# Limitations in Today's Passive Electrical Components

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BAE SYSTEMS

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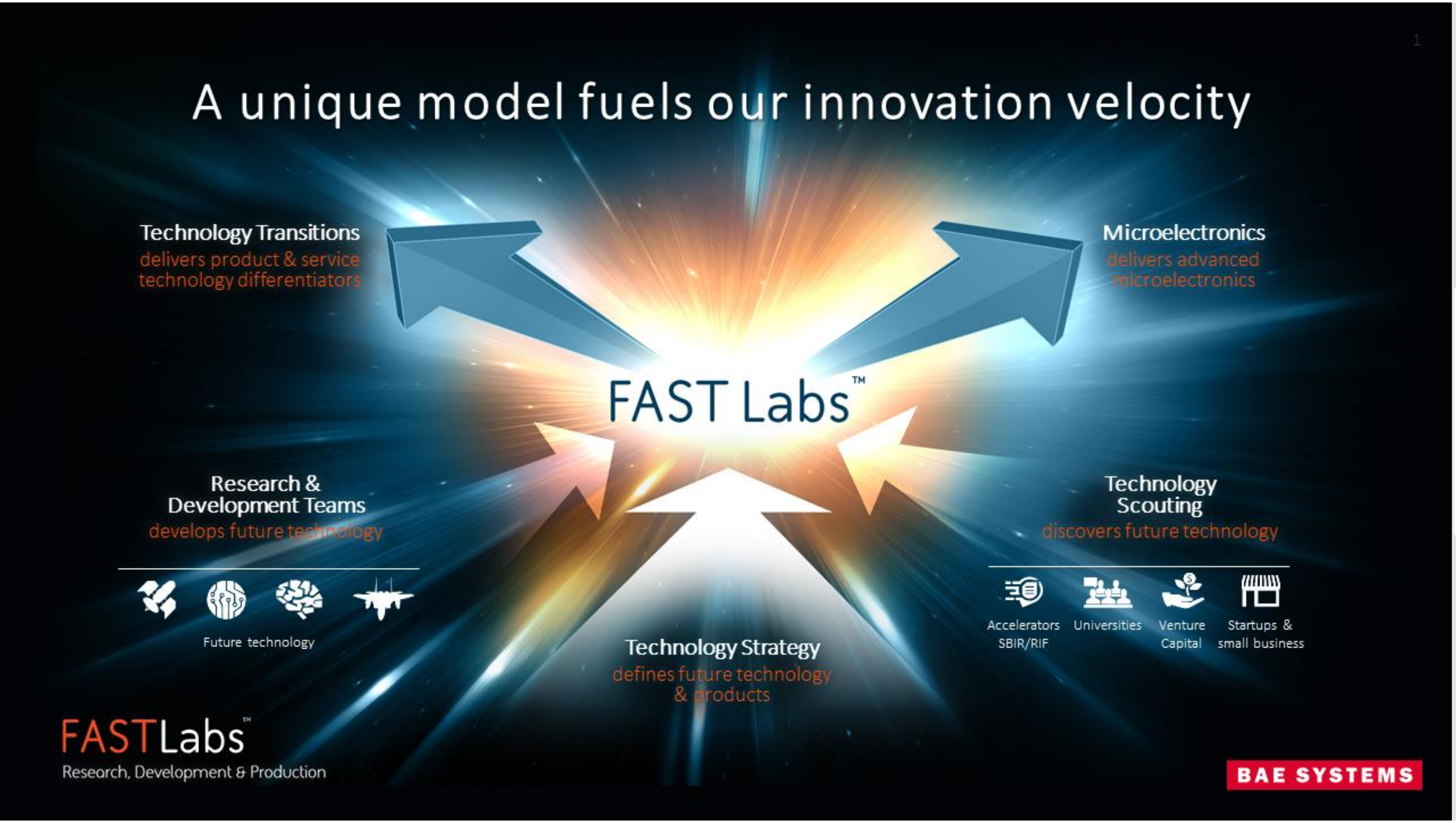
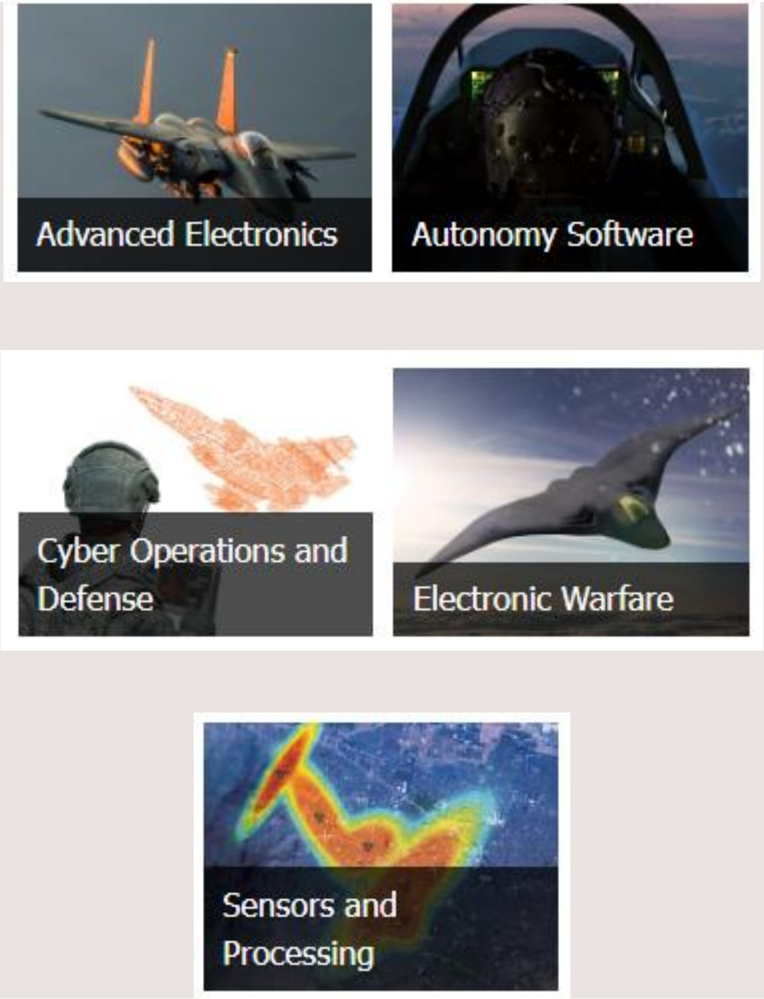
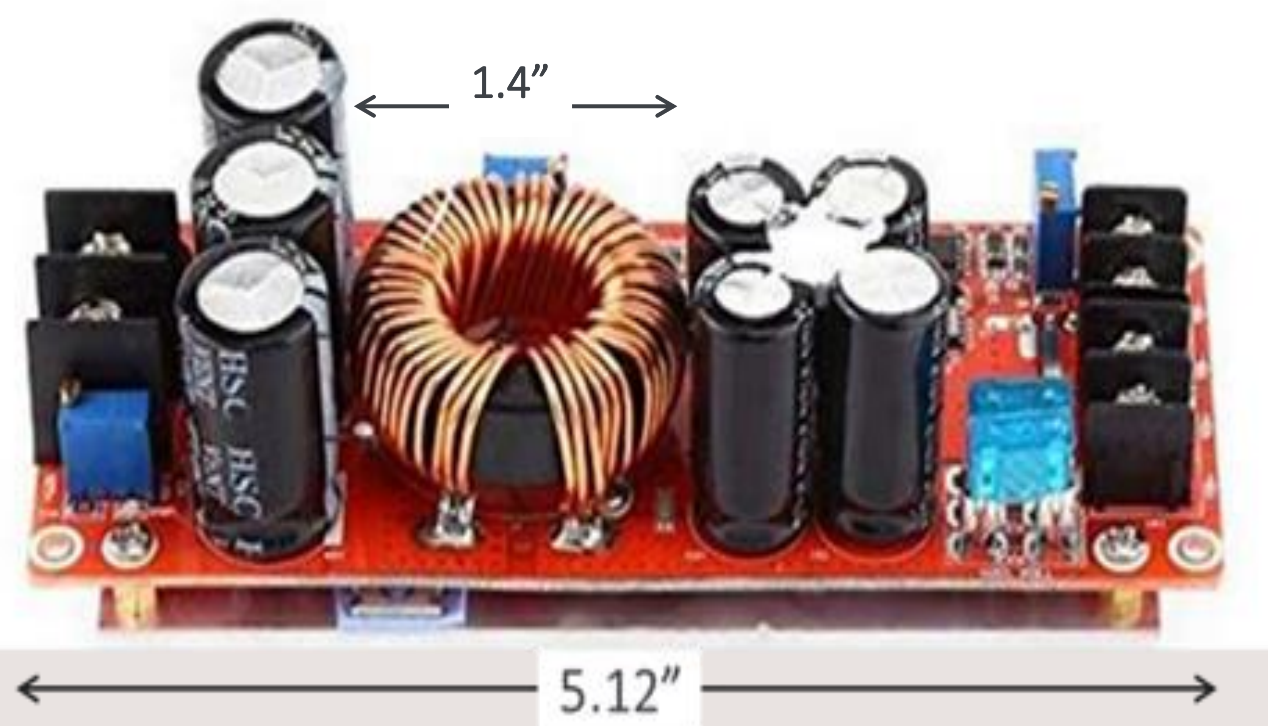
# BAE System FAST Labs



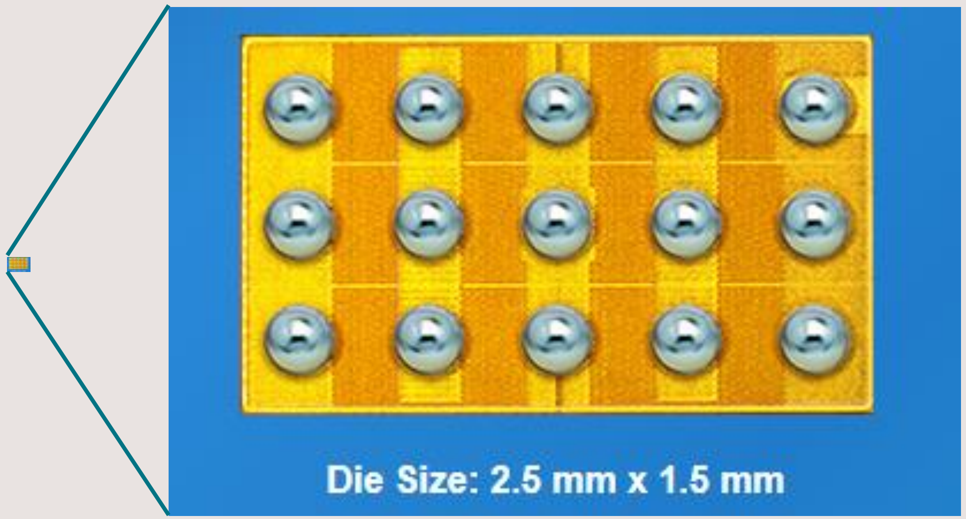



# Challenge #1 – Size Limitations in Passives: Power Electronics




*1200 W DC-DC Constant Current Boost Converter Step-Up Power Module LED Driver 10-60V To 12-83V

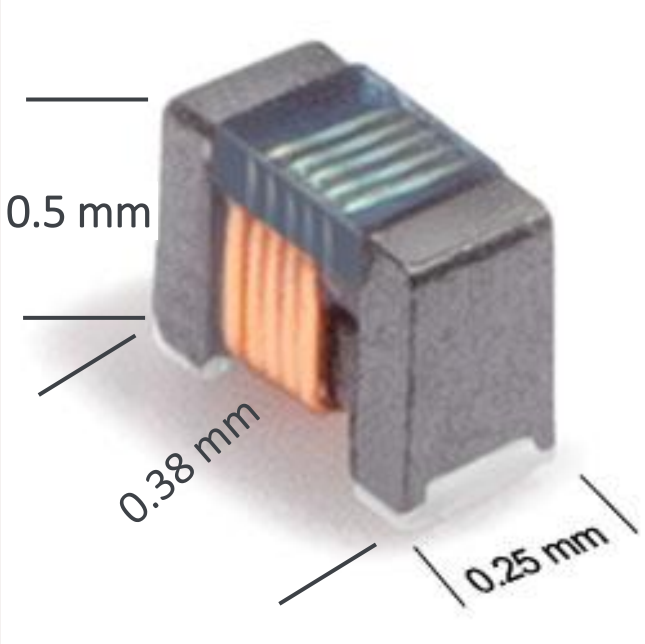
**Enhancement-Mode GAN Power Transistor



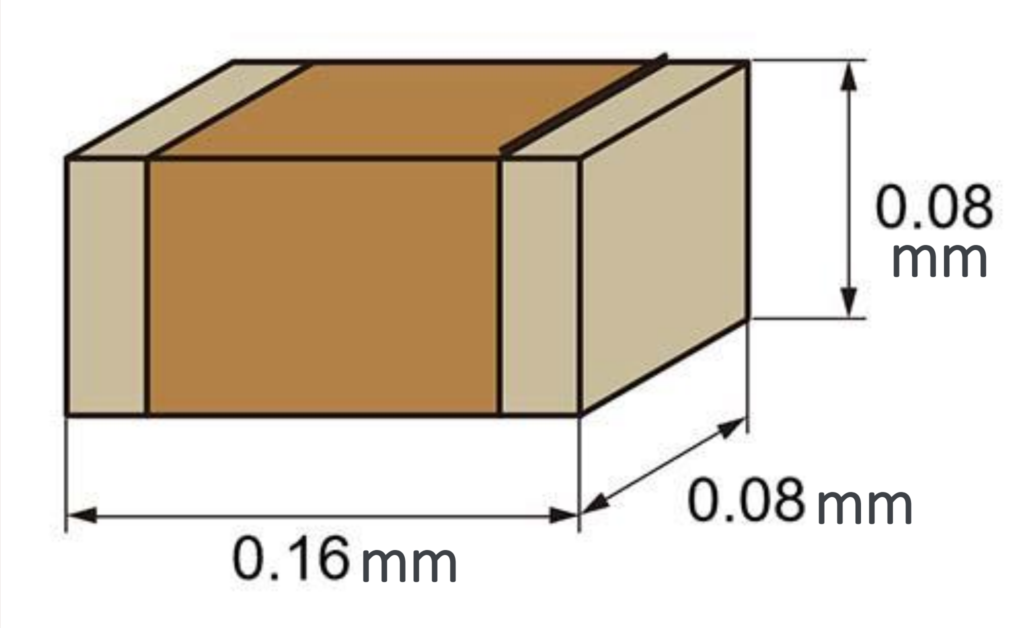

*https://www.amazon.com/ACEIRMC-Converter-Step-up-Supply-Module
**https://epc-co.com/epc/products/gan-fets-and-ics/epc2049

**Inductors and capacitors dwarf the active components in size by orders of magnitude!**

# Challenge #1 – Size Limitations in Passives: RF Electronics




*Ferrite Chip Inductor



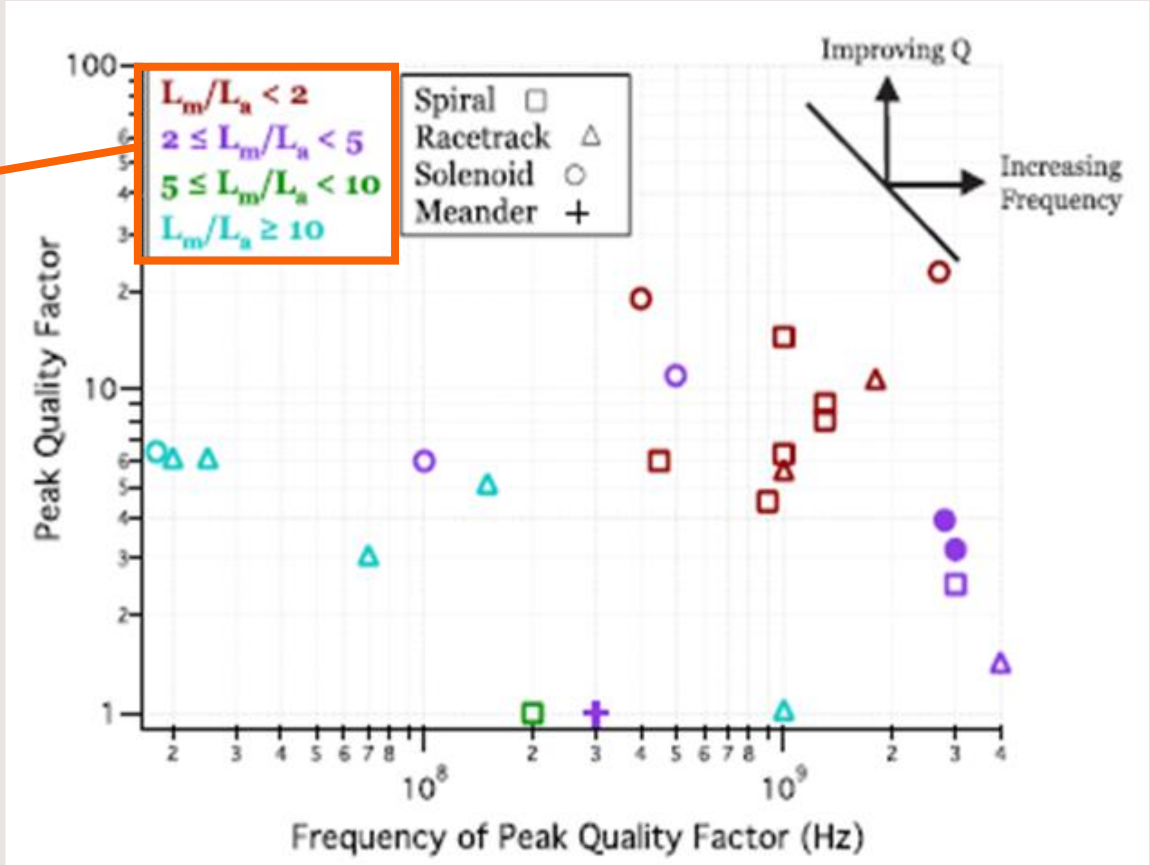

**Multilayer Ceramic Capacitor

*https://www.coilcraft.com/en-us/products/rf/ferrite-core-chip-inductors/01005-(0402)/016008f
**https://international.electronica-azi.ro/murata-redefines-miniaturization-with-the-worlds-smallest-006003-inch-size-0-16mm-x-0-08mm-multilayer-ceramic-capacitor/

**Passives sizes are not much better at RF frequencies!**

# Challenge #2 – Frequency Limitations: Magnetic Passives

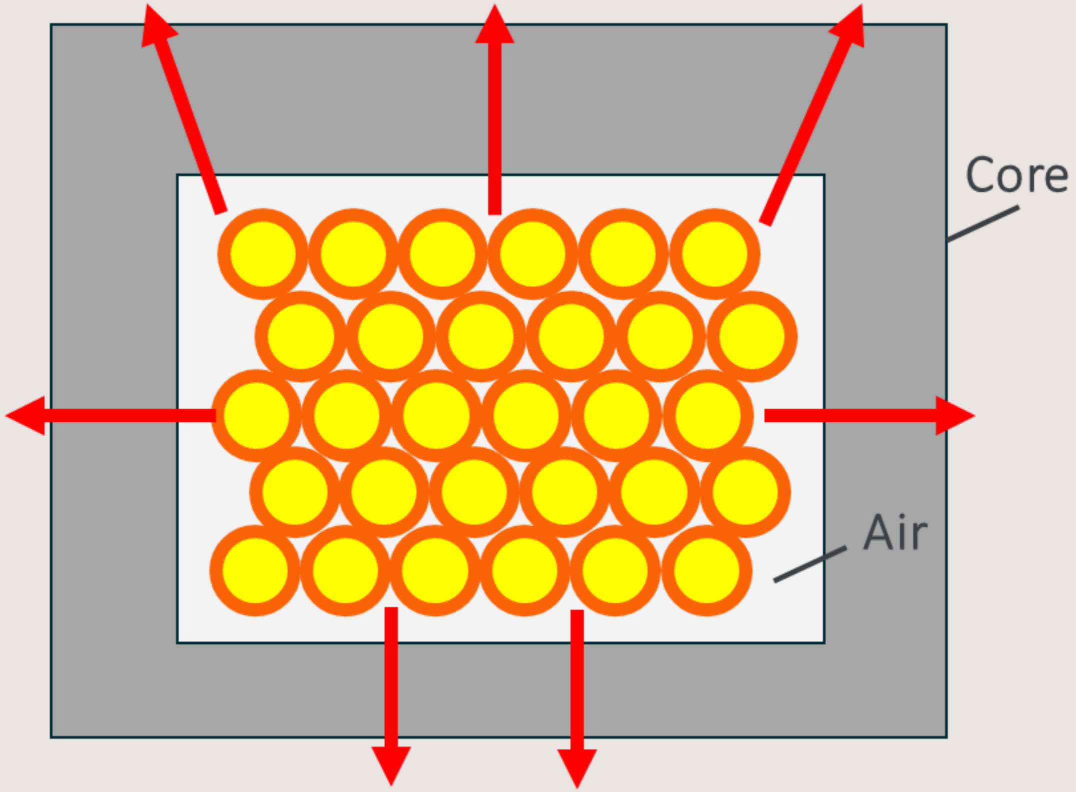
Inductance enhancement, $L_m/L_a$, of the device compared to its air-core equivalent.




A. El-Ghazaly, R. M. White and S. X. Wang, "Gigahertz-Band Integrated Magnetic Inductors," in IEEE Transactions on Microwave Theory and Techniques, vol. 65, no. 12, pp. 4893-4900, Dec. 2017, doi: 10.1109/TMTT.2017.2728040.

**Frequency performance is a key, limiting factor preventing magnetic materials use at RF**

# Energy Losses in Magnetic Passives: Coil Loss



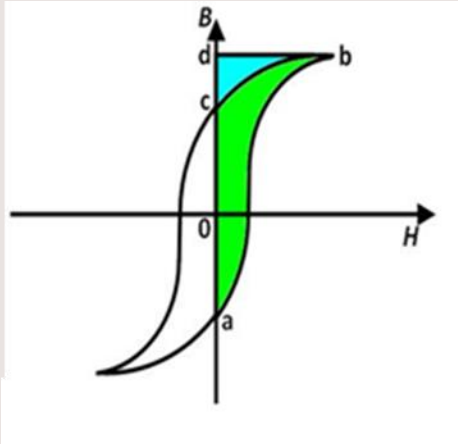

Coil losses arise due to:

- Joule heating
- proximity effect
- winding losses

**Copper windings may not be good enough in future magnetic passives**

# Energy Losses in Magnetic Passives: Core Loss

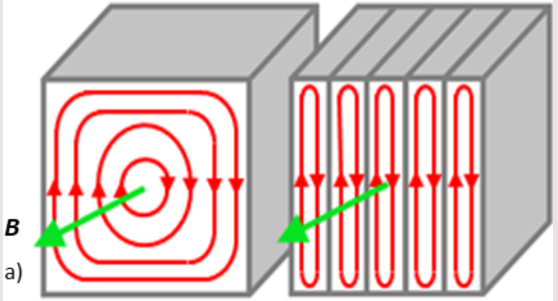
"Nature abhors a change in magnetic flux"




$$\frac{P_{hys}}{V} = \oint H(t)dB$$

$$P_{res} \sim B^{1.5} f^{1.5}$$

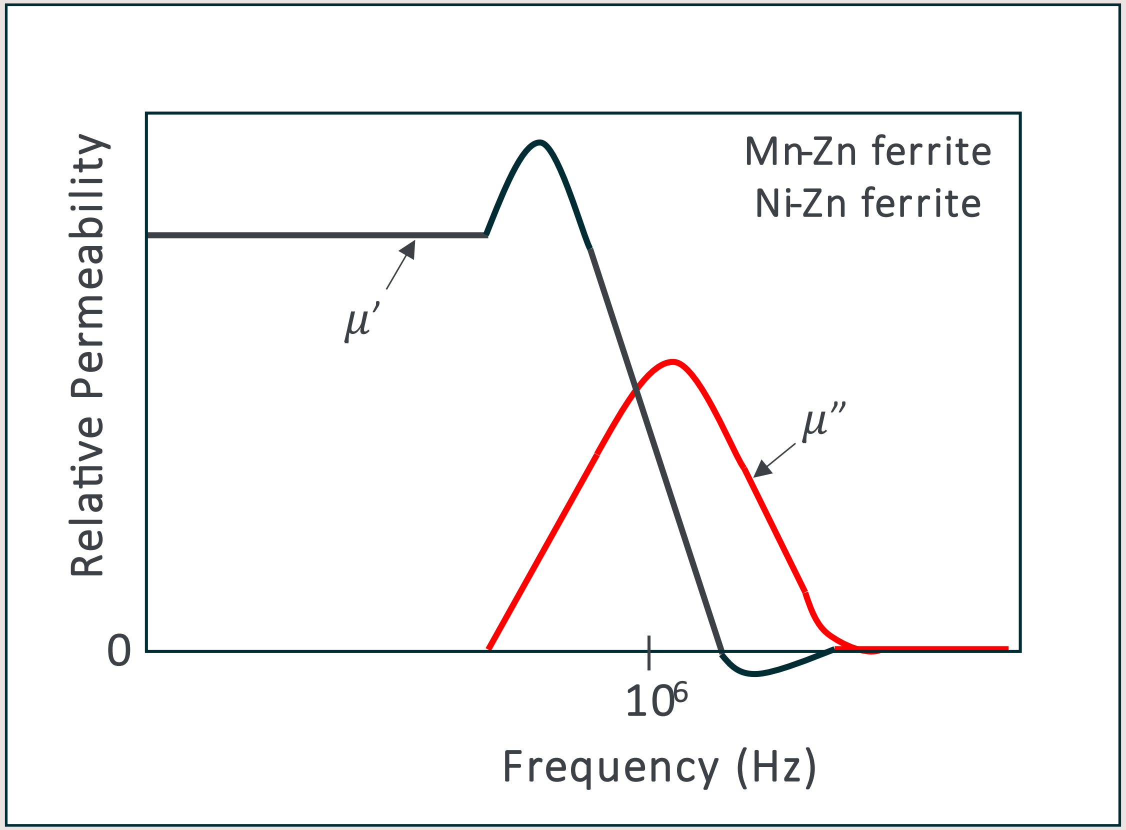
Poorly understood and attributed to domain wall resonance




$$\frac{P_{eddy}}{V} = \frac{\omega B^2 A}{48\boldsymbol{\rho}}$$

**Core loss mechanisms get worse with higher frequency**

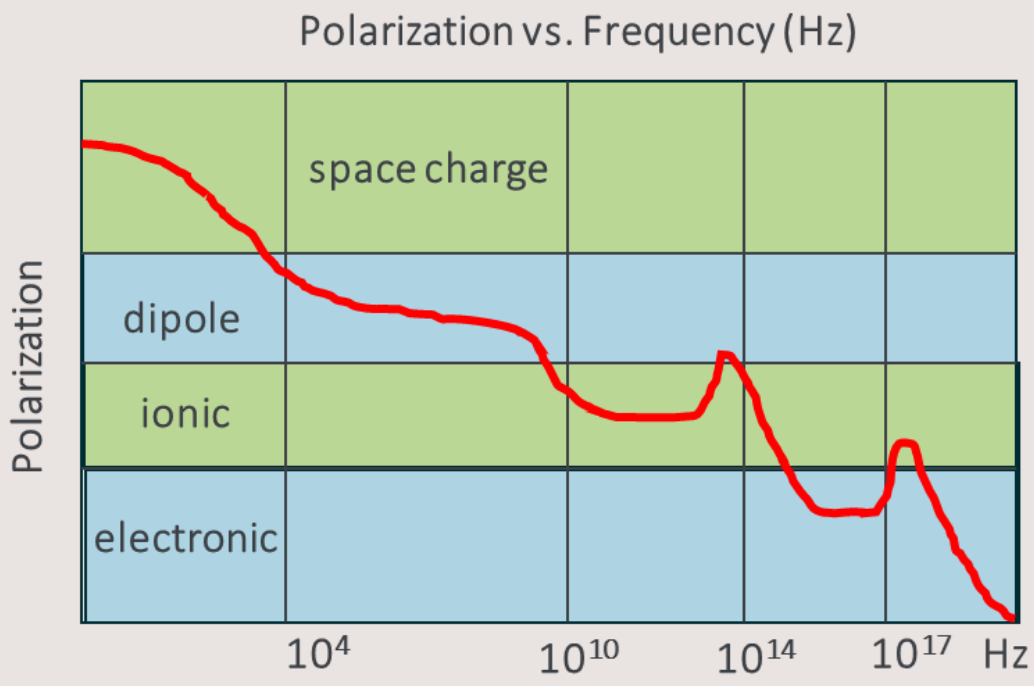
# Ferrite Degradation at High Frequencies

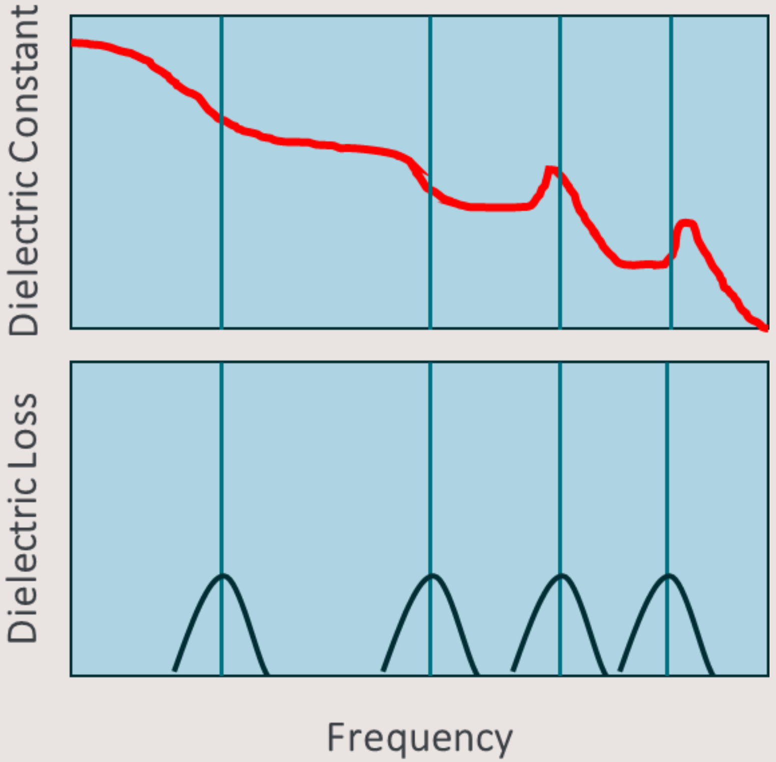



$T_C$'s of only ~210-240 °C (MnZn) and ~280 °C (NiZn)

**Ferrite materials have been pushed to their limits and new materials are needed**

# Challenge #2 – Frequency Limitations: Capacitors

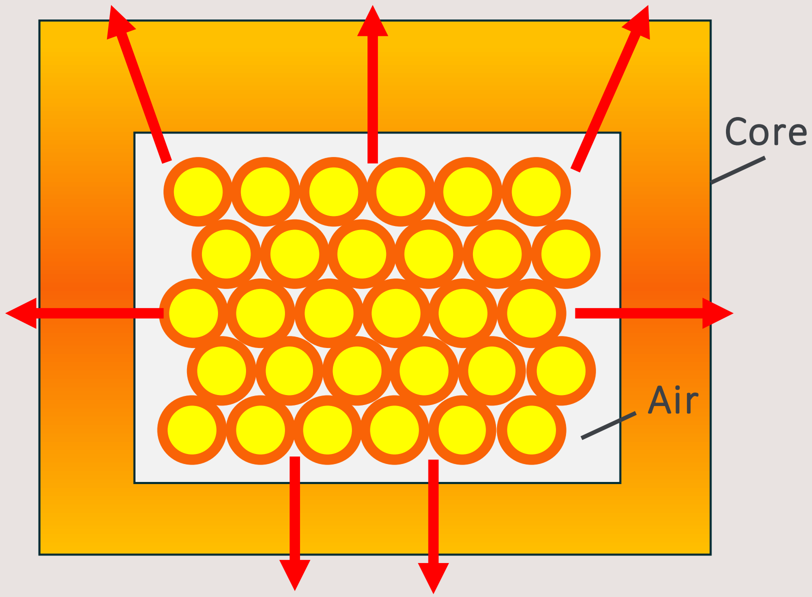


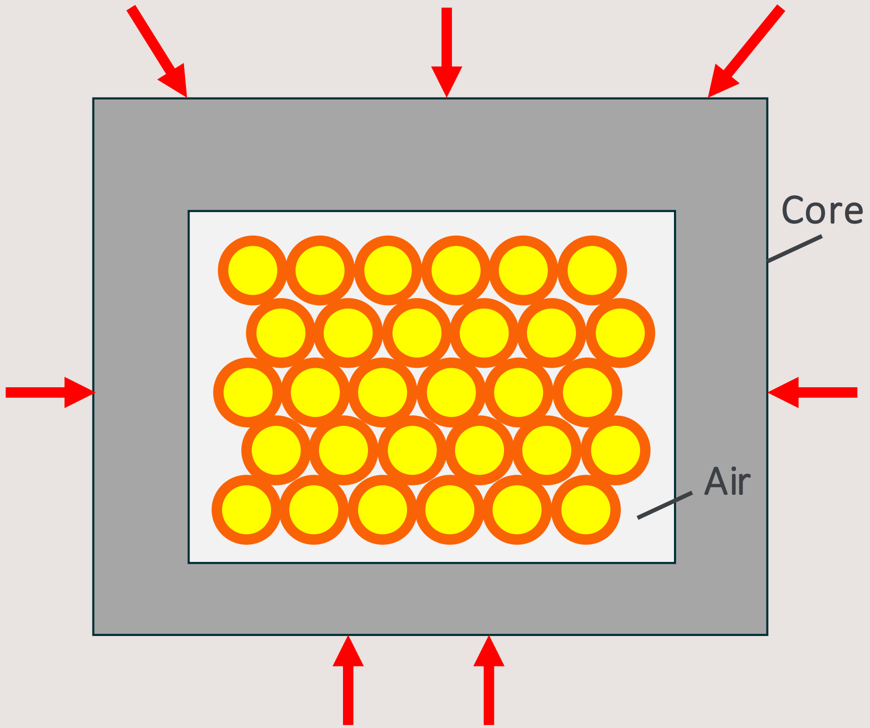

**The frequency of use directly effects usage, polarization mechanism, and loss**

# Challenge #3 – Temperature Limitations: Magnetic Passives

## Self-Heating

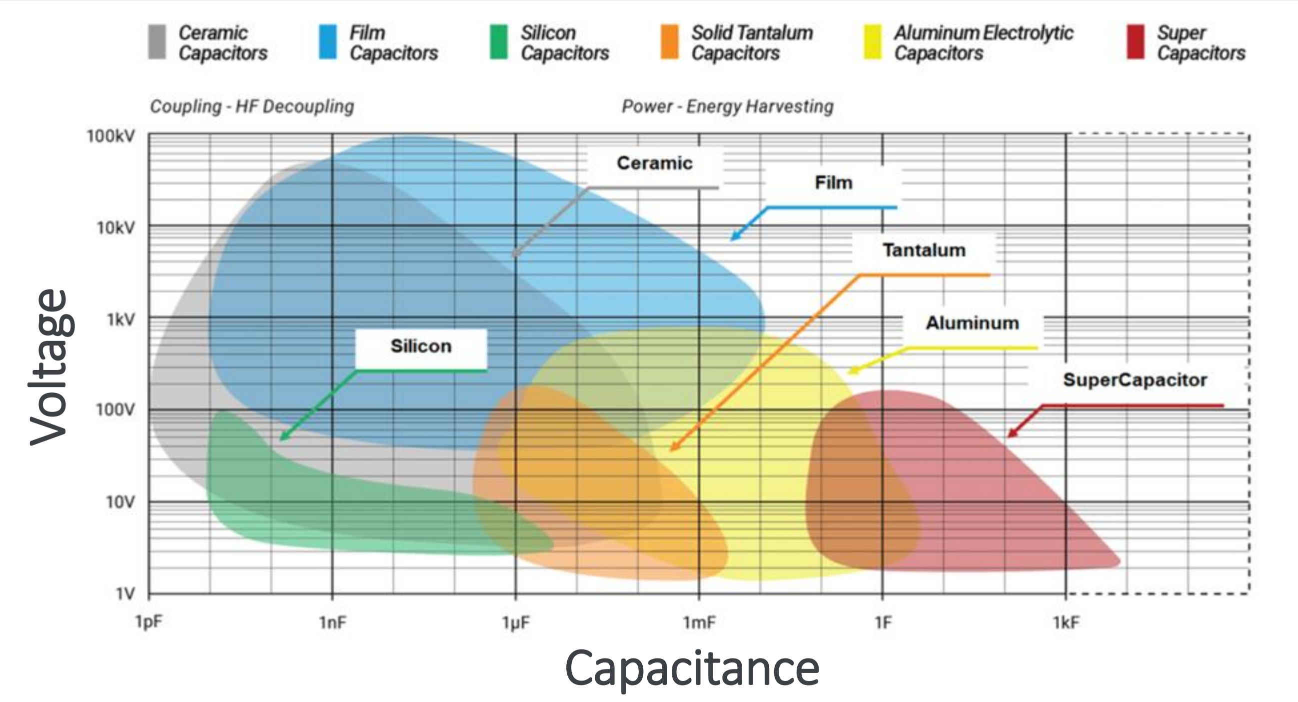



## External Heating (circuit & environment)




**Thermal effects necessitate the use of larger magnetic devices for better heat dissipation**

# Challenge #3 – Temperature Limitations: Capacitors




| Cap Type | Thermal Limitations |
|---|---|
| Ceramic | • Nonlinear temperature dependency<br>• Poor stability over temperature |
| MLCC's | • Not operable above 125 °C<br>• Catastrophic failure at high temperature and voltage operation |
| Film | • Degradation of electrode and dielectric with temperature<br>• $T_{max}$ for PET and PP, ~150 °C and ~105 °C, respectively |
| Electrolytic | • Lowest temperature ratings for caps, <125 °C<br>• Electrolyte evaporation over time increasing ESR and accelerating degradation |

https://www.doeeet.com/content/eee-components/passive-components/capacitor-technologies-overview/

**Capacitors with stable performance over temperature and voltage needed**

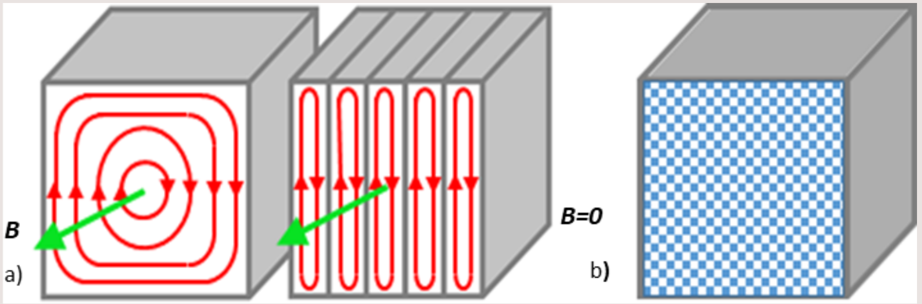
# Capacitor Reliability

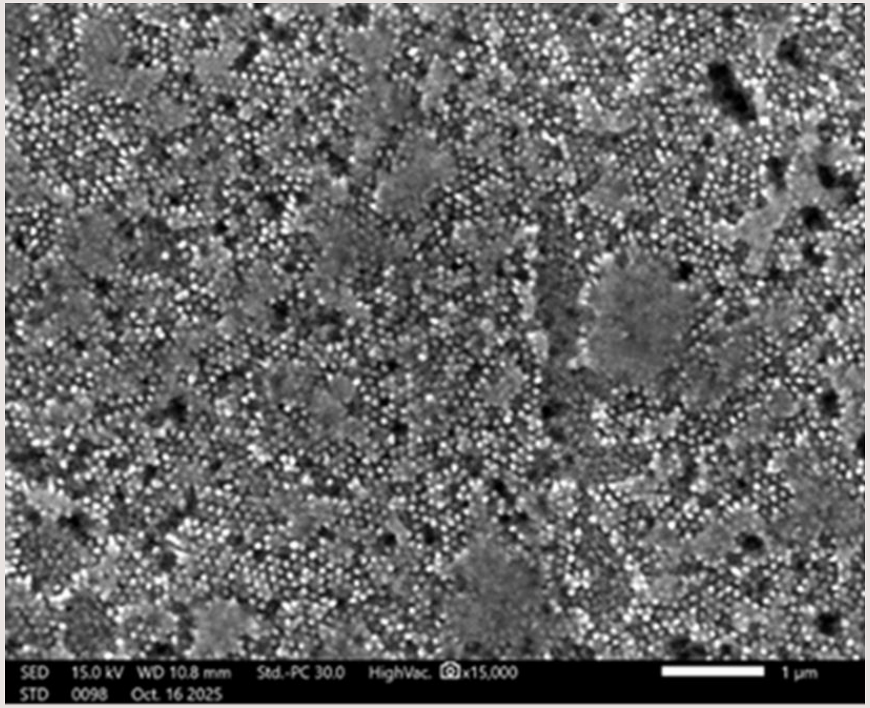
- Capacitor failure can result from time, voltage and temperature
- Failure mechanisms include:
  - time-dependent dielectric breakdown
  - delamination of dielectric and metal layers due to thermal expansion (CTE) mismatch
  - electromigration in metal layers
  - interaction of metals and dielectrics
  - current leakage due to inherent cracks and voids in the dielectric
  - the change in dielectric constant with temperature and voltage.

System designers do consider large, in-situ deviations in capacitance as justification to prohibit use of a particular capacitor technology.

# Opportunities for Improvement: Magnetic Passives

- Nano-scale dimensioning
- Higher Curie temperature magnetic composites with stable performance over temperature
- Lower loss conductors




SEM image of CoFe nanowires

# Opportunities for Improvement: Capacitors

- A wide swath of dielectrics has largely remained unexplored, in terms of material properties and feasibility of manufacturing and integration
- Thermally stable, constant permittivity higher breakdown field dielectric composites such as AlN-SiC
- Use existing AI models and known databases to train models that can rapidly identify potential high-k, low-loss dielectrics with superior temperature performance

# Summary

- Despite attempts, fundamental physics and lack of robust materials have prevented shrinking of passive devices to same degree as active devices
- Frequency-dependent losses and degradation at elevated temperatures are two of the main reasons for this.
- Opportunities exist to explore new nanoscale-dimensioned composites and discovery of new alloy formulations through AI/ML.


THANK YOU