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Low Loss 67 Material for High Frequency Power Applications

Presented by:
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Low Loss 67 Material for High Frequency Power Applications

- The development of high frequency switching power converters has driven the need for low loss magnetic materials.
- Due to the lack of material performance data, the design of power magnetic components for high frequency operation (2-20 MHz) has been difficult to achieve.
- This presentation will review the intrinsic material characteristics (such as power loss density & useable flux density) in low permeability NiZn ferrites and will focus on Fair-Rite type 67 material.

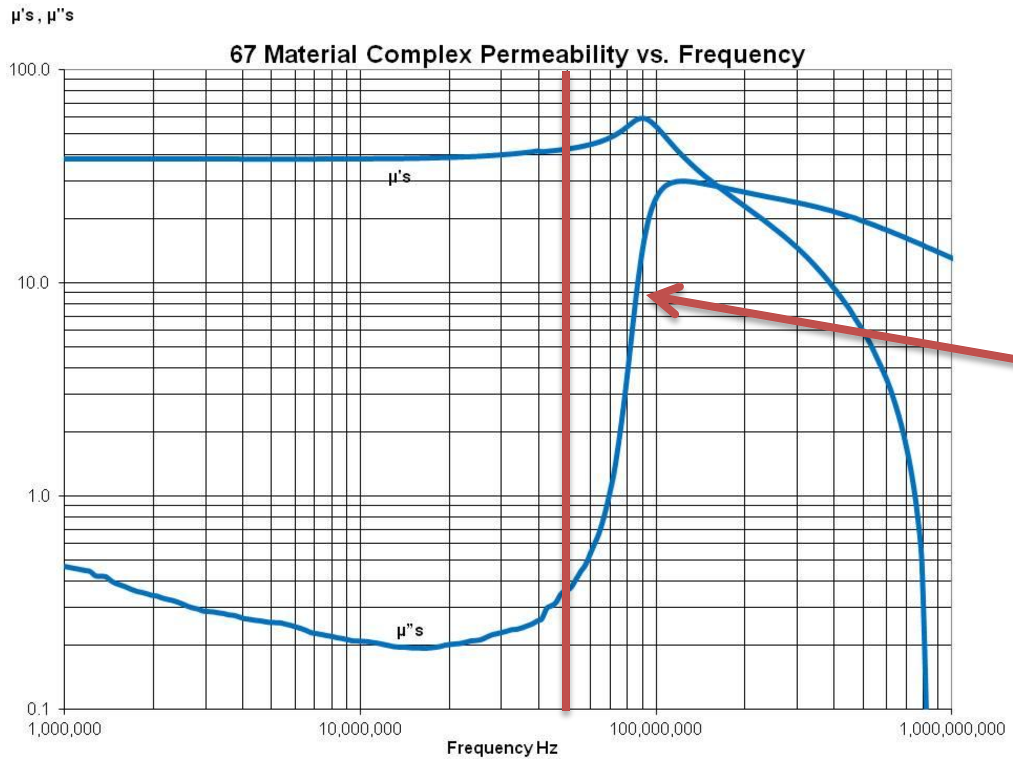
Agenda

- Market Motivation
- Classic methods for estimating Performance Factor
- New Test method – "Resonant Q"
- Performance data 67 and other Fair-Rite materials

Market Motivation

- Miniaturization is a driving force in electronics design.
  - Magnetics are typically the largest component in power supplies.
- In order to minimize power supply footprints, operating frequency has been increasing.
  - Power loss of magnetic components incorporated into these designs can cause issues with efficiency and heat management.

Limitations of Permeability



Losses (μ'') become unacceptable above 50 MHz.

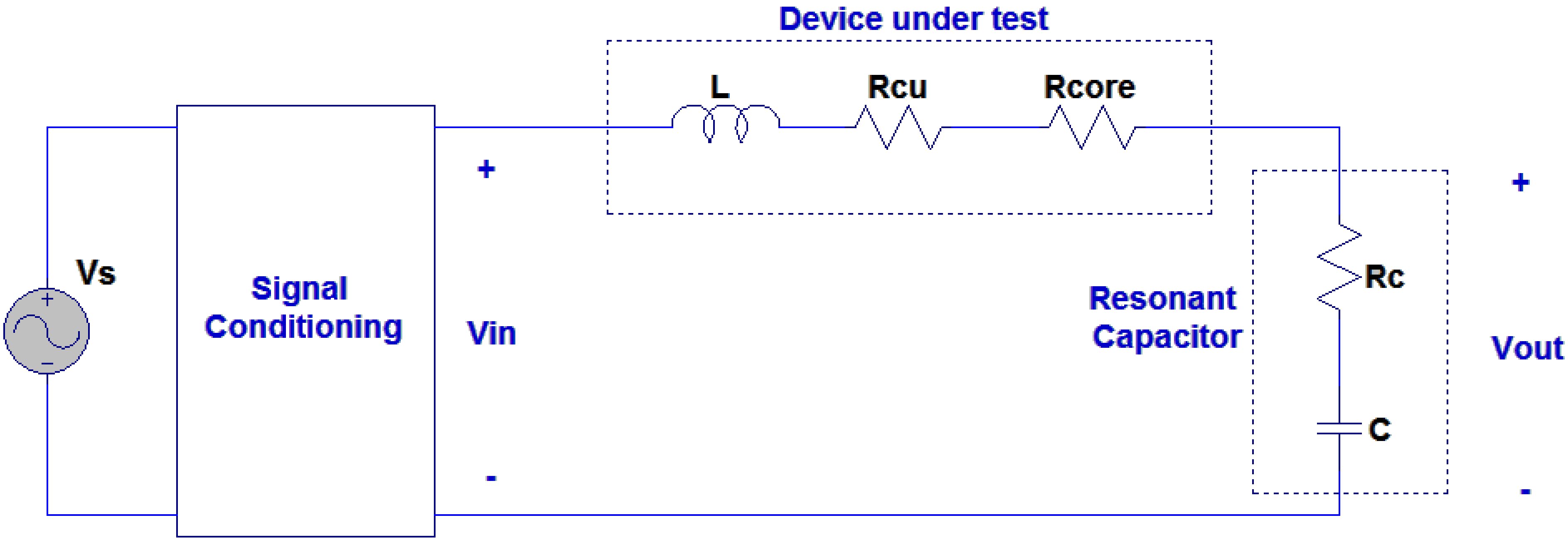
- μ' and μ'' curves are shown at **low flux densities**.
  - Measured at ≈ 0.1 mT
- Not reliable for power supply designs which operate at higher flux densities, but this is currently the only metric available at higher frequencies (f > 10 MHz).

Current Testing Methods

- Until recently, methods of testing power materials at higher frequencies have been expensive and/or unreliable.
  – Clark Hess has been the industry standard test method for materials up to 1MHz.
  – Current systems rely on phase angle, which at higher frequencies is difficult to measure accurately.
    - "As the phase angle θ becomes close to 90°, the measurement accuracy of the core loss Pc becomes worse." – Iwatsu Electric Co.
- Only measures up to 10MHz.

New Measurement Method

- Fair-Rite utilizes the "resonant Q" method developed by MIT to conduct measurements.
  - This system has been replicated at Fair-Rite with MIT's assistance.
- This method removes the reliance on phase angle as part of the measurement.



(1) Han, Y; Cheung, G; Li, A; Sullivan, C.R.; Perreault, D.J.; "Evaluation of Magnetic Materials for Very High Frequency Power Applications" in Power Electronics, IEEE Transactions on , vol. 27, no.1, pp.425-435

Calculations

- Peak Flux Density[1]:

$$B_{pk} = \frac{4 f_s C \mu_r \mu_0 N V_{out-pk}}{(d_o + d_i)}$$

- Power Loss Density[2]:

$$P_v = \frac{I^2{}_{L-pk} R_{core}}{2 V_L}$$

$$R_{core} = \frac{2\pi f_s L V_{in-pk}}{V_{out-pk}} - R_C - R_{cu}$$

Definitions

f_s = resonant frequency
C = resonant capacitor value
μ_r = relative permeability
μ_0 = permittivity of free space
N = number of turns on inductor core
d_o = outer diameter of inductor core
d_i = inner diameter of inductor core
$V_{out\text{-}pk}$ = peak output voltage

$I_{L\text{-}pk}$ = peak current through inductor
V_L = inductor core volume
L = inductance of core
$V_{in\text{-}pk}$ = peak input voltage
R_c = resistance of resonant capacitor
R_{cu} = resistance of copper winding

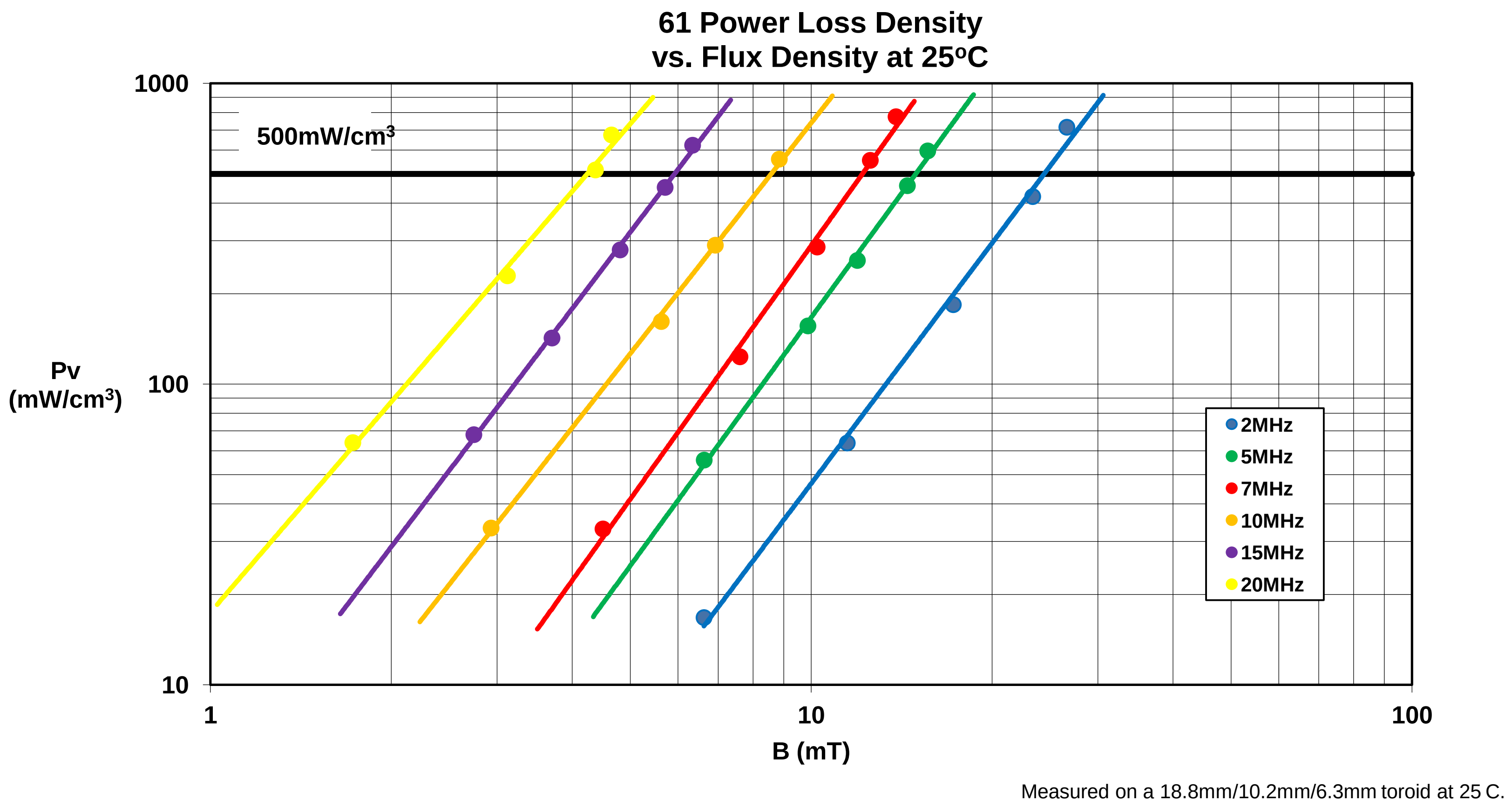
(2) Hanson, A.J.; Belk, J.A.; Lim, S.; Perreault, D.J.; Sullivan, C.R., "Measurements and performance factor comparisons of magnetic materials at high frequency," in Energy Conversion Congress and Exposition (ECCE), 2015 IEEE , vol., no., pp.5657-5666, 20-24 Sept. 2015

HF Power Loss Curves @ 25°C

Measured on a 22.1mm/13.7mm/6.35mm toroid at 25° C.

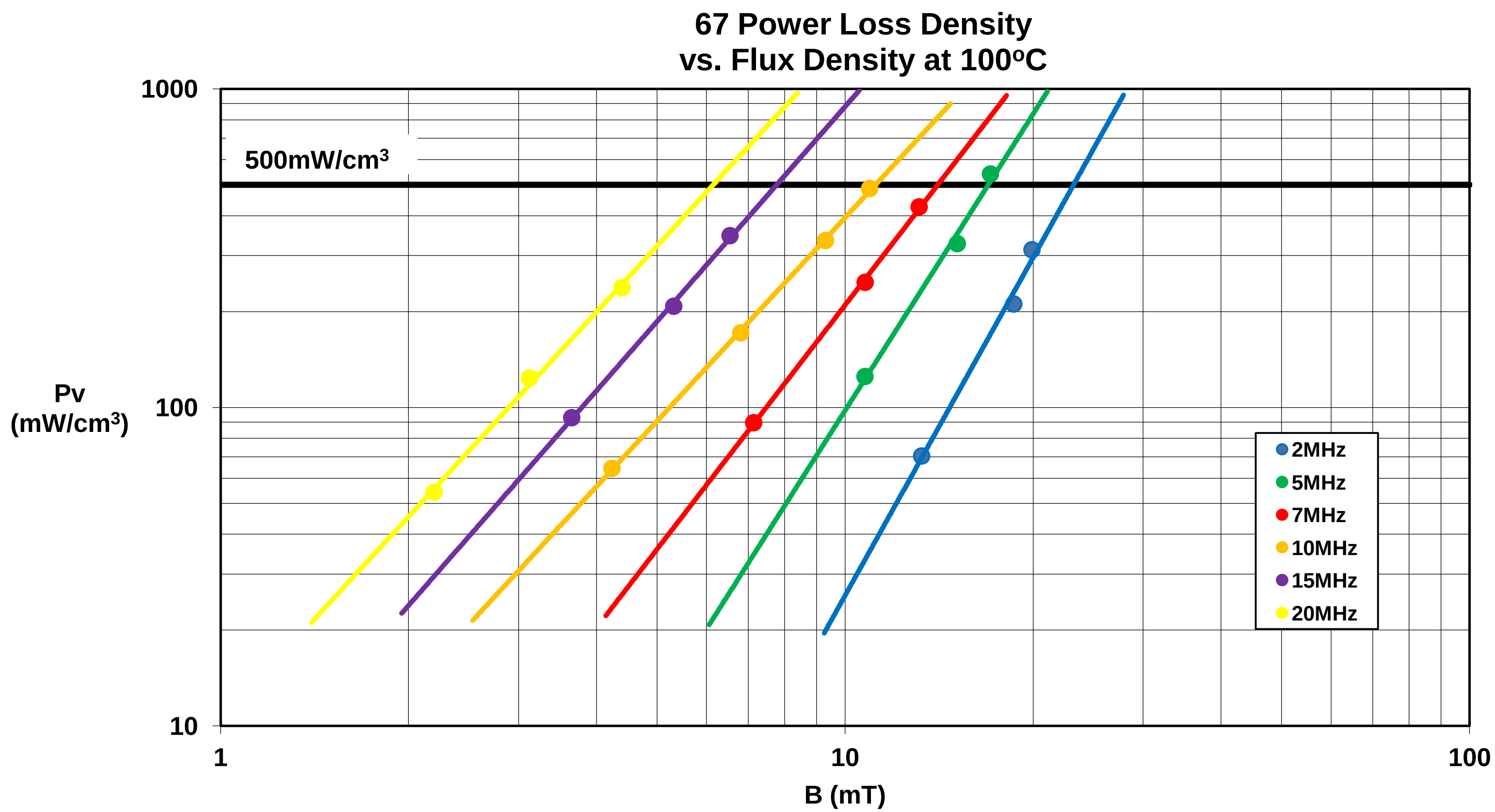
- **Typical** power loss curves (Power Loss vs. Flux Density) provided at higher frequencies.

HF Power Loss Curves @ 25°C



- **Typical** power loss curves (Power Loss vs. Flux Density) provided at higher frequencies.

HF Power Loss Curves @ 100°C



Measured on a 22.1mm/13.7mm/6.35mm toroid at100º C.

- **Typical** power loss curves (Power Loss vs. Flux Density) provided at higher frequencies.

What is “Performance Factor”?

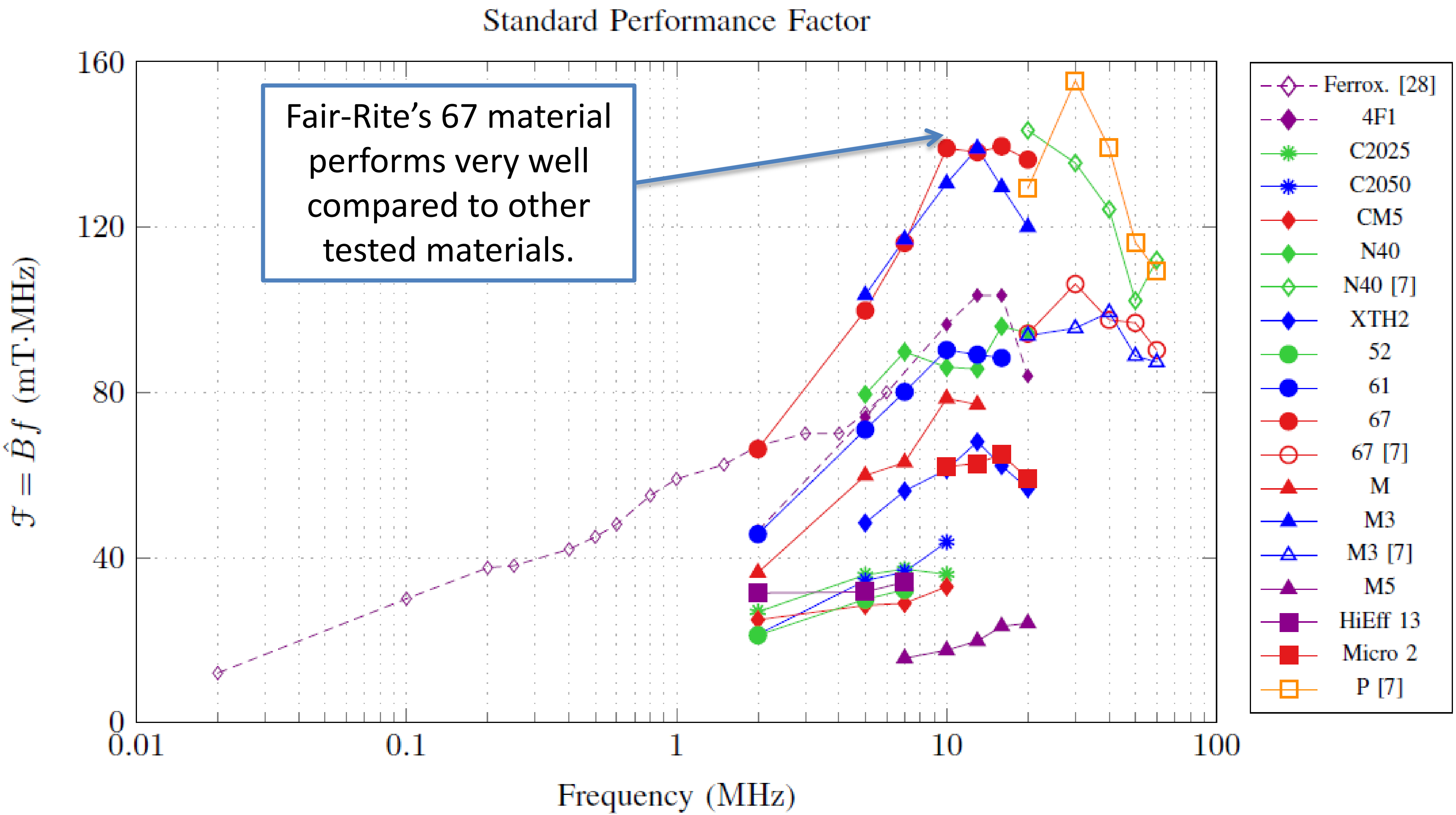
- Represents the maximum **flux density** at a specific **power loss density**

$$\mathscr{F} = B_{pk} \cdot f$$

  – Power loss density used for measurements = 500 mW/CC

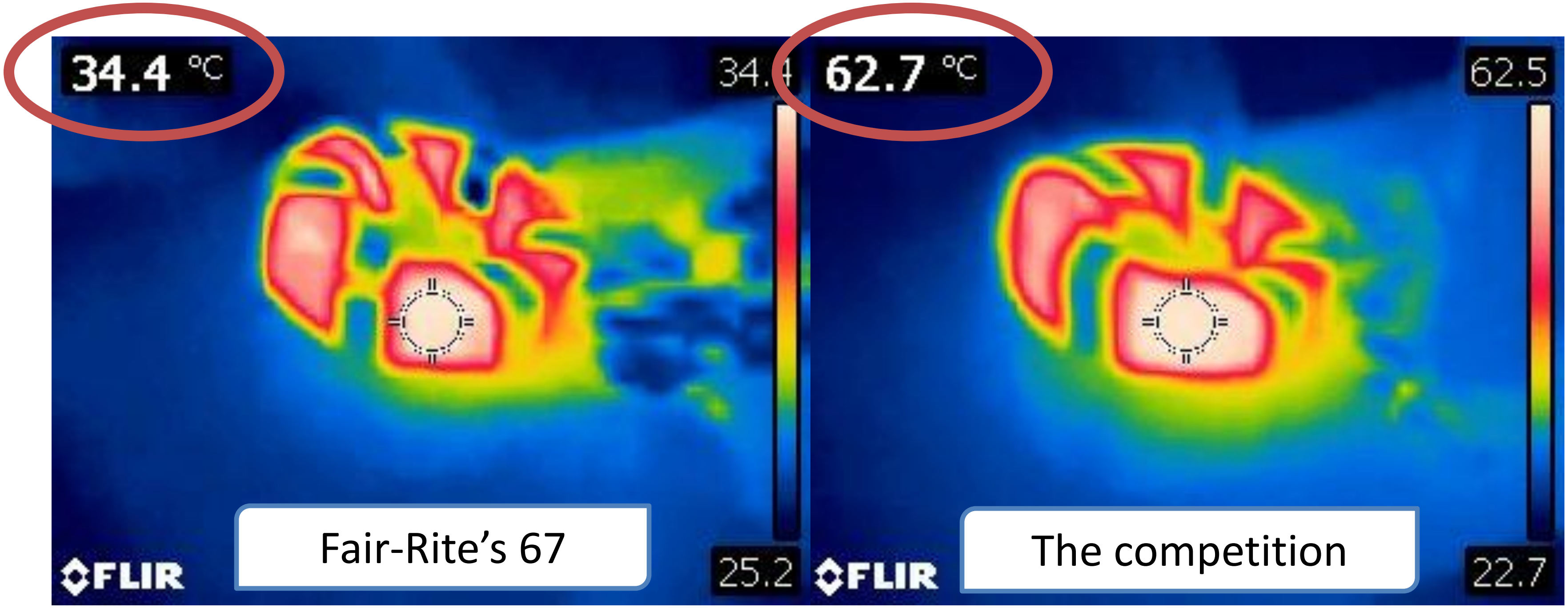
- “It is defined as the maximum product of peak flux density and frequency as a function of frequency at a constant power loss density”
  - “Soft Ferrites: A User’s Guide” © 1992 by Magnetics Materials Producers Association

Data from MIT[2]

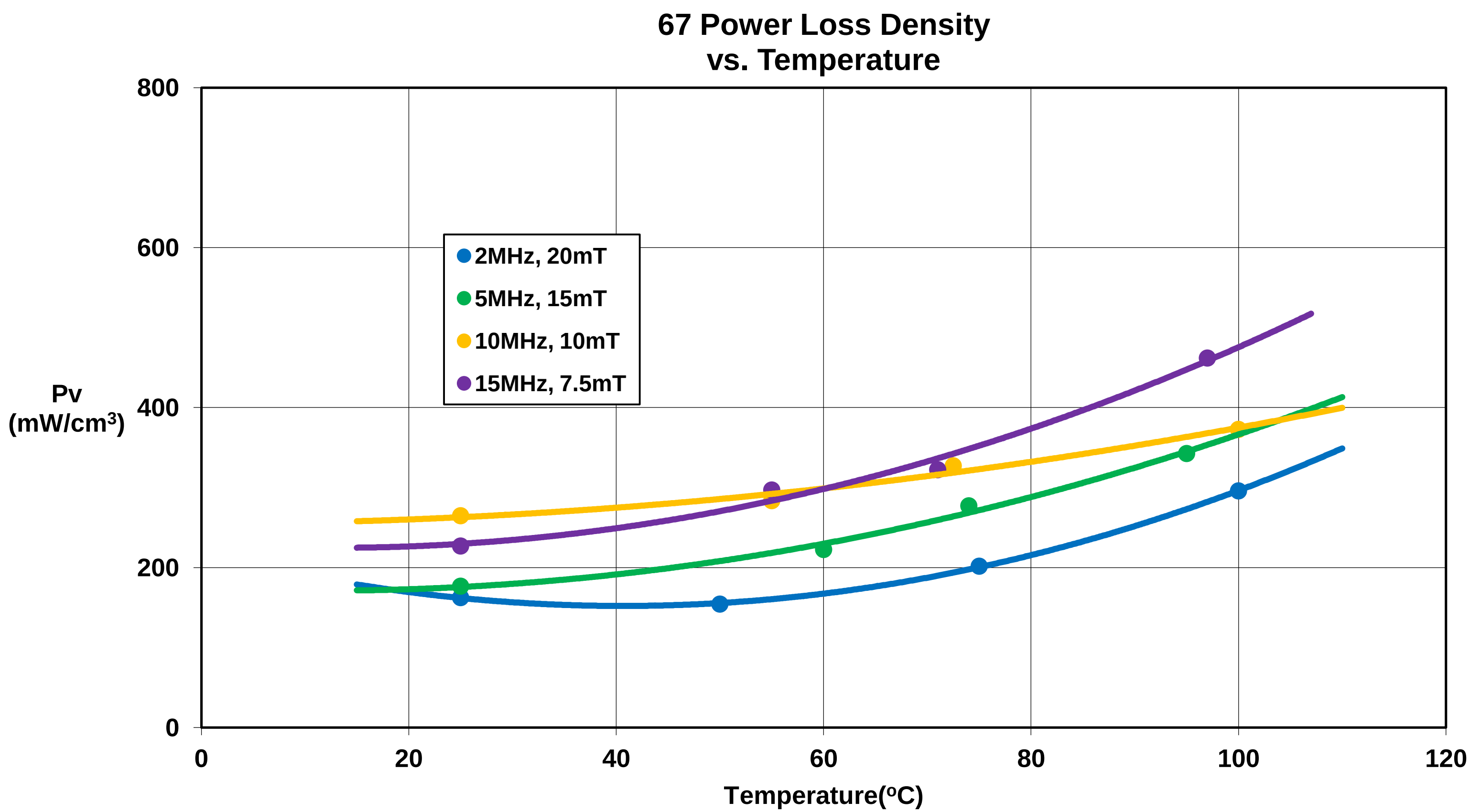


Operating temperature comparison

- Similar competitor material has a higher power loss density under the same test conditions as compared to Fair-Rite's 67 material.
  - Test conditions: 12mT 10 MHz



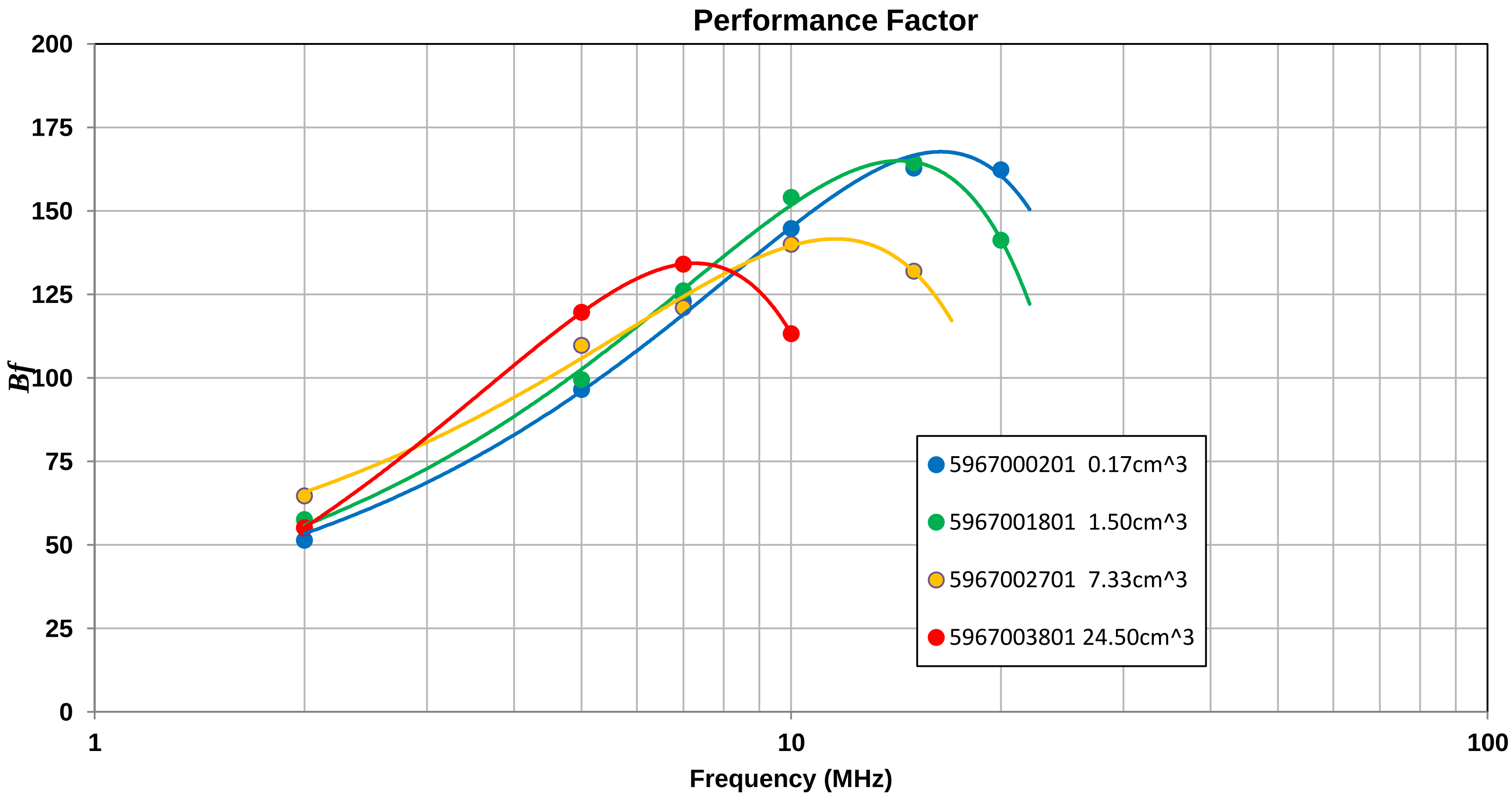
Power Loss vs. Temperature



Measured on a 22.1mm/13.7mm/6.35mm toroid .

- Fair-Rite's 67 material is reasonably stable over temperature.

Performance Factor Curves for different size cores



- Optimal operating frequency decreases as core size increases

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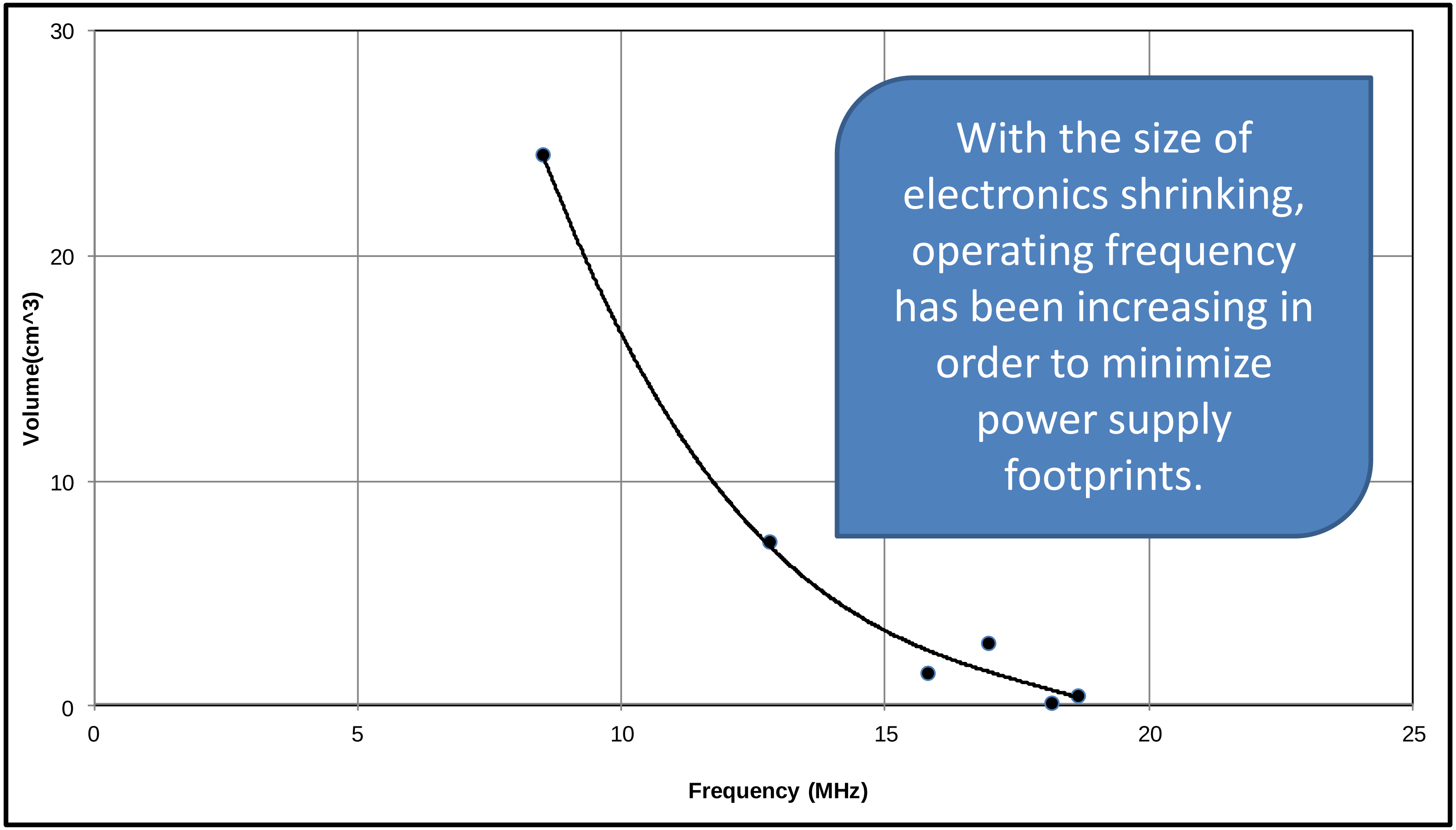
Peak Performance Frequency vs. Core Size

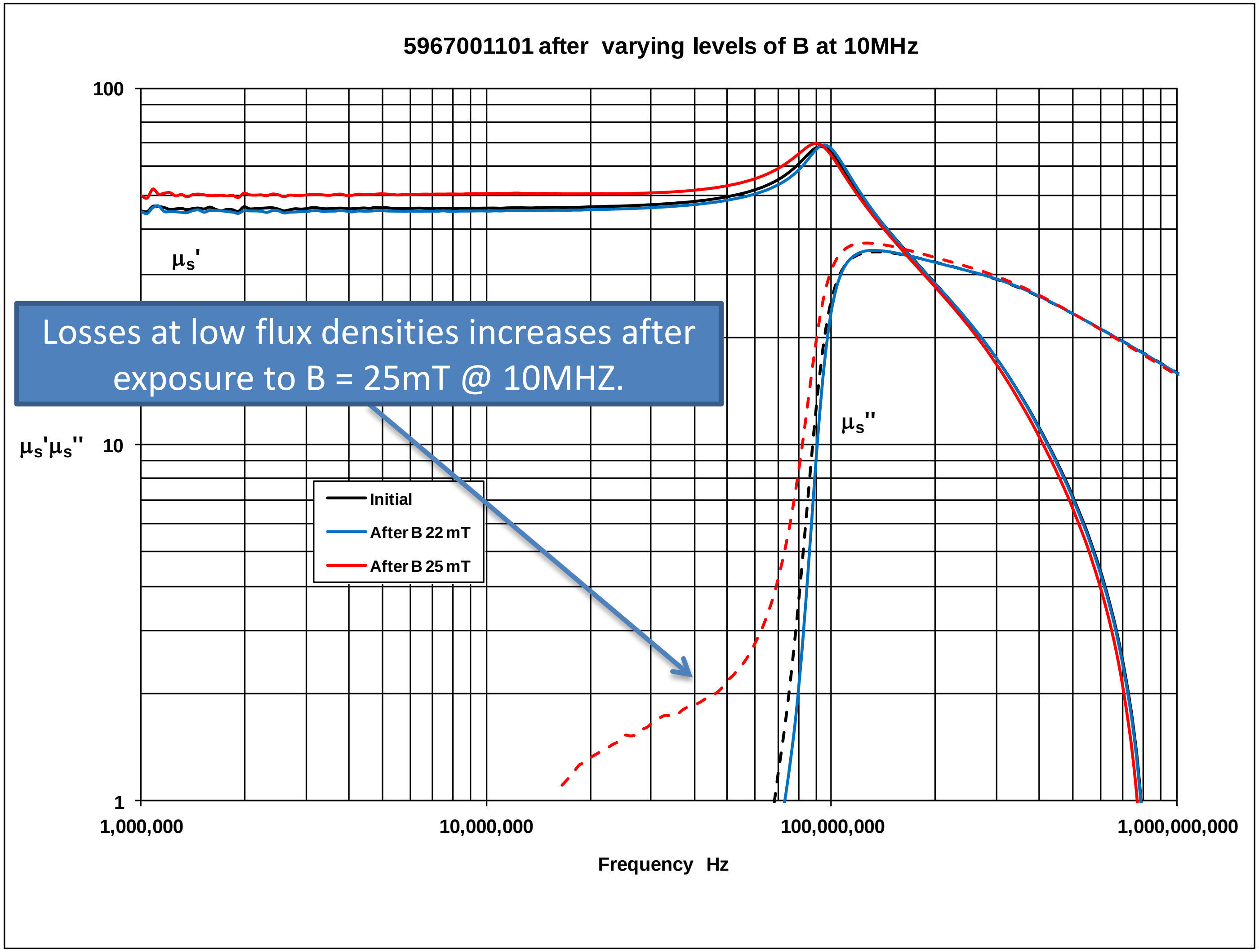


- Want to operate where performance factor is highest, but smaller cores cannot handle as high a power level.

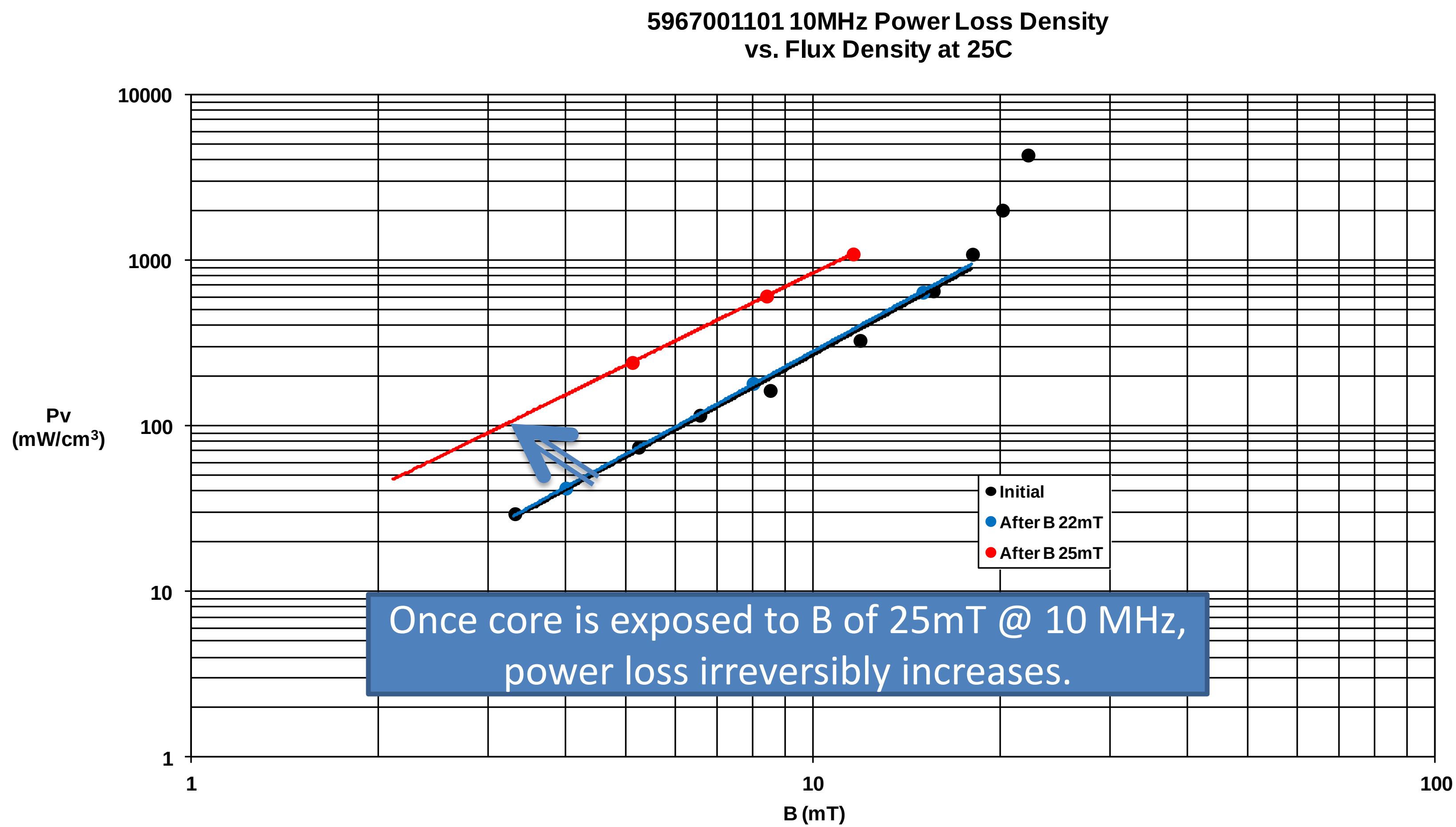
Design Considerations

- 67 material is a **perminvar** material, meaning that strong magnetic fields or excessive mechanical stresses may result in irreversible changes in permeability and losses.
- Benefits of a permivar material are:
  - Flatter temperature response
  - Higher Curie temperature
  - Lower losses out to higher frequencies.

Affect on Permeability

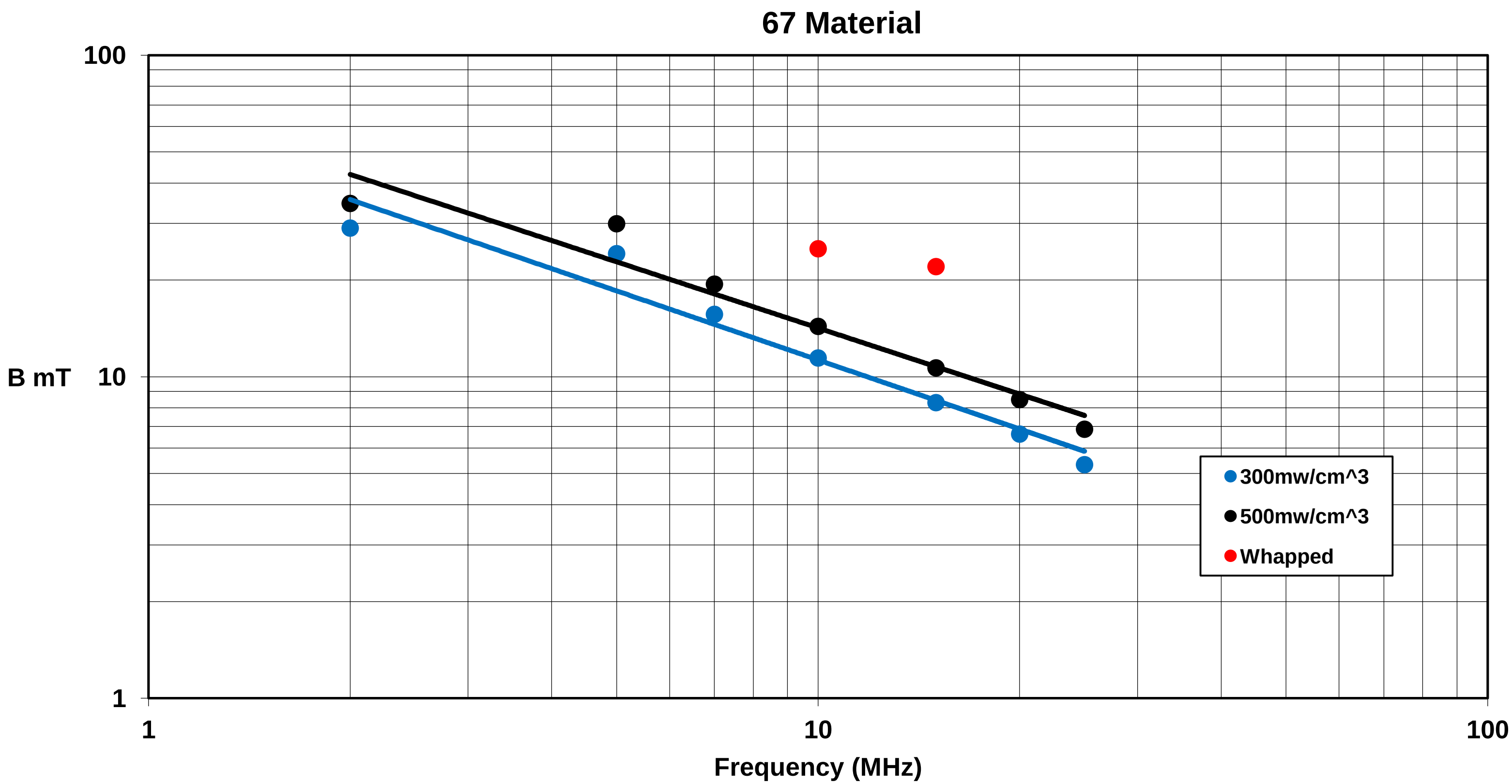


Affect on Power Loss



Measured on a 12.7mm/7.9mm/6.35mm toroid at 25° C.

Whapping Threshold



Measured on a 12.7mm/7.9mm/6.35mm toroid at 25º C.

- At lower frequencies, a higher B is needed to "whap" the part.
- At higher frequencies, a lower B will "whap" the part.

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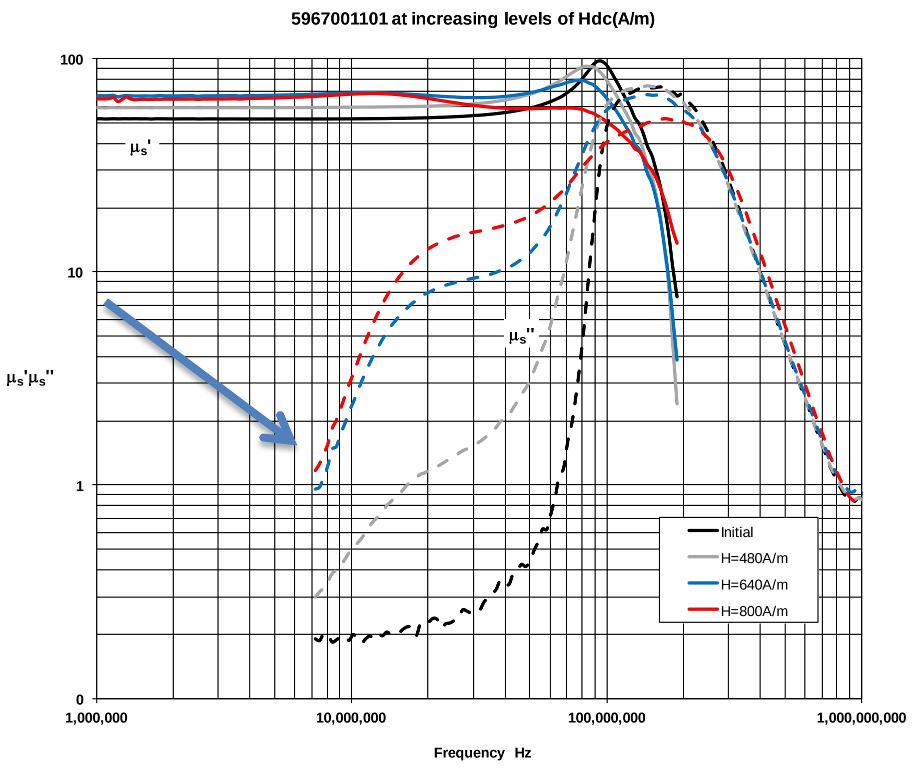
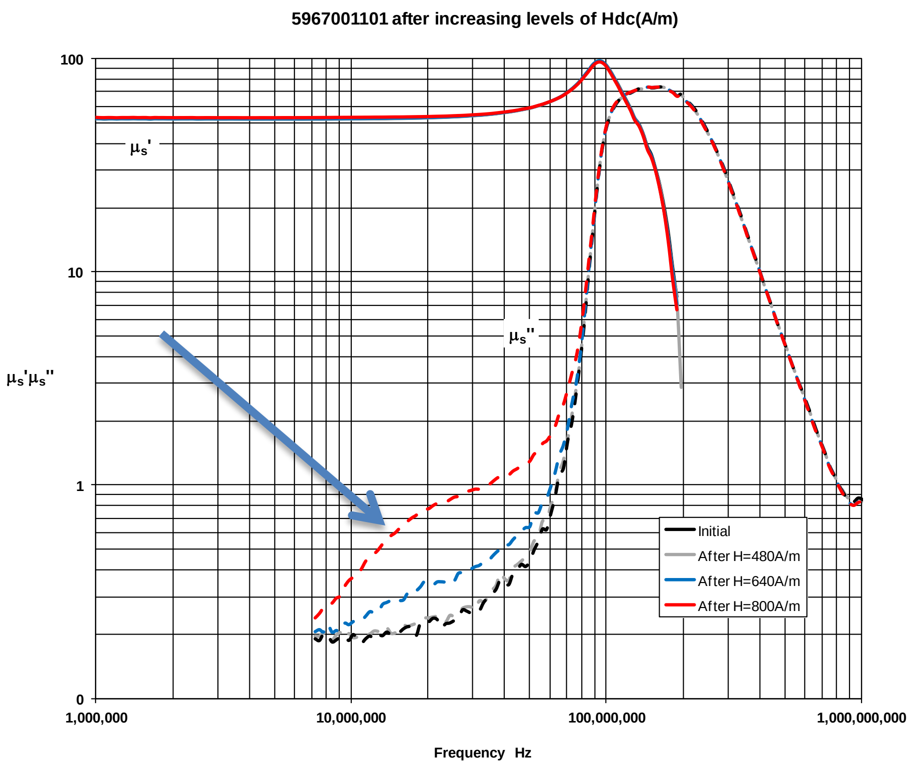
Effects of DC Bias



During DC bias exposure



After DC bias exposure

- If part is exposed to a DC bias that is too high, there is a noticeable and irreversible change to the losses.

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