NEW POWDER CORE MATERIALS FOR INPUT FILTER CHOKES

Edge™ and High DC Bias XFlux®

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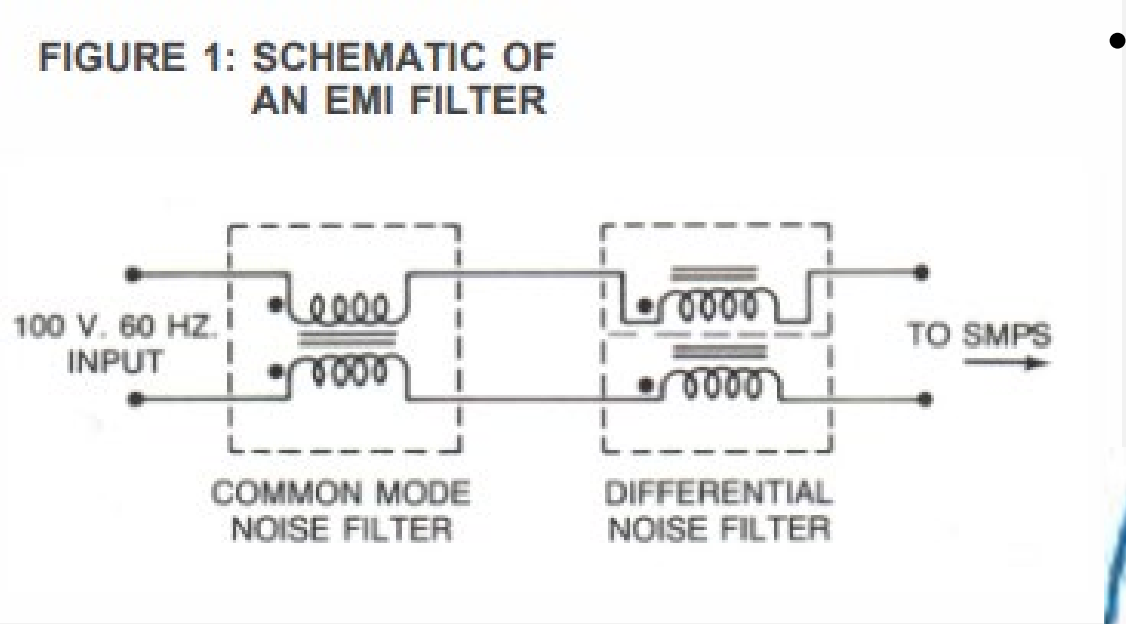
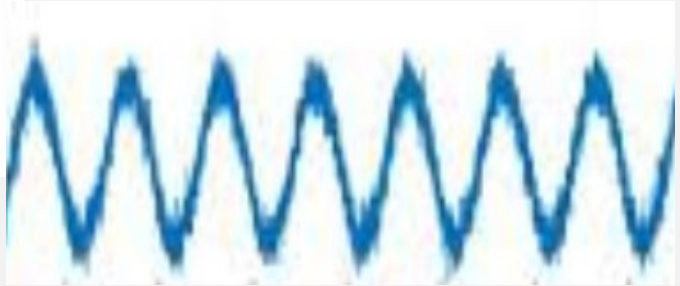
OVERVIEW

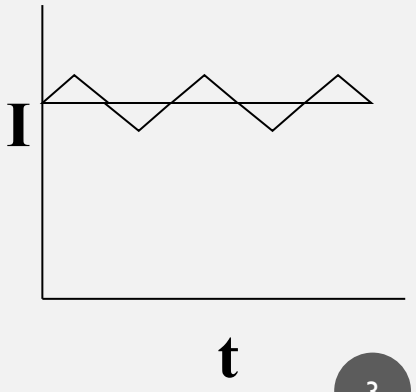
- Integrated Magnetics Example
  - 2 Coil Differential Choke for Input Filter
- Core Material Considerations
- New Powder Core Options
  - High DC Bias XFlux®
  - Edge™
- Performance Summary

INPUT FILTER CHOKES



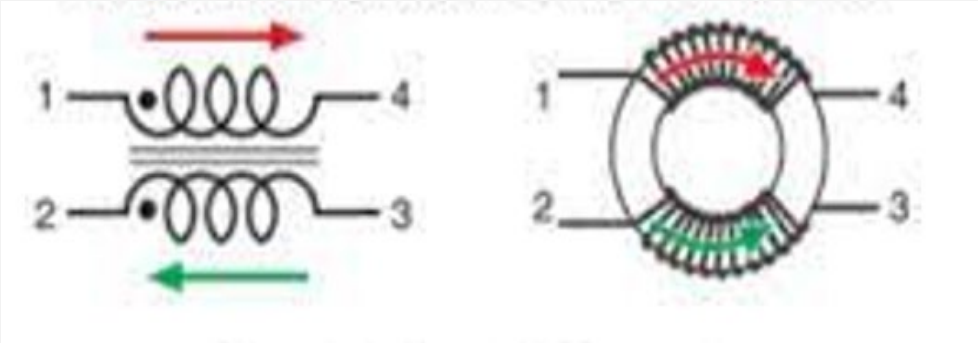
- Consider 2 Stage (LC) Differential Input Filter
- Same Concepts Apply For:
  - Differential Chokes For Output Filters
    - DC-DC, AC-DC, DC-AC
  - 3 Stage and 2 Section Input Filters

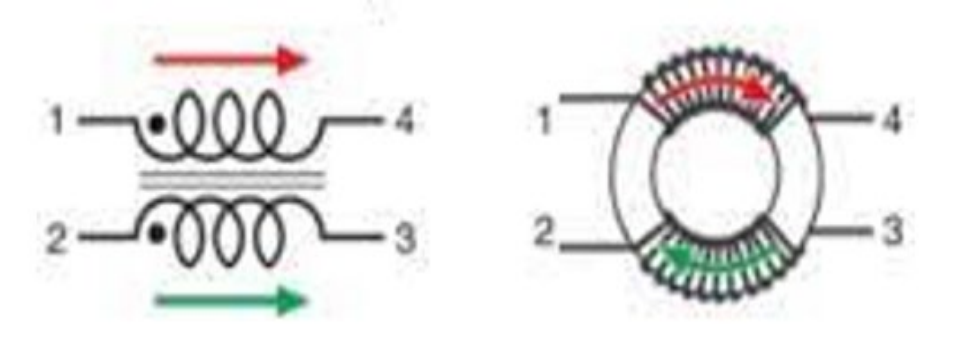




COMMON MODE CHOKES

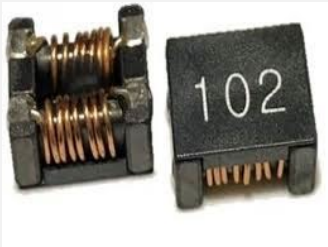
- Higher Amp 60Hz Flux Cancels
  - Mitigates Core Saturation Concerns
  - Allows for High Perm Materials
    - Ferrite: 3,000-15,000 perm typical
    - Nanocrystalline: 30,000-100,000 perm typical





- Only Lower Amp Common Mode Noise Is Impeded

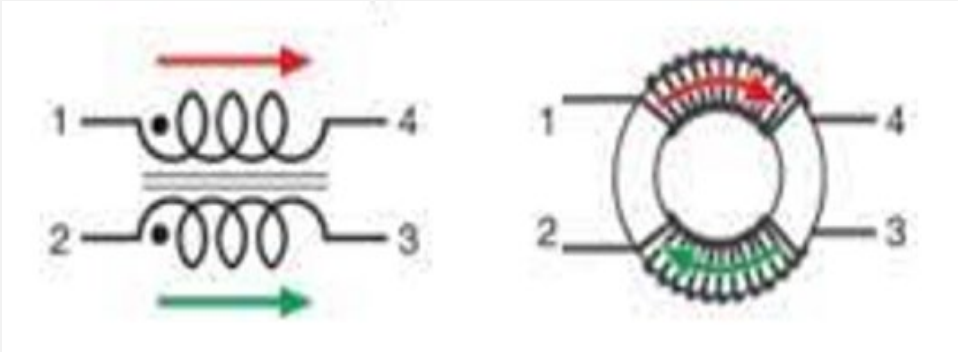
2 COIL CONSTRUCTION OPTIONS



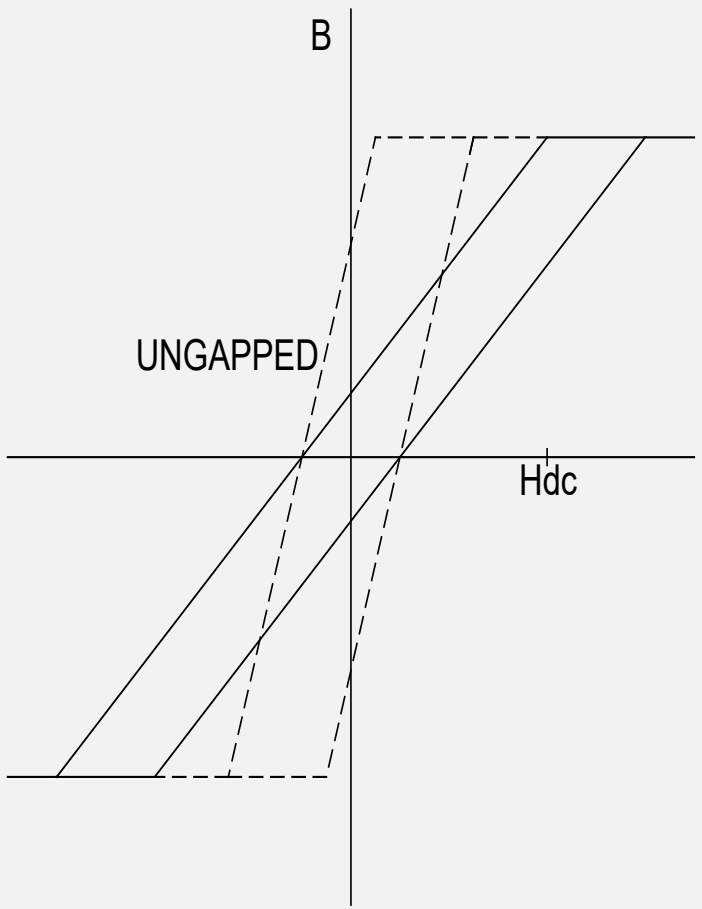
- Toroid
  - One piece best for high perm
  - Single Layer Turns
    - voltage isolation
    - low parasitic capacitance
  - Bifilar OK with proper insulation
- 2-Piece Shapes
  - Typically Lower Amps
  - Air gap reduces perm
    - Might need higher turns

DIFFERENTIAL MODE CHOKES

- Higher Amp 60Hz and Lower Amp Noise In Phase
  - No Flux Cancellation
  - Must Avoid Core Saturation at Peak Amps



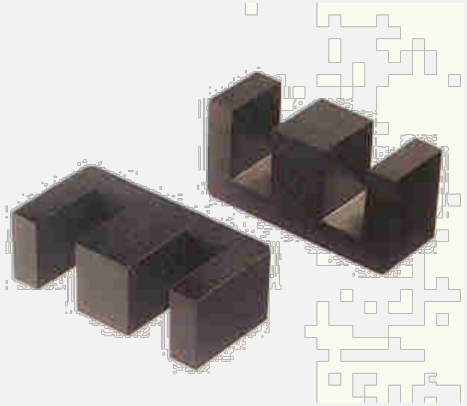
HOW TO AVOID CORES SATURATION?

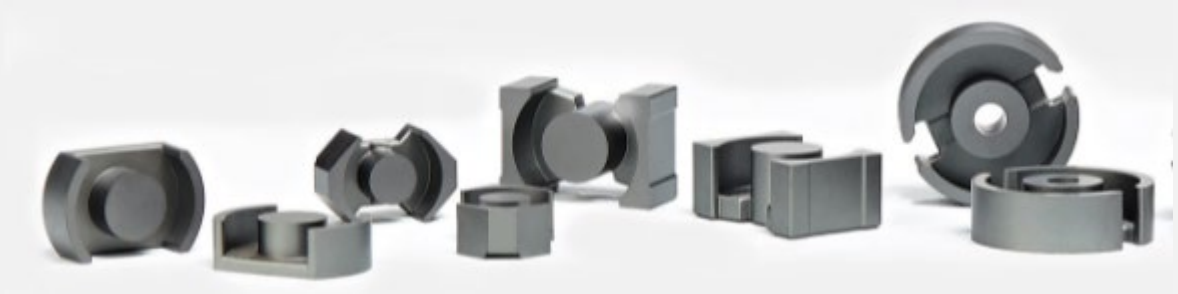


- Must Avoid Saturation (B_{max})
- Highest B_{max} Materials have Highest AC Losses
- Use Low Permeability cores → $\mu = B/H$
  - Introduce Air in Magnetic Path, $\mu_{Air} = 1$
    - Discrete gap cores
    - Distributed gap cores

DISCRETE GAP CORES

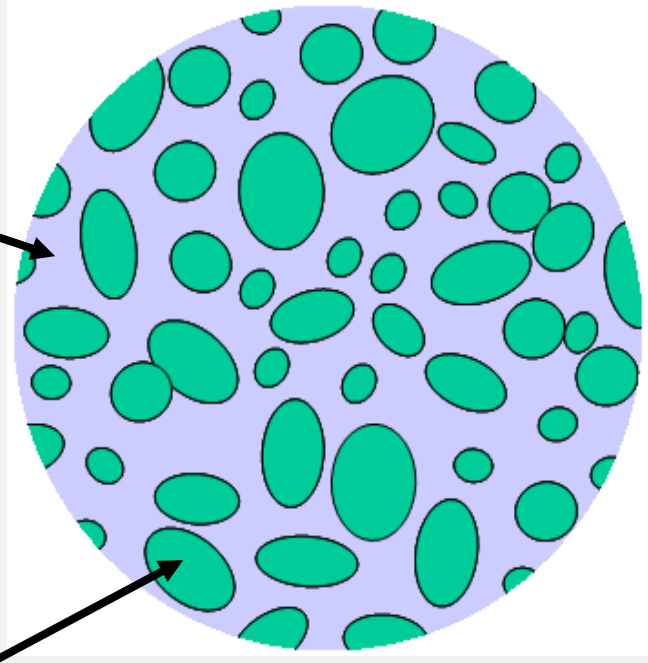
- Discrete Gap Needed for Ferrite & Strip Core Inductors
  - SiFe, Nickel, Amorphous Strip All need Gap
- Air gap introduced between 2 mating pieces
  - Grind Air Gap in Ferrite Center Leg
  - Or Nonconductive Shim between Mating Surfaces
- Hard Saturation Characteristic

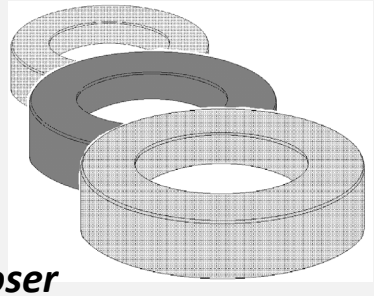




Distributed Air Gap Powder Cores

Non-magnetic insulation (Gap) Perm is low (=1)





High Perm Magnetic Alloy

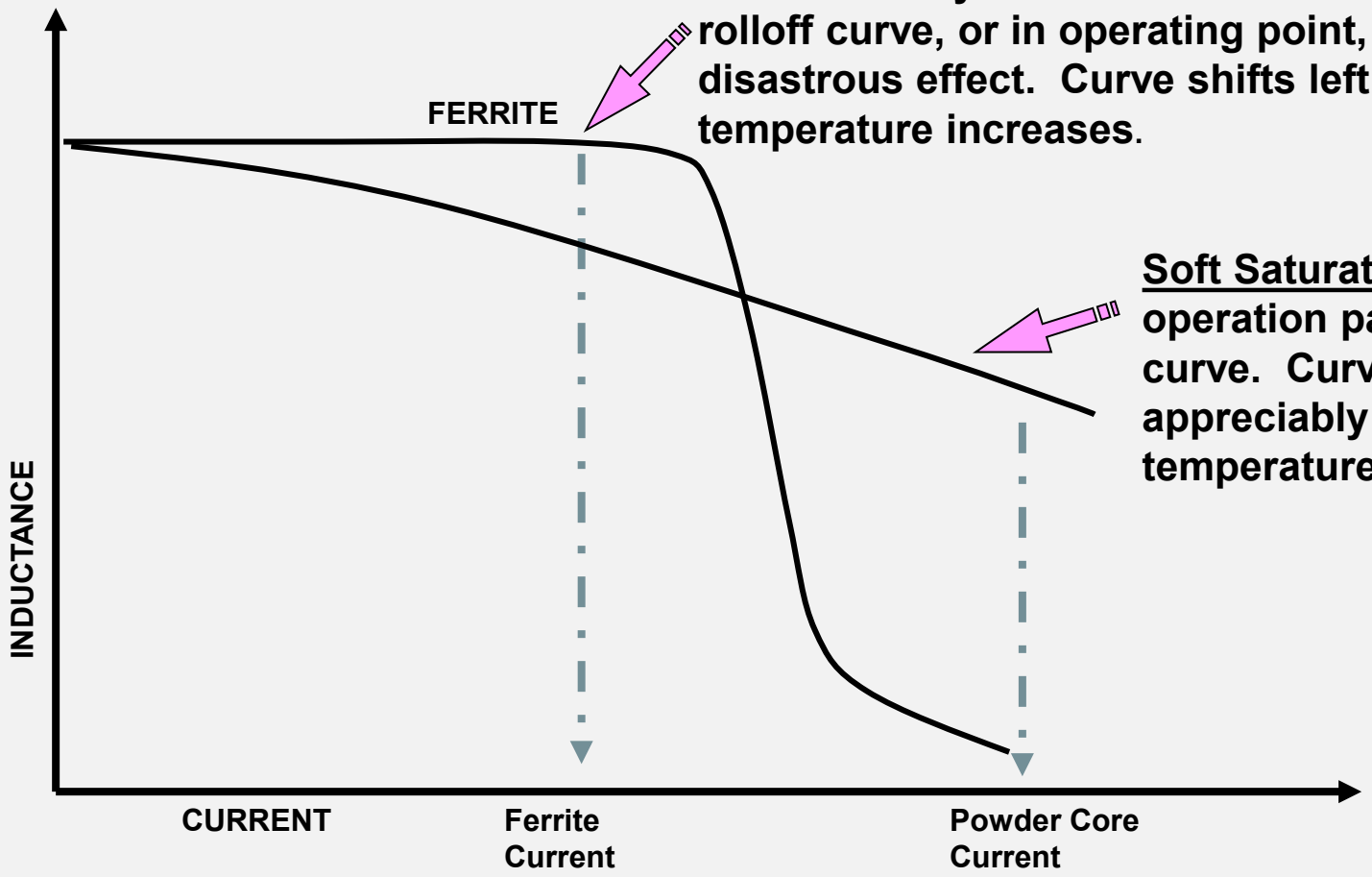
Microscopic Schematic View
(Gap exaggerated; alloy particles are really much closer than this.)

Powder Core Options

- Nickel Based
  - 80% Nickel – MPP
  - 50% Nickel - High Flux, Edge
- Iron Based
  - Iron Powder
  - FeSiAl - Kool Mμ®, Kool Mμ Max, Kool Mμ H*f* (Sendust)
  - FeSi – XFlux, High DCB XFlux
- Blends

- All Have Soft Saturation Characteristic

SOFT SATURATION ADVANTAGES



<u>Hard Saturation</u> materials must be kept safe distance away from rolloff. Small shifts in rolloff curve, or in operating point, could have disastrous effect. Curve shifts left as temperature increases.

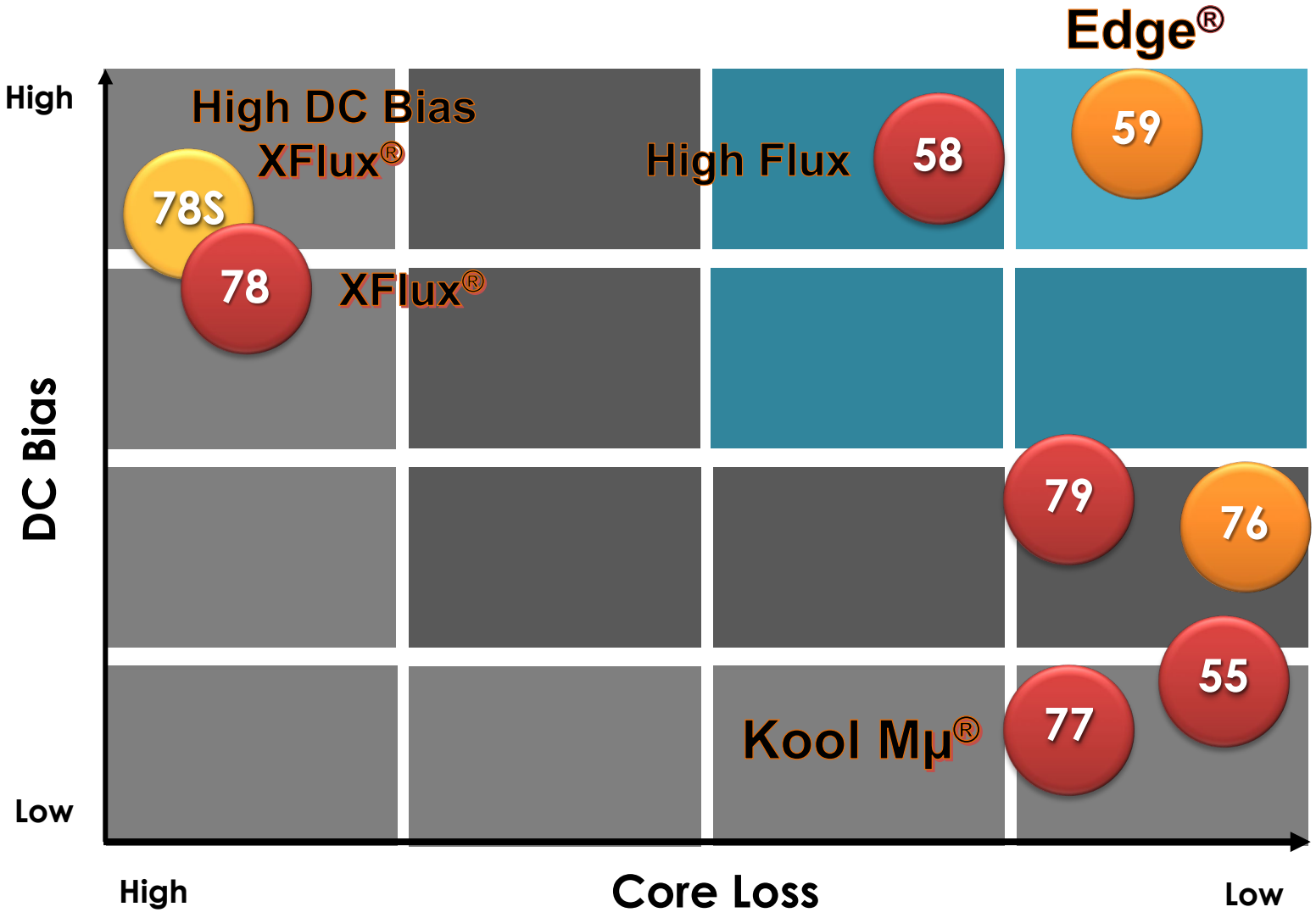
<u>Soft Saturation</u> allows operation part way down curve. Curve doesn't shift appreciably with increasing temperature.

5 Powder Core Options For EMI Filter Example

	Kool Mμ®	XFlux®	NEW HDCB XFlux®	High Flux	NEW Edge™
Alloy Composition	FeSiAl	FeSi	FeSi	FeNi (50%)	FeNi (50%)
Available Perms	14-125	19-125	26-60	14-160	14-125
Core Loss (mW/cc) 50kHz, 1000G	190	575	625	250	160
Perm vs. DC Bias (Oer) 50% of μ_i	95	170	200	185	205

Core Loss and DC Bias performance values for 60μ toroids

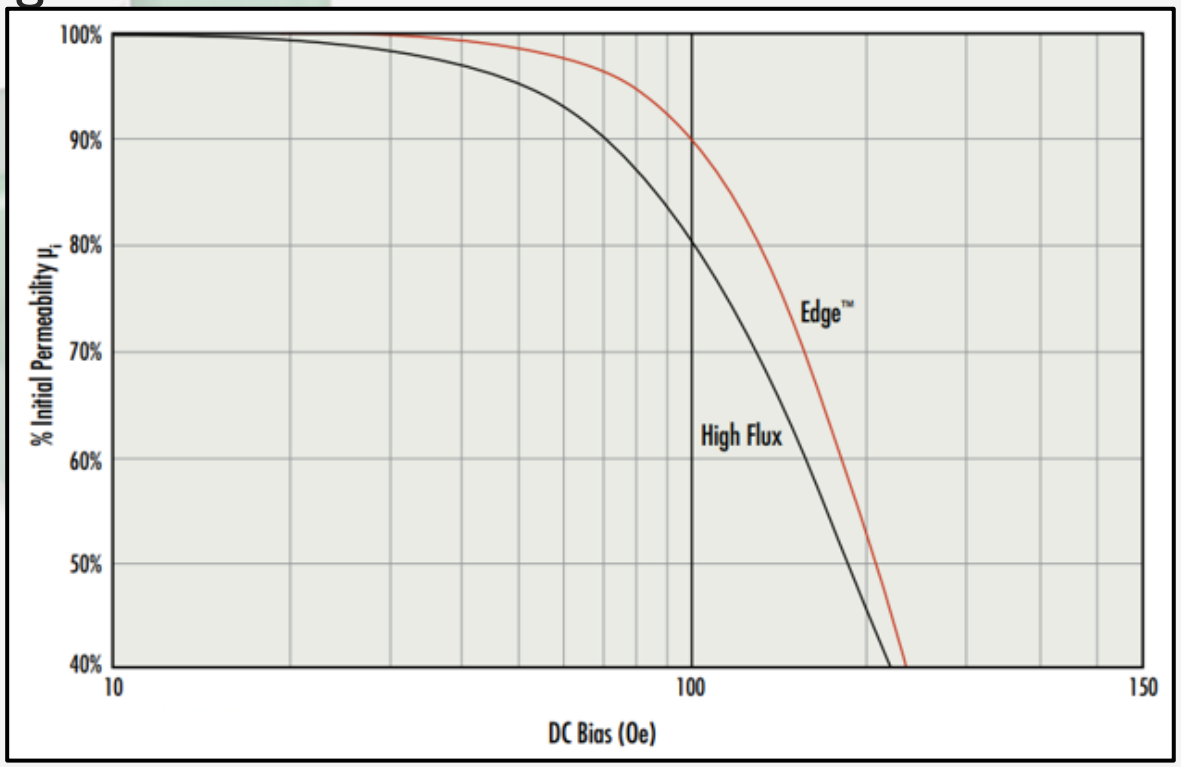
5 Powder Core Options For EMI Filter Example



NEW EDGE™ FOR COMPACT, EFFICIENT POWER

- Material Composition: 50% Ni 50% Fe (same as High Flux)
- Optimized for high efficiency, high density designs
- Edge™ vs. High Flux
  - 30-40% Lower Core Losses
  - 10-30% Higher DC Bias

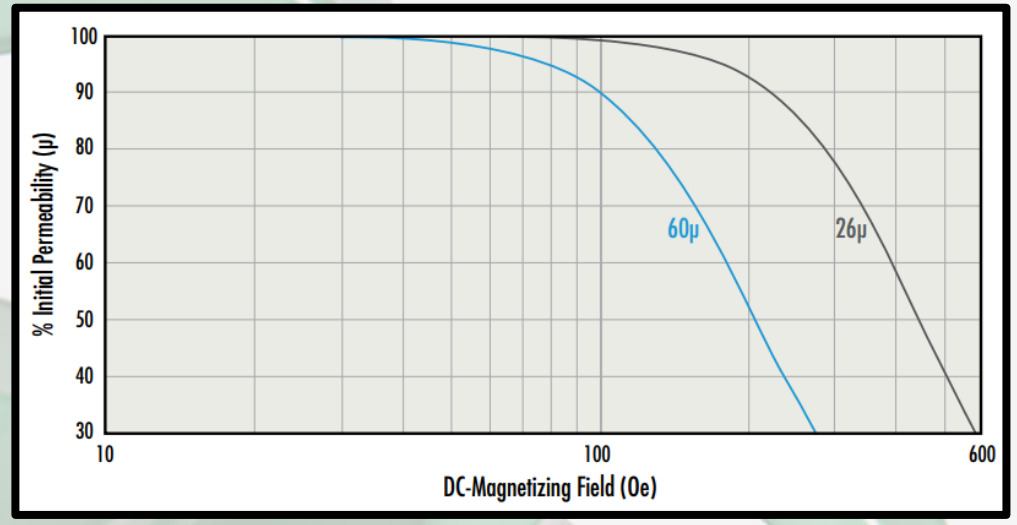
Material	Perm vs. DC Bias (Oer)		Core Loss (mW/cc)	
60μ	**80% μ_i**	**50% μ_i**	**100kHz, 1000G**	**50kHz, 1000G**
Edge	***130***	***205***	***375***	***160***
High Flux	101	185	625	250



NEW EDGE™ FOR COMPACT EFFICIENT POWER

DC Bias

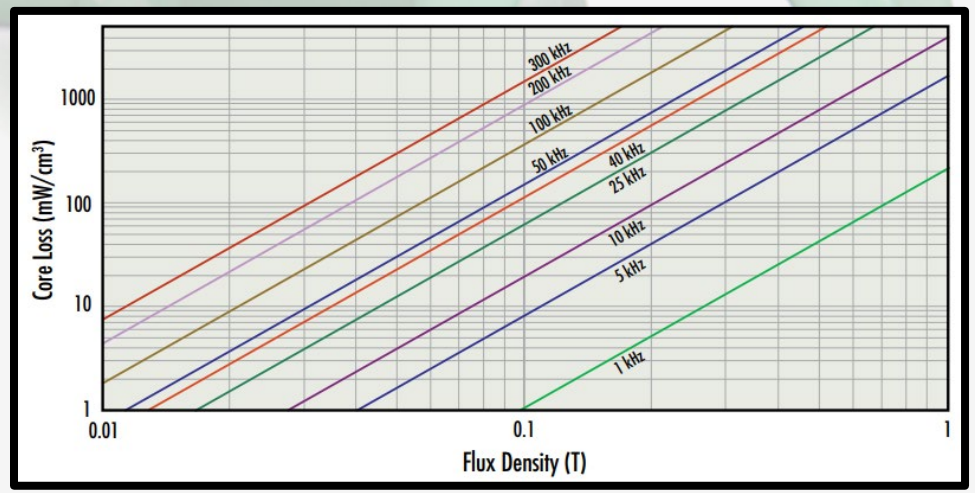
Initial Permeability = 1 / (a+bH^c)			
	a	b	c
26µ	0.01	3.65E-11	3.192
60µ	0.01	9.20E-10	3.044



Core Loss

P = a (B^b) (f^c)			
	a	b	c
26µ	227.54	2.209	1.27
60µ	211.51	2.309	1.28

B in Tesla, f in kHz



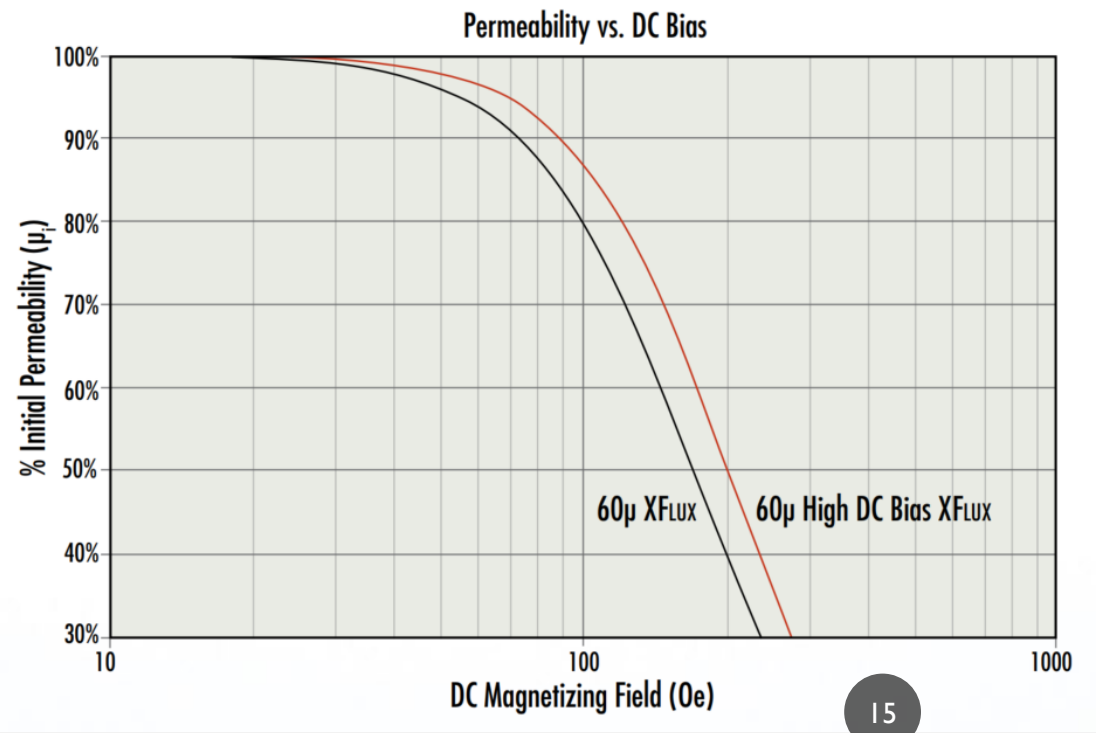
60µ Core Loss Density Graph shown

NEW HIGH DC BIAS XFLUX®

- Material Composition: Silicon Iron, same as XFlux®
- Provides Up To 20% Higher DC Bias with 10%-20% Penalty in Higher Cores Losses vs. XFlux®

Perm	Perm vs. DC Bias (Oe)		Core Loss (mW/cm³)
26μ	**80%**	**50%**	**$W_{1000\ G,\ 50\ kHz}$**
High DCB XFLUX	285	505	725
XFLUX	270	450	600

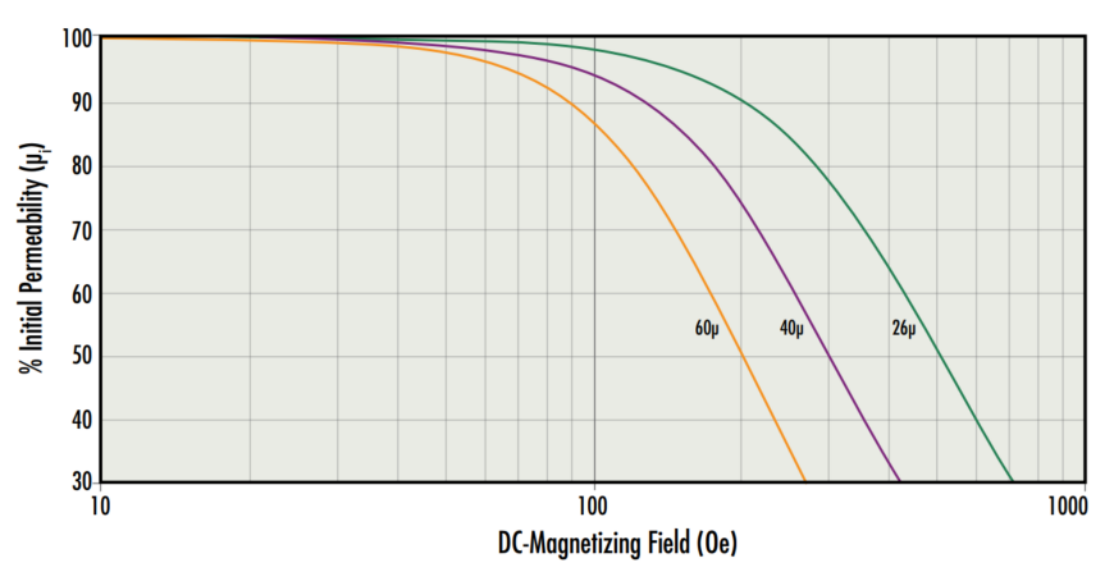
Perm	Perm vs. DC Bias (Oe)		Core Loss (mW/cm³)
60μ	**80%**	**50%**	**$W_{1000\ G,\ 50\ kHz}$**
High DCB XFLUX	120	200	625
XFLUX	100	170	575



NEW HIGH DC BIAS XFLUX®

DC Bias

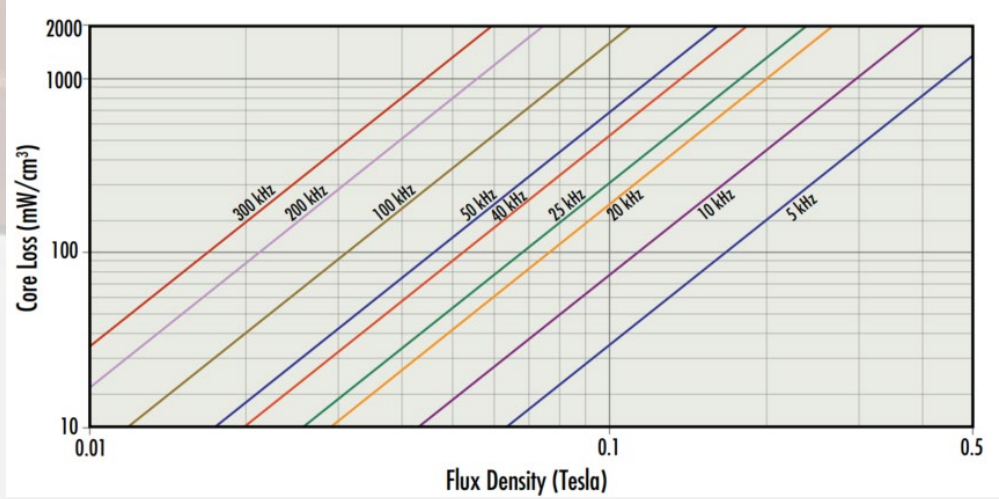
% Initial Permeability = 1 / (a+bH^c)			
	a	b	c
26µ	0.01	2.81E-09	2.423
40µ	0.01	4.25E-09	2.572
60µ	0.01	5.69E-09	2.714



Core Loss

P = a (B^b) (f^c)			
	a	b	c
26µ	845.36	2.477	1.41
40µ, 60µ	842.18	2.388	1.33

B in Tesla, f in kHz



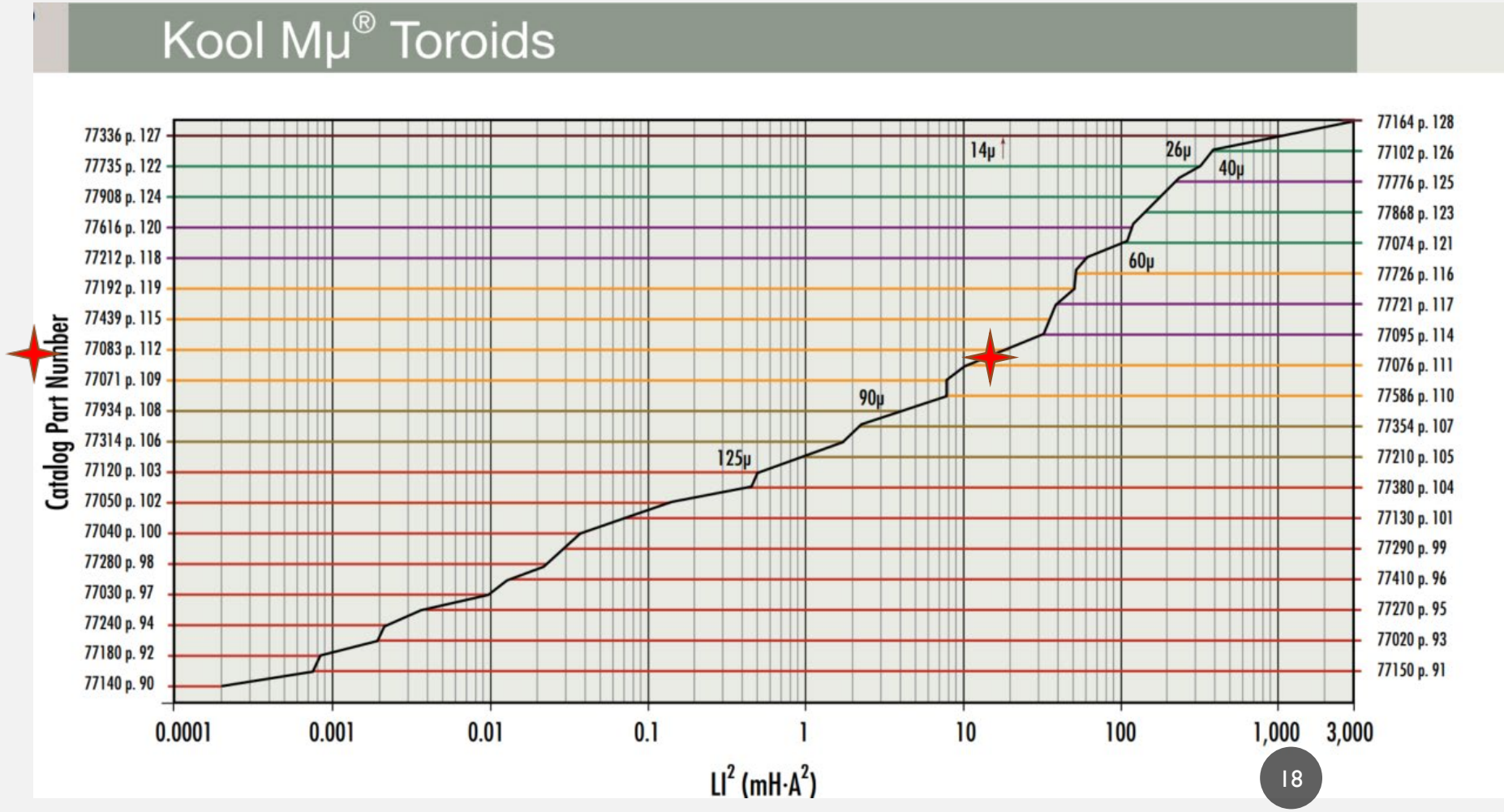
60µ Core Loss Density Graph shown

2 COIL DIFFERENTIAL CHOKE DESIGN

- Need 8uH nominal inductance per coil, with $25A_{rms}$ continuous load
- Select Core
  - LI^2 = 0.008mH x 25^2 = 5, for 1 Coil with 40% Fill
  - Need larger core for 2 single-layer coils, assume LI^2 = 10-20 with Core Selector Chart
  - Start with Kool Mu
- Select Wire
  - Need 11AWG based on 600 Amp/cm^2 at $25A_{rms}$
  - Use 4-strands x 17AWG for equivalent copper area

2 COIL DIFFERENTIAL CHOKE DESIGN

- Start with 77083A7
  - 60 perm
  - 39.9mmOD x 14.5mmH
  - AL = 81 +/-8%
  - Path Length = 9.84cm



2 COIL DIFFERENTIAL CHOKE DESIGN

- Calculate Turns for 8uH nominal inductance per coil
  - μH = AL x N^2 x 10^{-3}, use 10 turns per coil
  - Evaluate Inductance Roll-off at Different Loads
    - Oersteds Law & Curve Fit Equation Tool
    - Flux Adds, - Must Add Oersteds for Both Coils
    - 25 Amps rms
    - 35 Amps peak
    - 45.5 Amps, 30% overload for fault + noise

$$H(Oersteds) = \frac{0.4\pi * N * I}{L_\varepsilon}$$

$$L(mH) = \frac{A_L * N^2}{10^6}$$

2 COIL DIFFERENTIAL CHOKE DESIGN

Each Design Has Same Core Size, Perm, & Copper	**Inductance (uH)**					
Condition	**Oer**	**Kool Mu (77)**	**XFlux (78)**	**High DCB XFlux (78S)**	**High Flux (58)**	**Edge (59)**
No Load		8.1	8.1	8.1	8.1	8.1
25 Amps rms	63.8	5.5	7.5	7.8	7.5	7.9
35 Amps peak	89.3	4.3	6.8	7.3	6.8	7.5
45.5 Amps (30% overload, fault + noise)	116.2	3.3	5.9	6.6	6.0	6.9
Relative Cost		1.0	1.4	1.4	5.8	7.0

2 COIL DIFFERENTIAL CHOKE DESIGN COMMENTS & CONCLUSIONS

- Expect uH Measurements Higher Than Calculated
  - No Load uH +6% Higher Due To Flux Leakage in This Case
  - Leakage Adder Depends On Perm, Core Dimensions, & Turns
- Test Inductance with 2 Coils in Series to Minimize Leakage Effect
  - Expect 4x inductance increase for 2x turn increase
- Core Loss Not Considered For This Input Filter Example

2 COIL DIFFERENTIAL CHOKE DESIGN MATERIALS SUMMARY

- Kool Mμ®
  - 53% inductance at 35A peak, OK if 4.3uH squelches EMI noise
  - 41% inductance at 30% overload also OK, depends on Noise & Fault Conditions
- Silicon Iron Alloys
  - XFLux® : 58% Higher uH at 35A peak and 79% Higher uH at 30% Overload
  - High DC Bias XFlux® : 79% Higher uH at 35A peak and 100% Higher uH at 30% Overload
  - Better Filtering or Size Reduction

2 COIL DIFFERENTIAL CHOKE DESIGN MATERIALS SUMMARY

- Nickel Alloys
  - High Flux provides 58% Higher uH at 35A peak and 82% Higher uH at 30% Overload
  - Edge™ provides 74% Higher uH at 35A peak and 109% Higher uH at 30% Overload
  - What Justifies Cost Adder?
    - Core Loss Advantage at 50kHz and 1000Gauss (0.1Tesla)
      - High Flux -57% Lower Than XFlux® , Edge™ -72% Lower Than XFlux®
    - Push These Materials
      - At 35Amp peak, Edge™ has 93% and High Flux has 84% Permeability Remaining
      - Downsize
      - Raise uH, High Flux Available Up To 160 perm

THANK YOU!

QUESTIONS?, COMMENTS?, SUGGESTIONS?

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