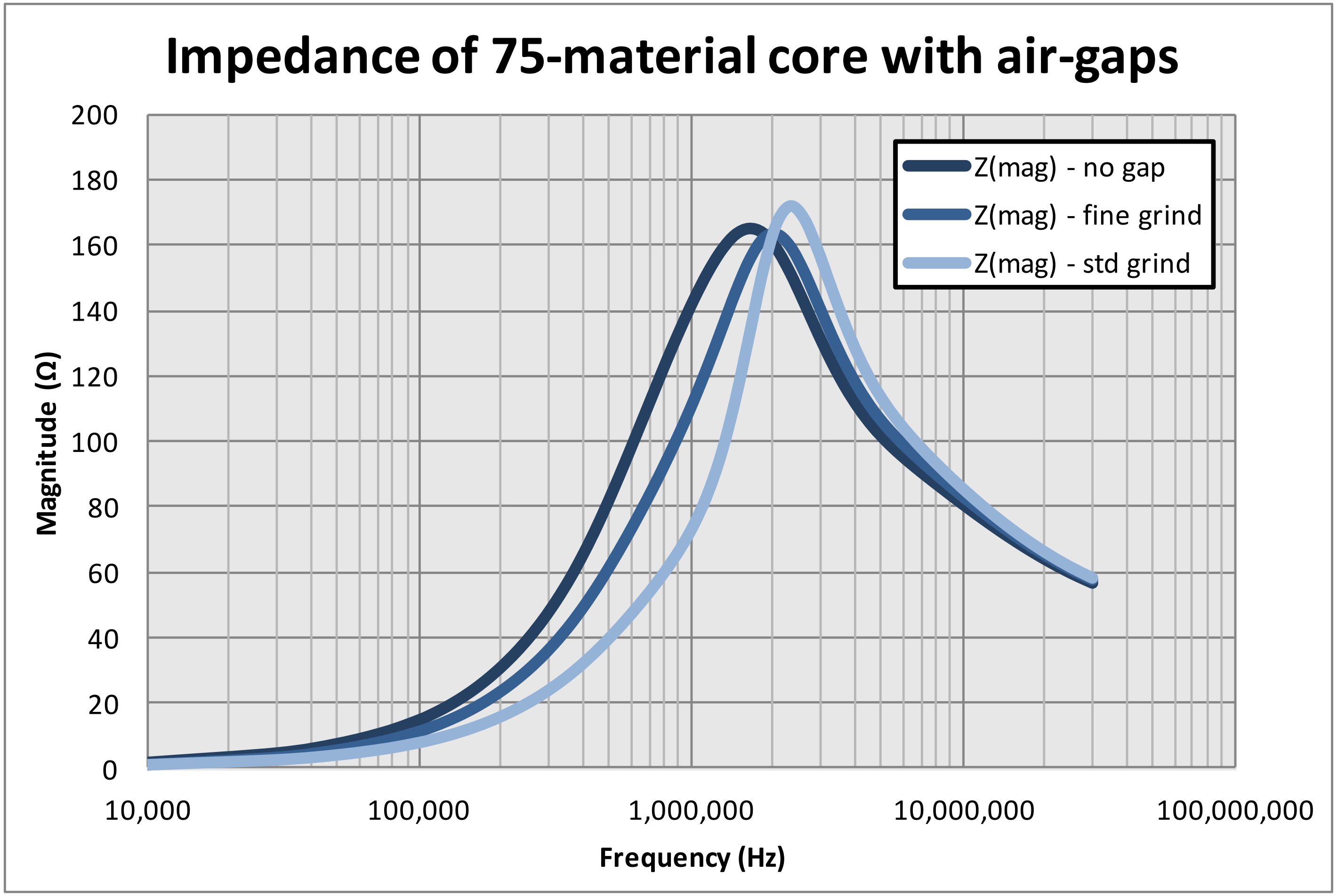


So what??

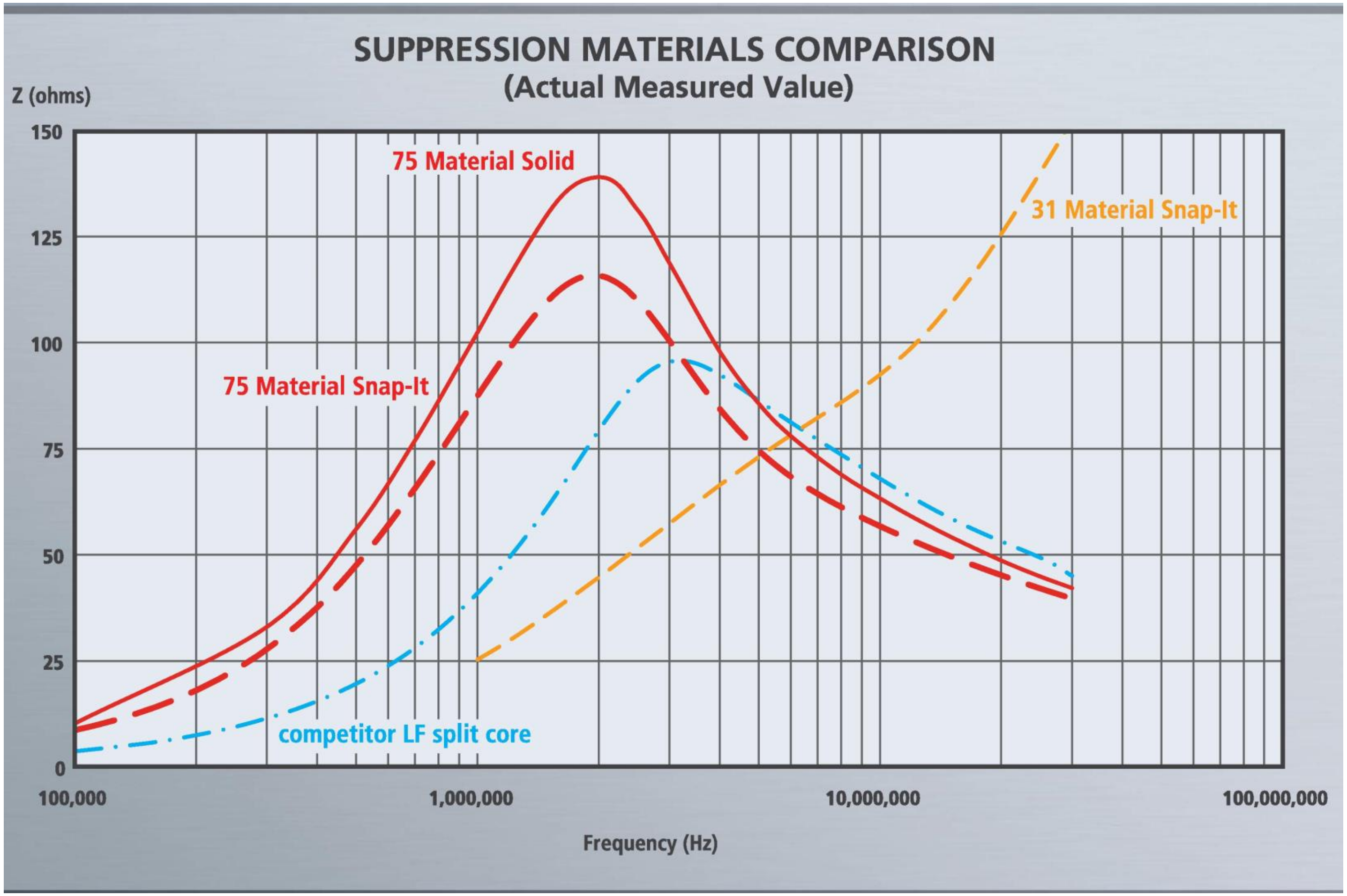
- For a high-permeability such as 75-material, even the smallest gaps can degrade performance tremendously!



Minimizing the air-gap

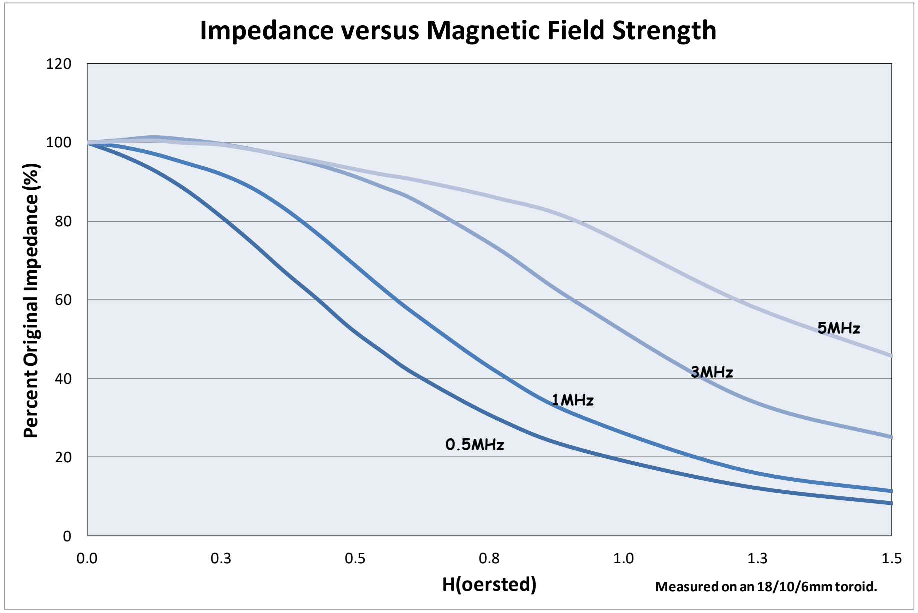


The solution!



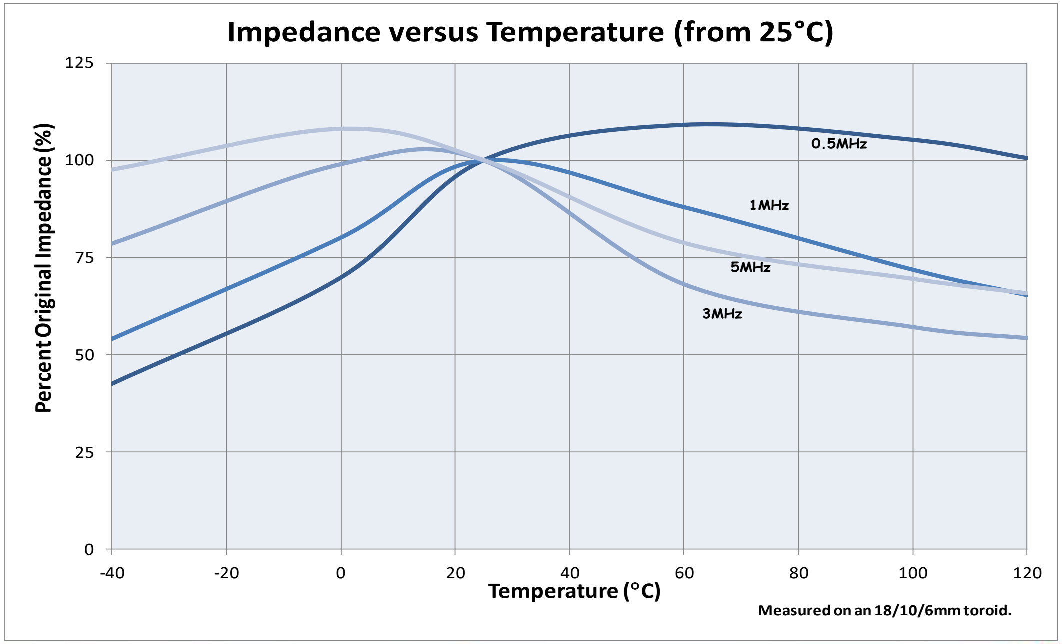
Design Considerations

- DC Bias
  - Derating can occur at high current levels, so ferrites are ideal for common-mode noise issues.
  - When applicable, both current-carrying conductors should pass through the core.



Design Considerations

- Operating Temperature
  - μ_i for 75-material can change **0.6%** per degree Celsius in an operating range from 20° - 70°C.
  - μ_i for 31-material can change **1.6%** per degree Celsius in an operating range from 20° - 70°C.



Thank You!

- Questions?