High Frequency Magnetics; Black Magic, Art or Science?

Magnetics Core Loss

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APEC Industry Session on Magnetics

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Ridley Engineering

www.ridleyengineering.com

Introduction

Core loss calculations and measurements

New core material needs

Need for extensive data

Approximations to data

Different excitation waveforms

Temperature variations

Standardized data base proposals

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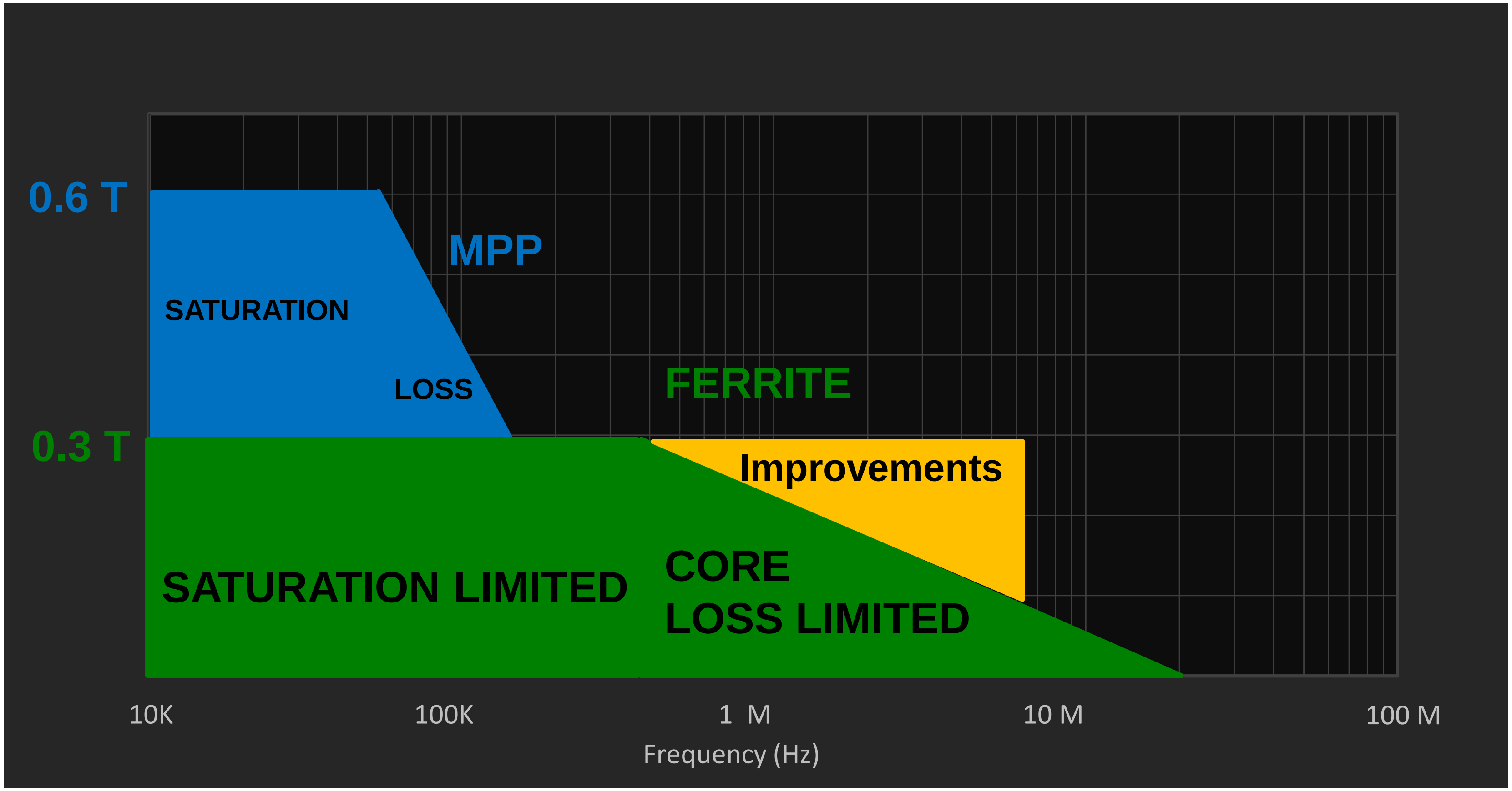
Immediate Goals for Core Materials



Would be nice to at least extend saturation range further

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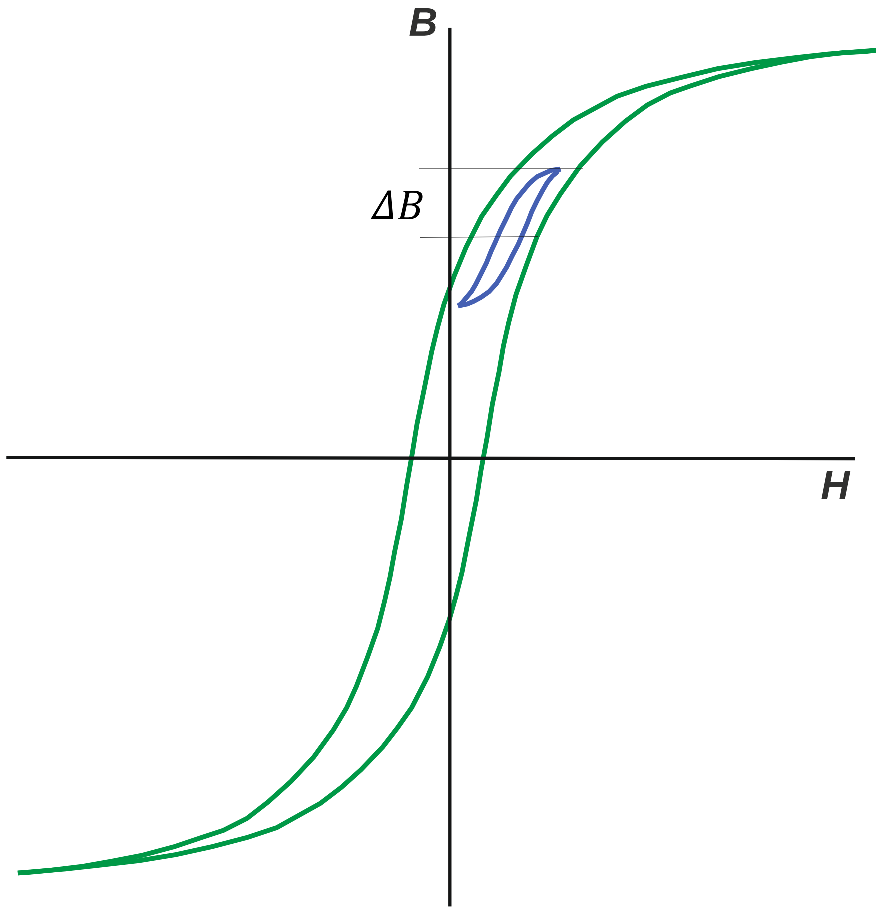
B-H Loop and Core Losses



Core loss calculations and measurements

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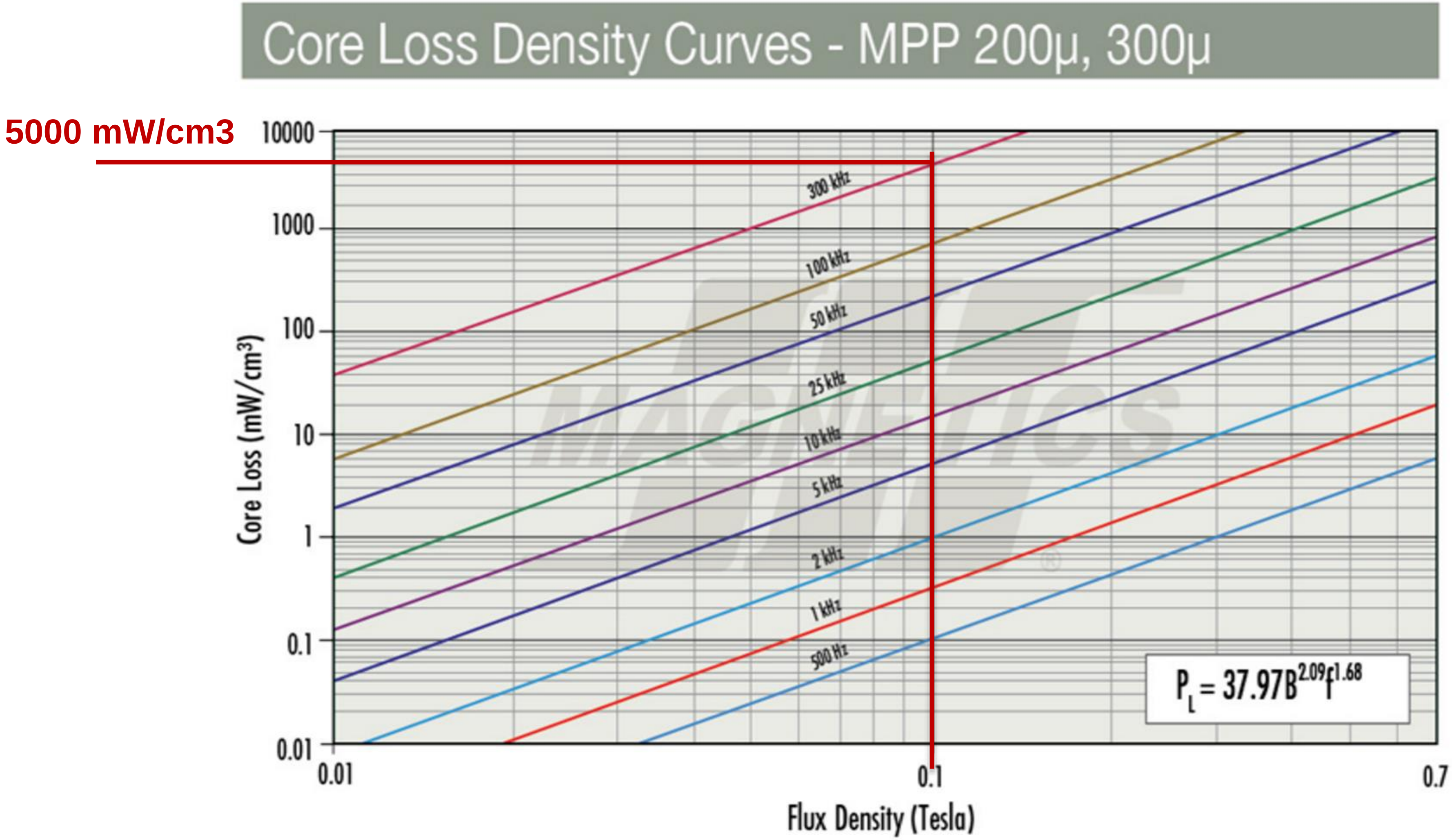
Core Loss MPP 200u



300 kHz 0.1 T 5 W/cm3

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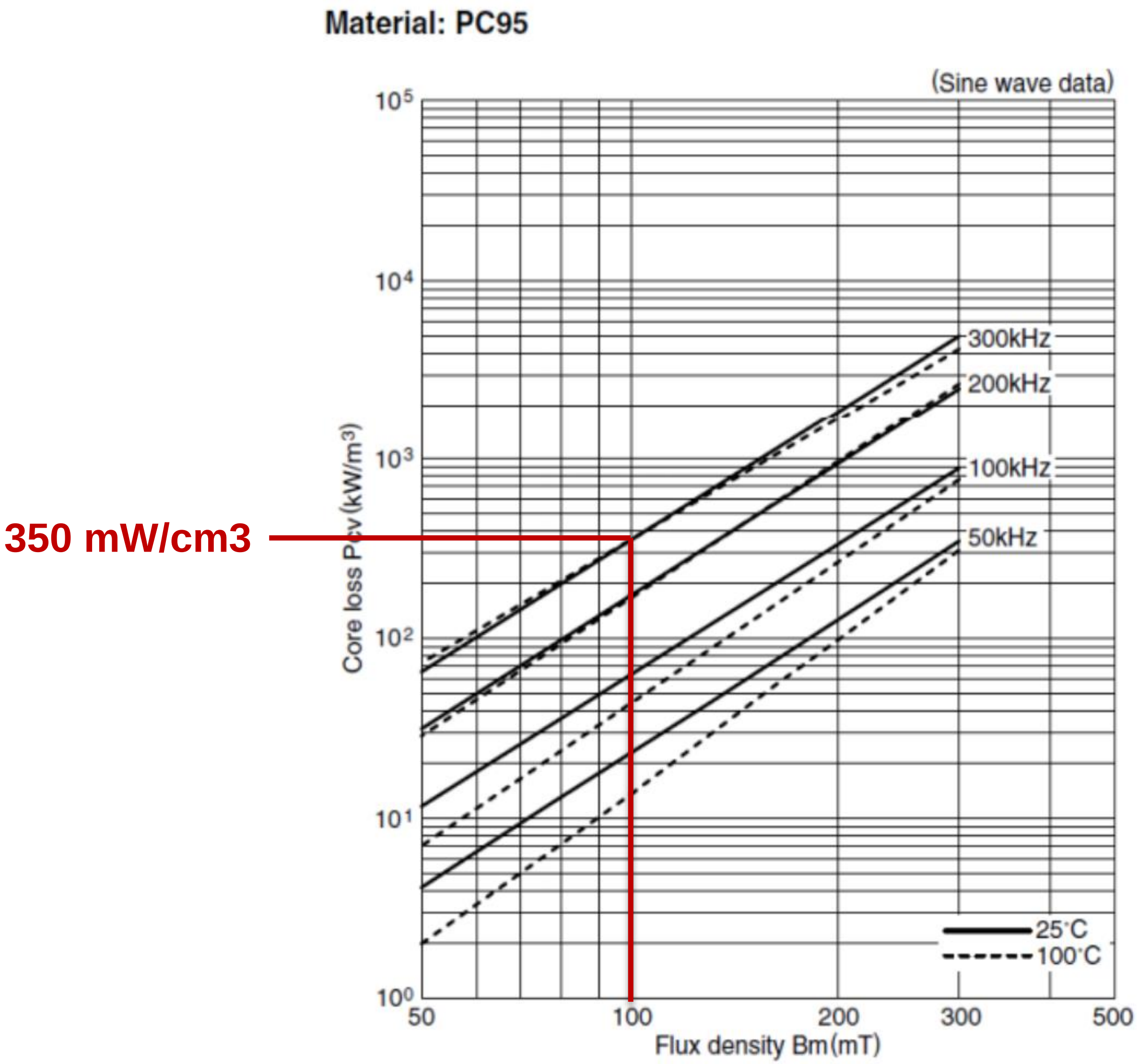
Core Loss PC95



300 kHz 0.1 T 0.350 W/cm3 > 10 times better than MPP

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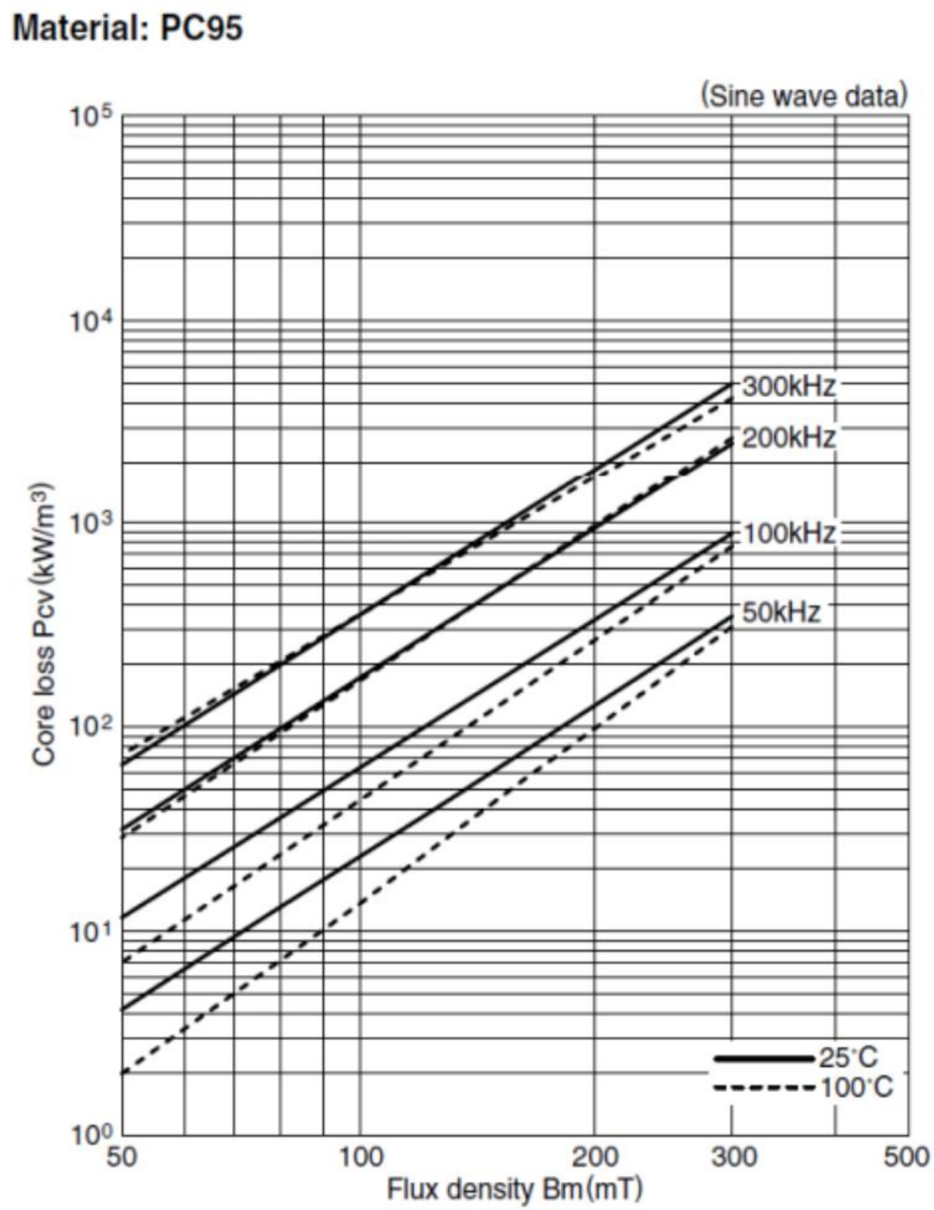
Core Loss Steinmetz Equation

$$P_c = kf^x \Delta B^y$$

Steinmetz equation can be used to approximate the actual loss measurements

Three coefficients define the loss for a given material



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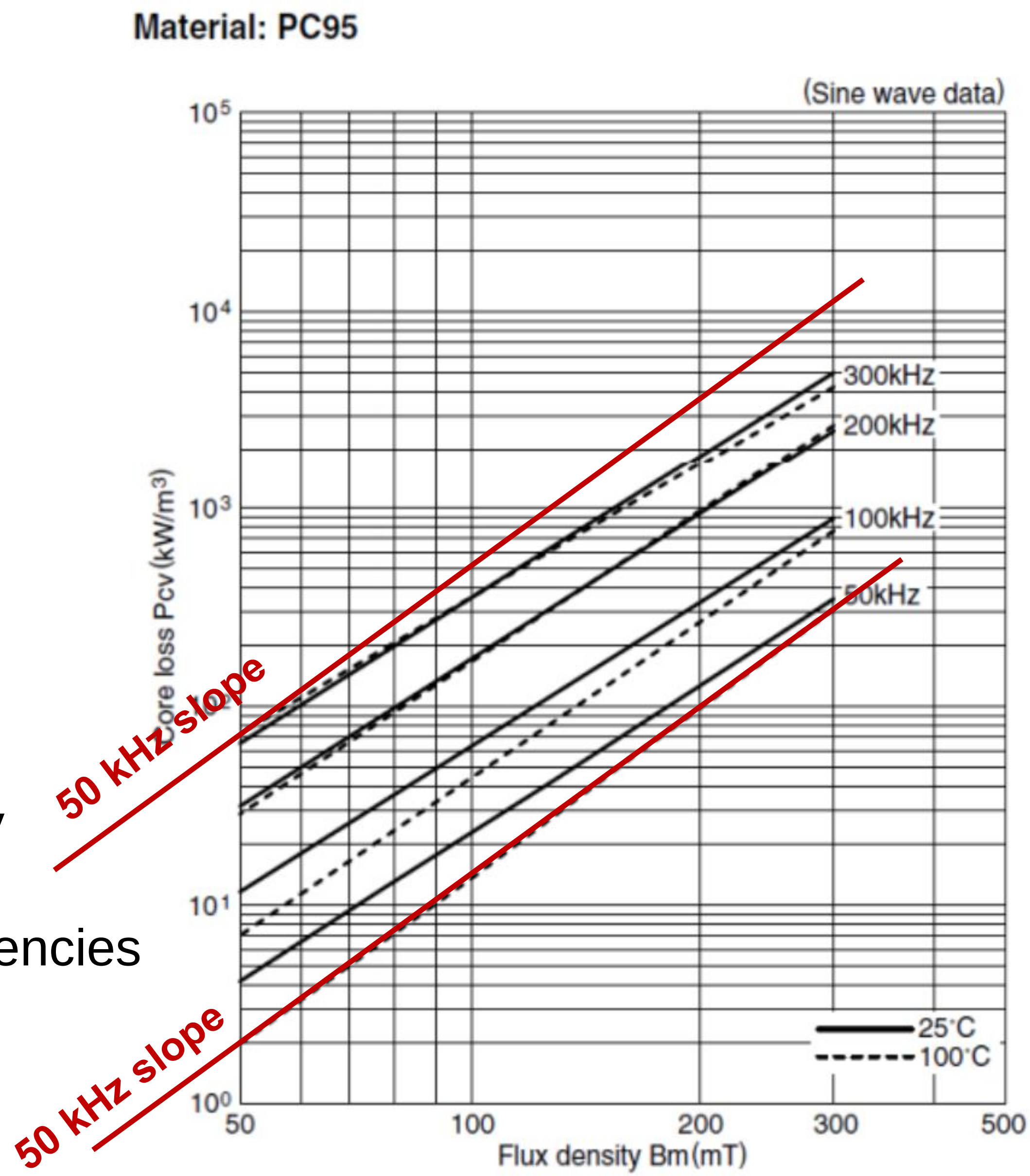
Steinmetz Equation Limitations

$$P_c = kf^{x} \Delta B^{y}$$

Equation assumes curves are

1) Equally spaced with frequency

2) Equal slopes at different frequencies



Modifying the Steinmetz Equation

$$P_c = kf^{x} \Delta B^{y}$$

Discrete step changes in coefficients from Mag Inc.

	a	c	d
<100 kHz	0.074	1.43	2.85
100-500 kHz	0.036	1.64	2.62
>500 kHz	0.014	1.84	2.28

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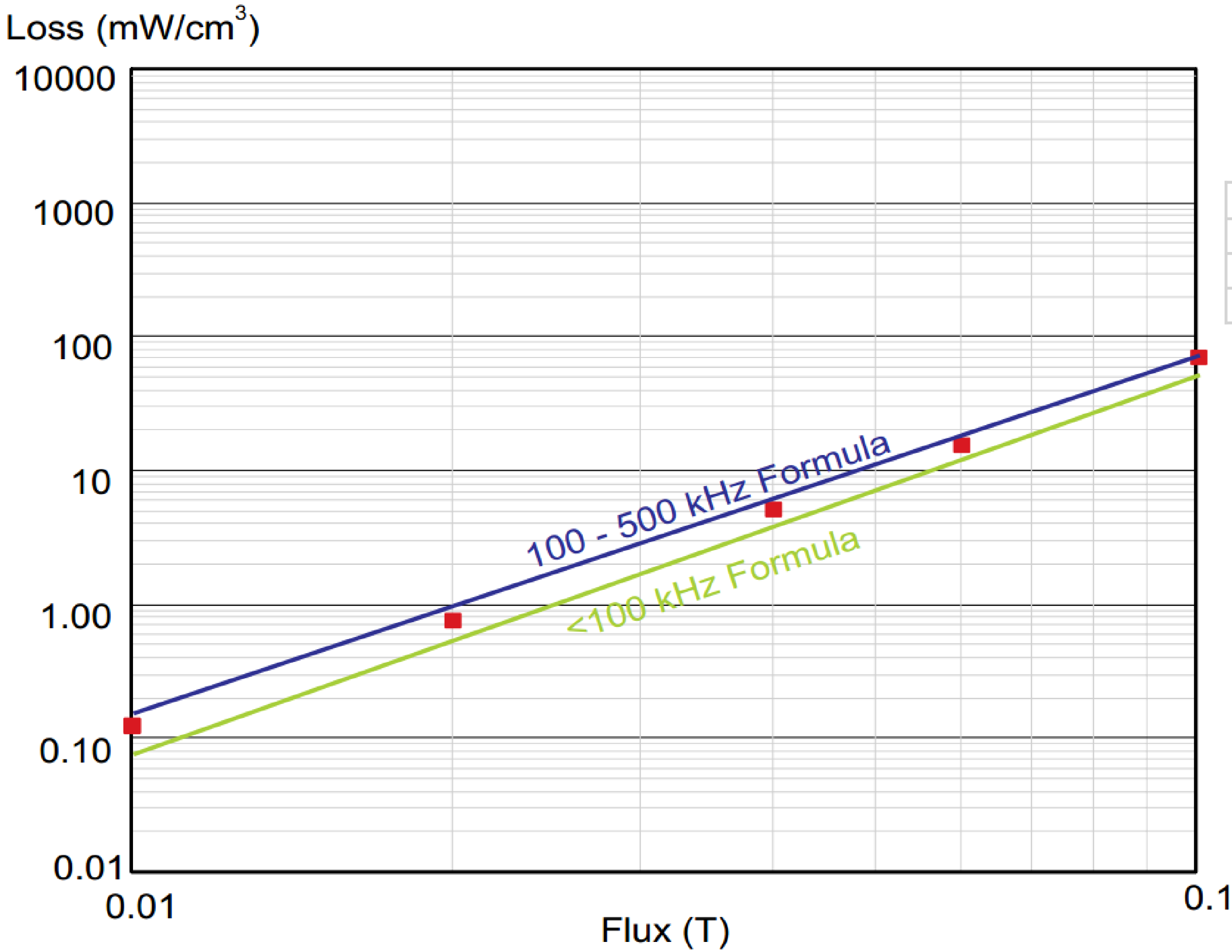
Steinmetz Equation Changing Coefficients



$$P_c = kf^x \Delta B^y$$

	k	x	y
<100 kHz	0.074	1.43	2.85
100-500 kHz	0.036	1.64	2.62
>500 kHz	0.014	1.84	2.28

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Ridley-Nace Variable Steinmetz Equation

Continuously-variable coefficients with Ridley-Nace formula

$$P_c = (a \ln f + b) f^{c} B^{(df + e)}$$

Five coefficients needed to describe materials

Example for Magnetics R material:

$$P_c = (-3.626 \ln f + 28.32) f^{1.729} \Delta B^{(-0.00076 f + 2.8332)}$$

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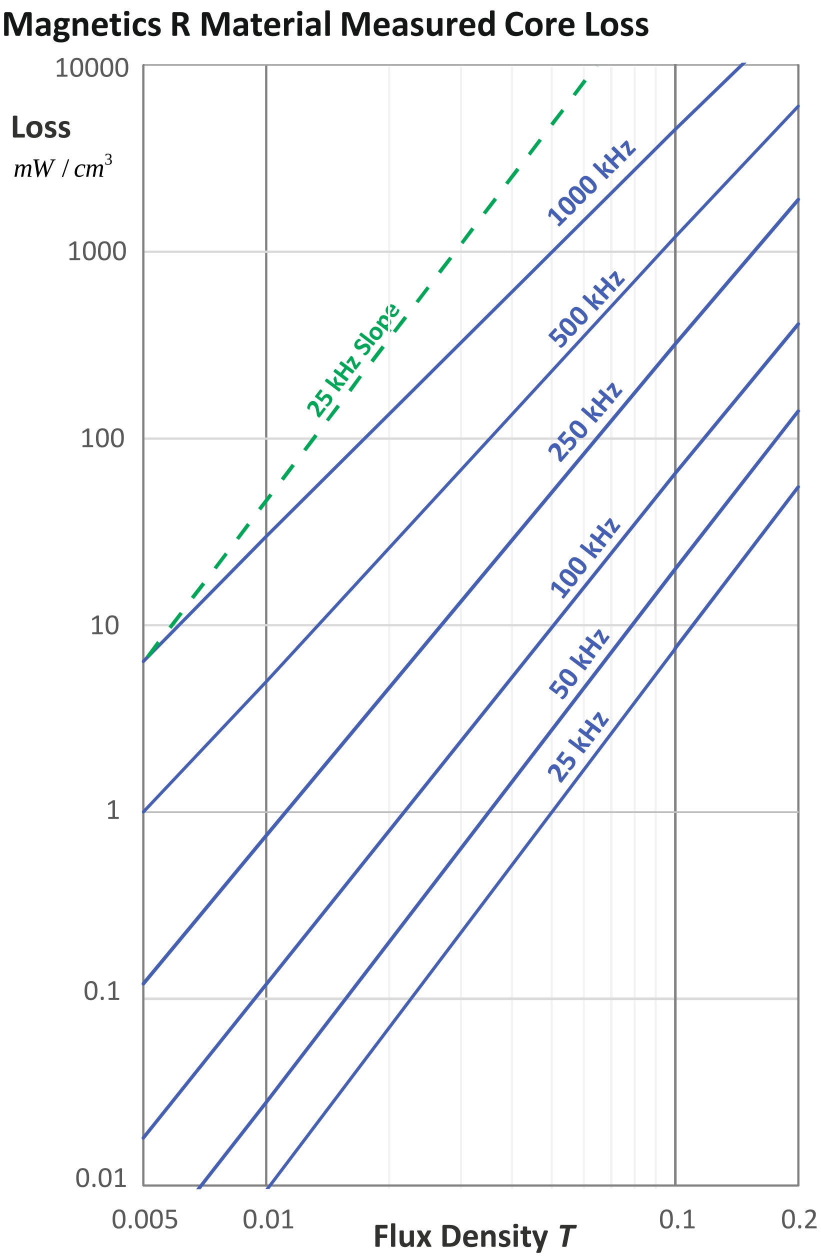
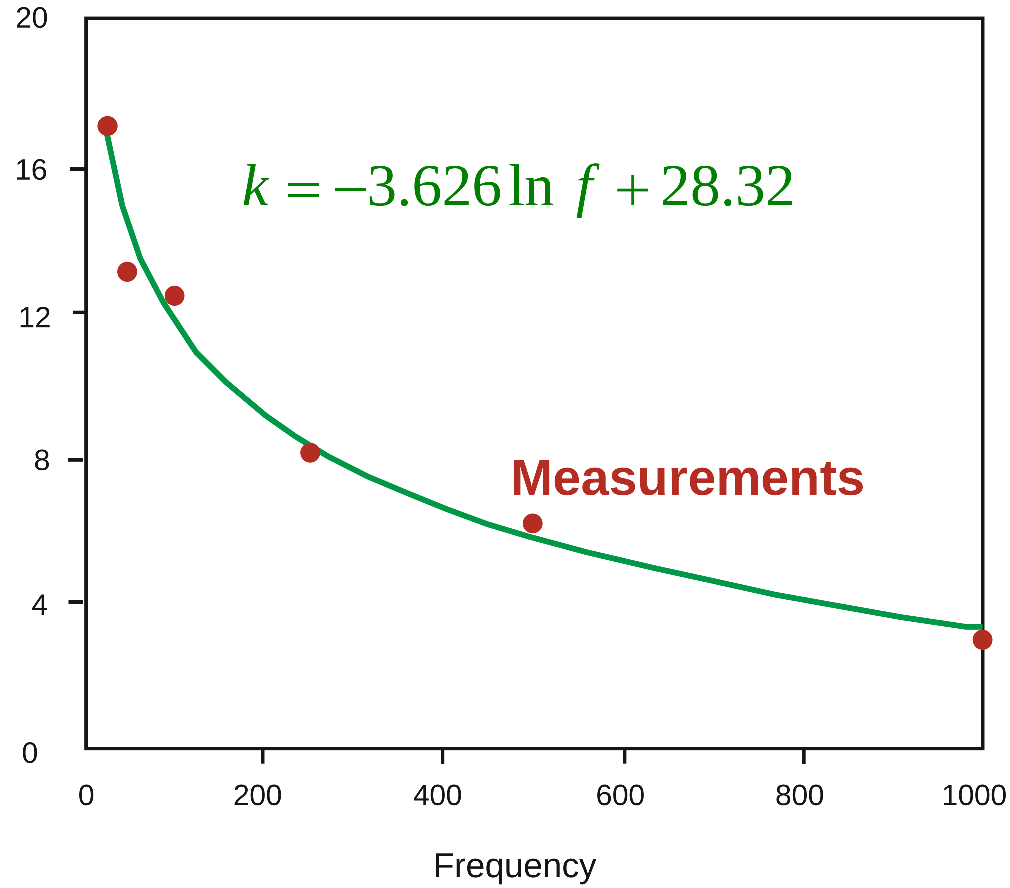
Continuously Variable *k* Term



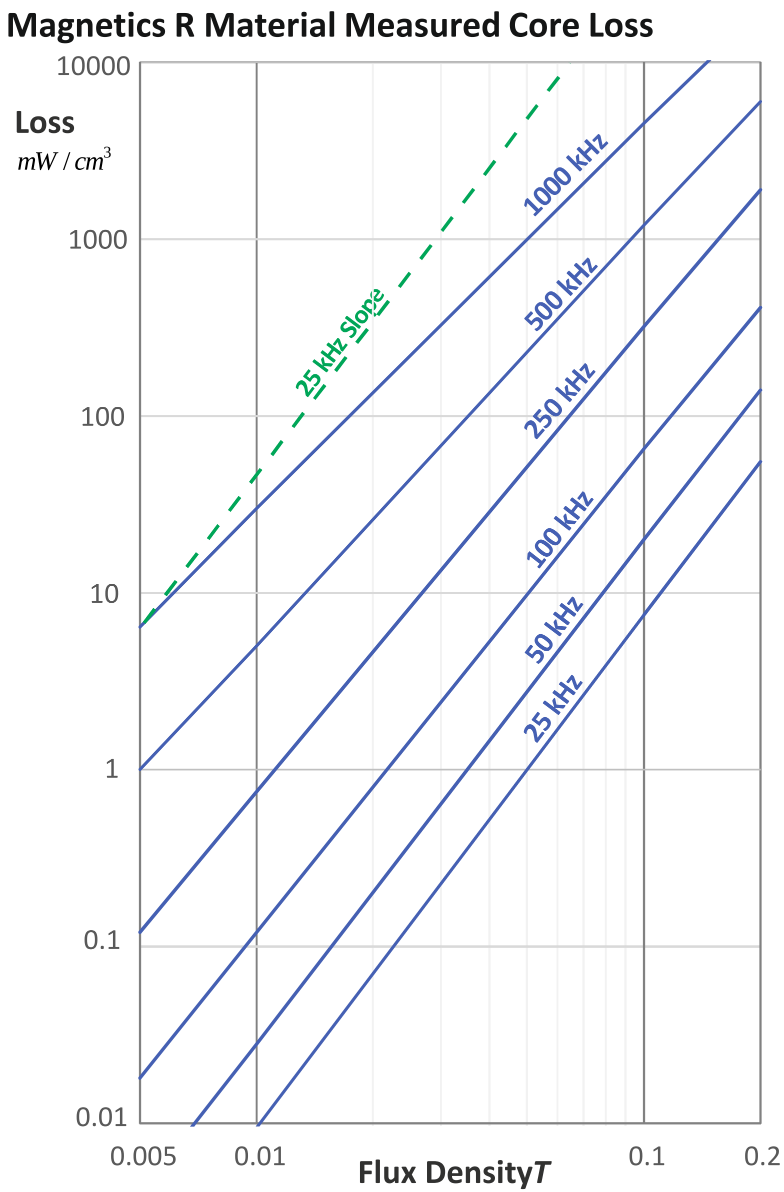


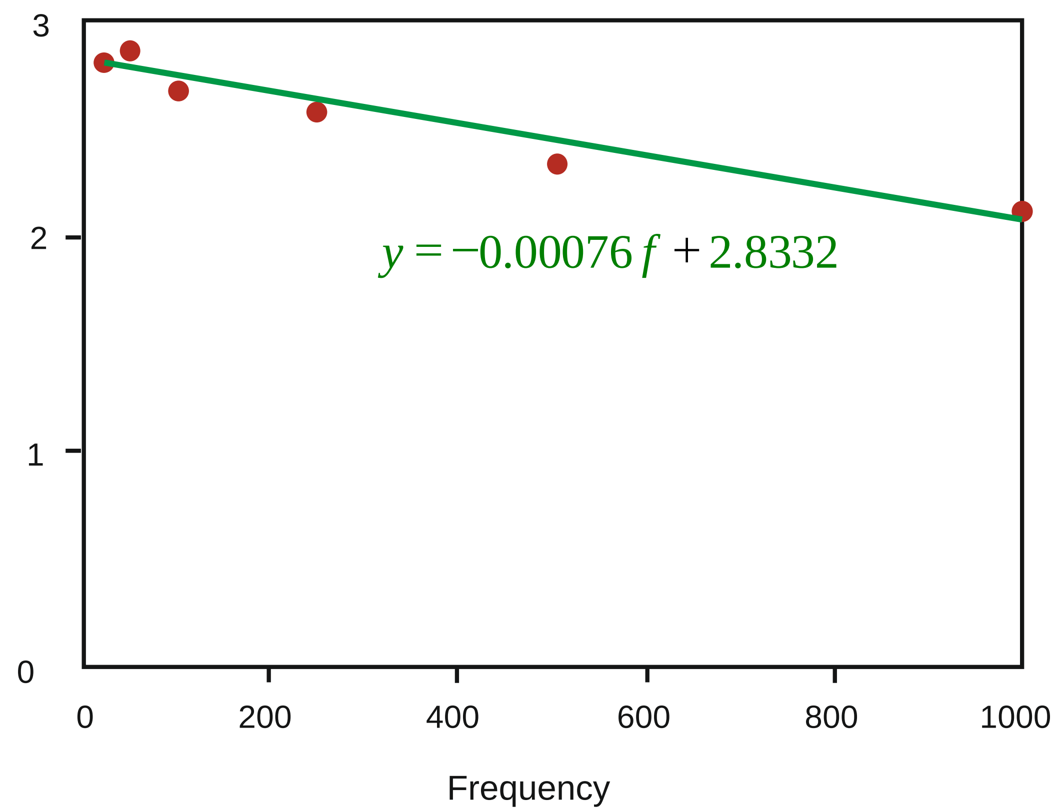
$$k = -3.626 \ln f + 28.32$$

$$P_c = (a \ln f + b) f^c B^{(df + e)}$$

$$a = -3.626 \quad b = 28.32$$

Continuously Variable y Term





$$P_c = (a \ln f + b) f^c B^{(df+e)}$$

$$d = -0.00076 \qquad e = 2.8332$$

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Oliver Variable Steinmetz Equation
(Powdered Iron Core Material)

$$P_{core} = \frac{f}{\frac{a}{B^3} + \frac{b}{B^{2.3}} + \frac{c}{B^{1.65}}} + df^2B^2$$

Continuously-variable coefficients with Oliver formula

Four coefficients needed to describe materials, plus 2.3 and 1.65 exponents subject to change with different materials

www.micrometals.com/appnotes/appnotedownloads/coreloss update.pdf

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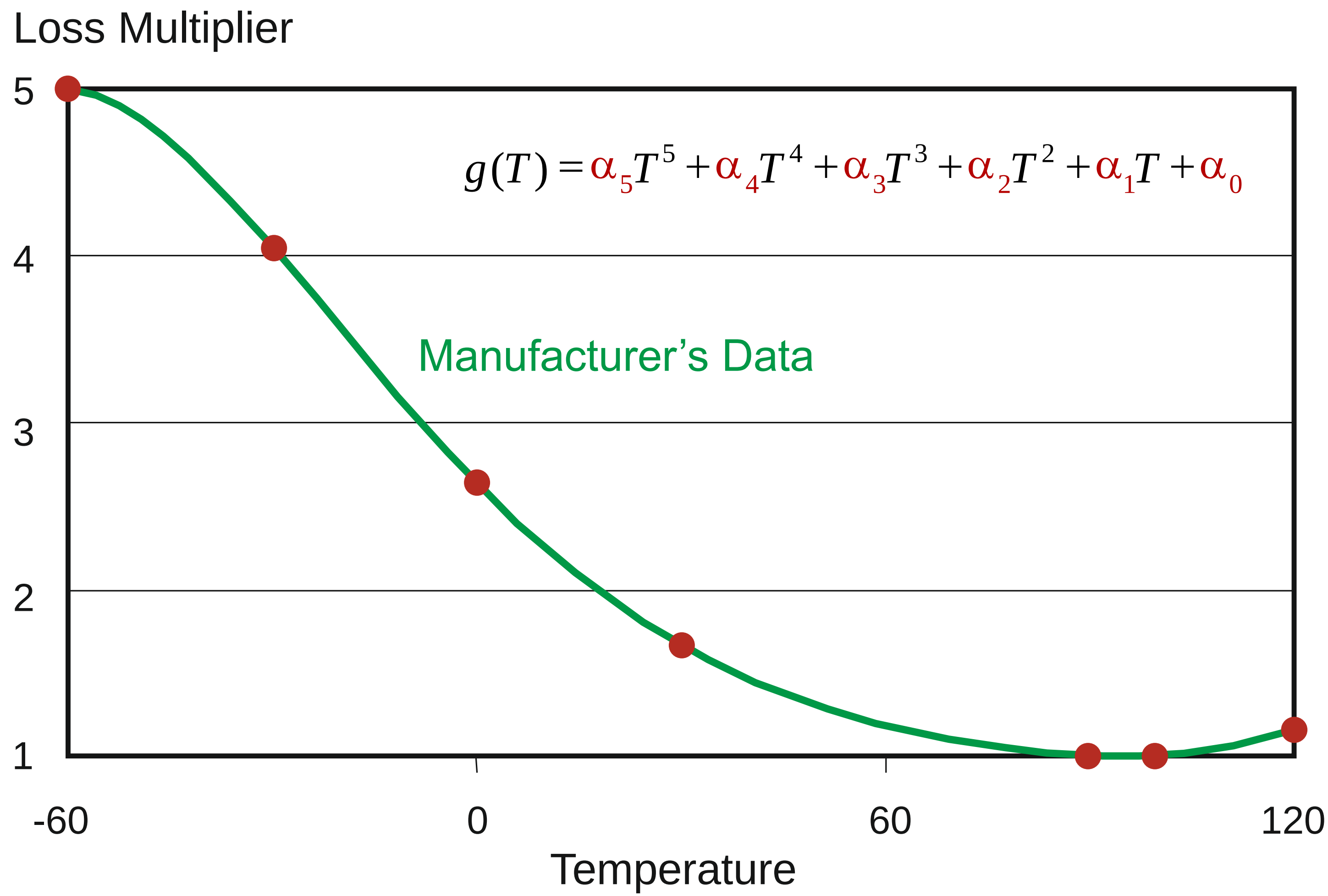
Core Loss Temperature Variation



Six coefficients needed to describe temperature variation

Every material has a different curve

Does the curve also change with frequency and flux level?

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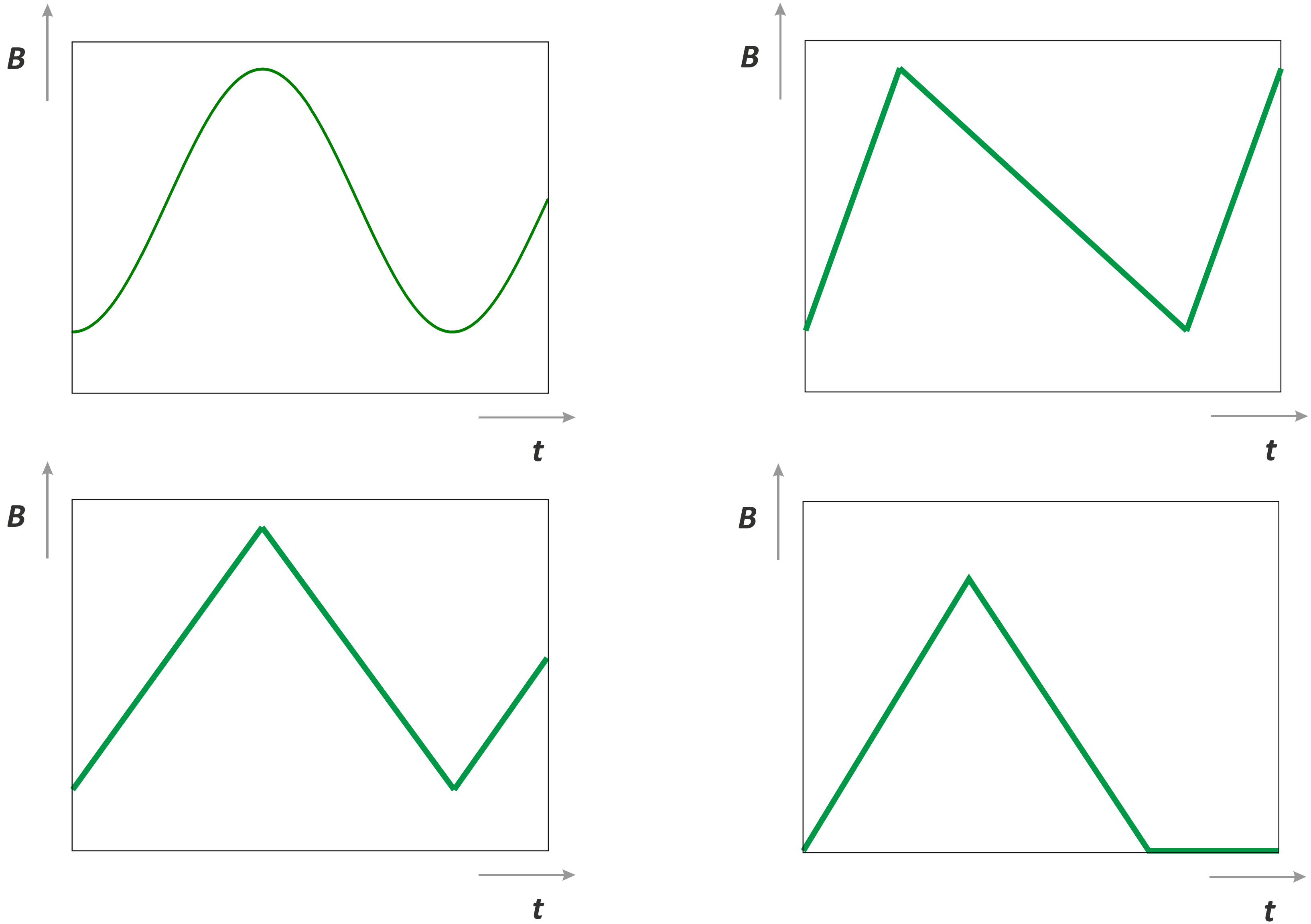
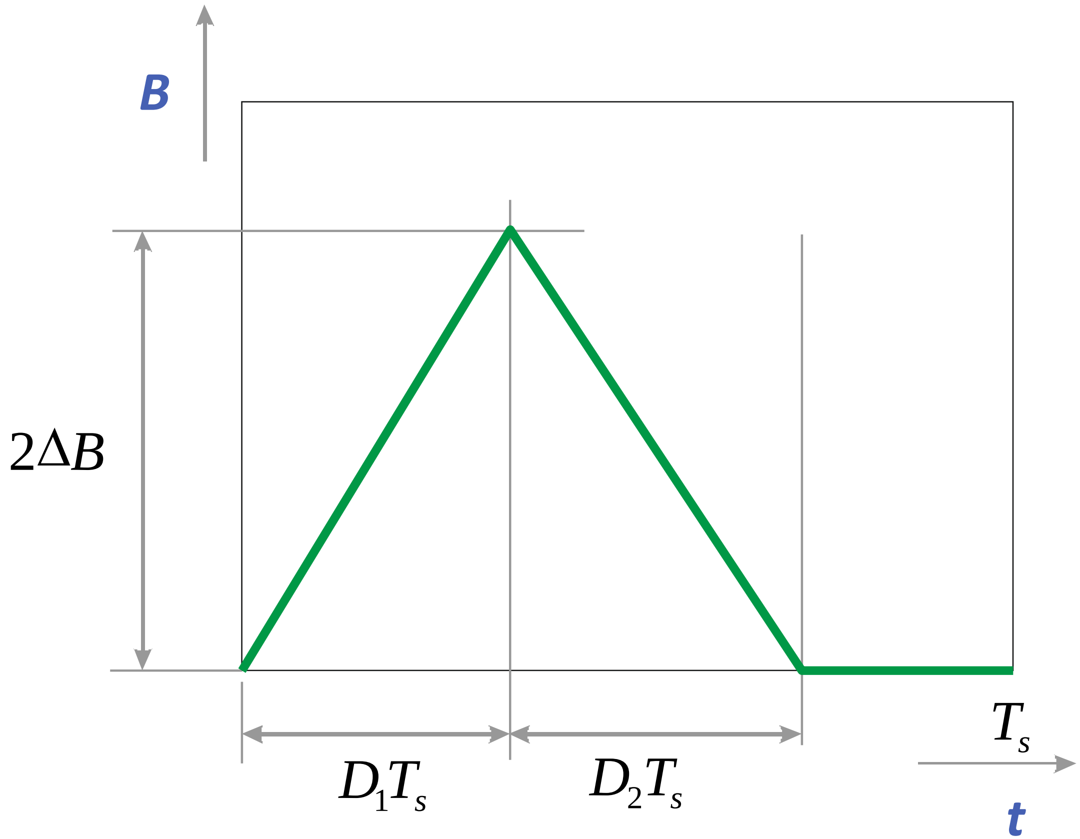
Different Core Excitations



Need to modify equations to suit each of these waveforms

General Triangular Flux Waveform



$$P_c(D) = D_1 P_c\Big|_{\frac{f}{2D_1}} + D_2 P_c\Big|_{\frac{f}{2D_2}}$$

$$P_c = (a \ln f + b) f^c B^{(df+e)}$$

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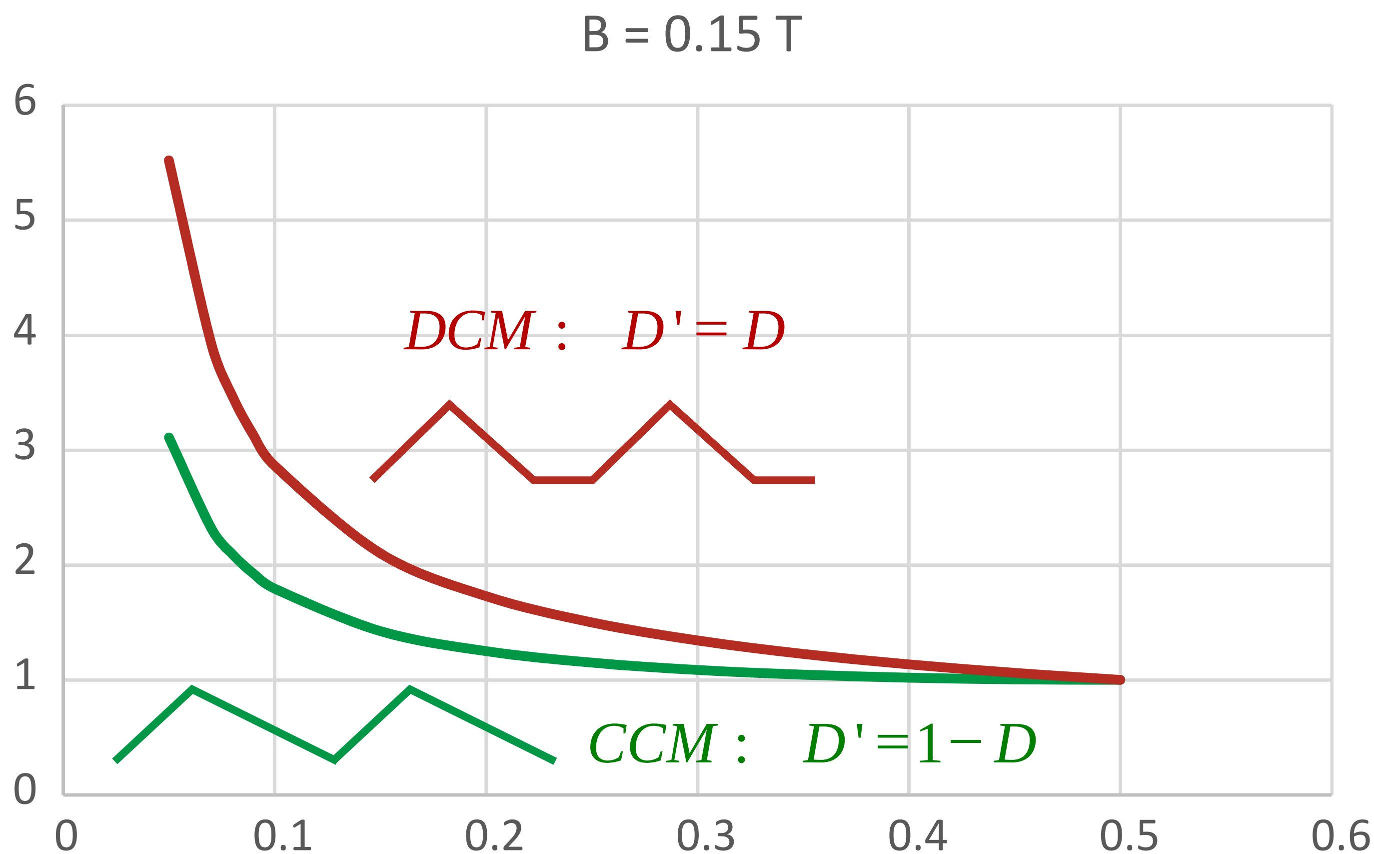
Duty Cycle Core Loss Multiplier



$$P_c(D) = D_1 P_c\Big|_{\frac{f}{2D_1}} + D_2 P_c\Big|_{\frac{f}{2D_2}}$$

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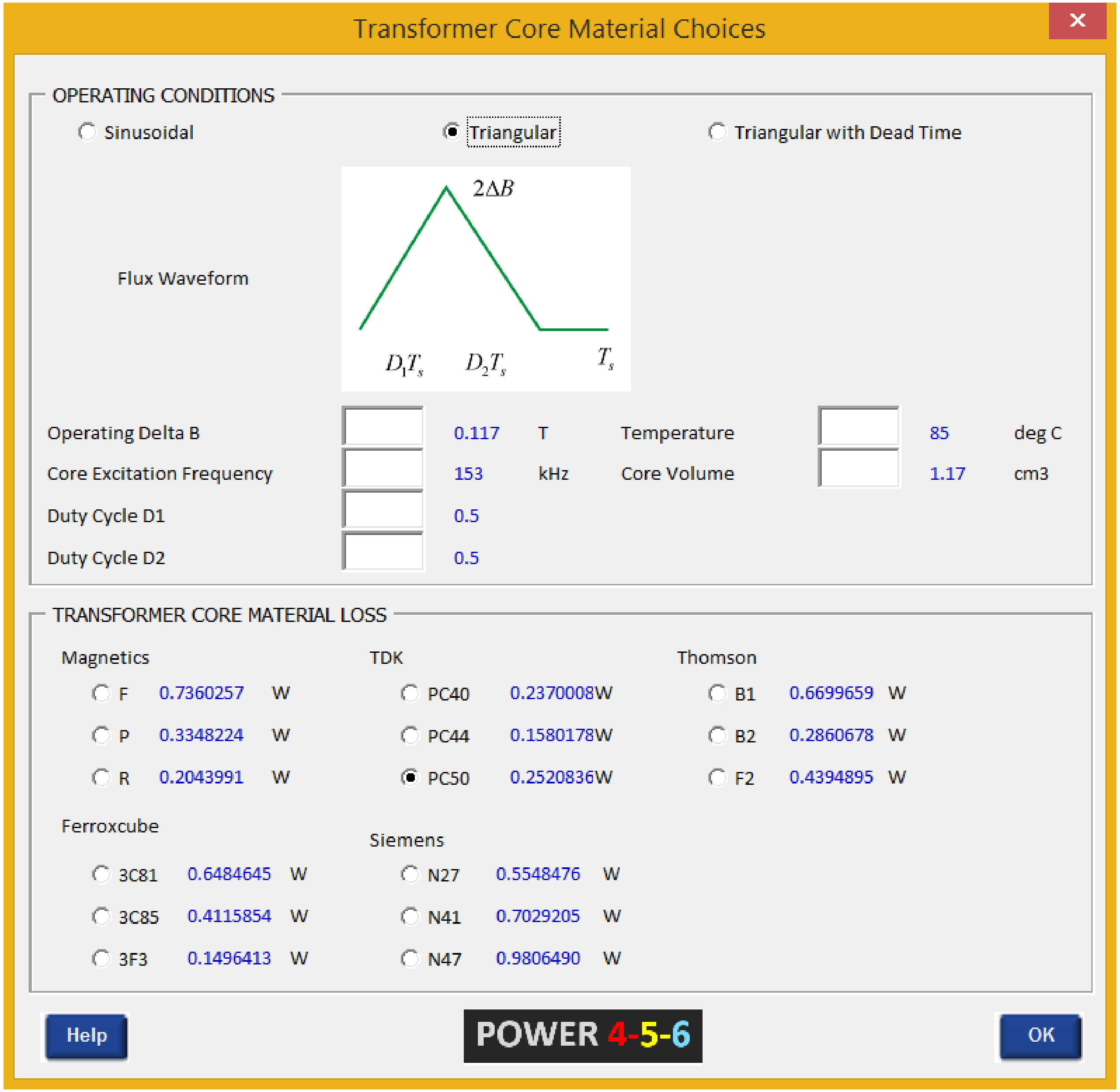
Putting it All Together



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What We Need from the Manufacturers

1) **Raw core loss sinewave test data over wide range of frequency, B, temperature**

2) **Who is going to fund the modeling into a standard format database?**

Magnetics Forecast

High-ripple current inductor designs will dominate the practical high-performance market

Practical “high performance” means converters up to 5 MHz

Core material improvements will be just incremental (unless some breakthrough material emerges)

Insufficient funding is going into fundamental magnetic material research to give a good chance of any breakthroughs.

Data Standardization is badly needed from the core manufacturers to ease confusion

Core loss raw data is needed, not just curves.

Creative core geometries need to be applied to POL inductors and other high-ripple parts

Magnetic core will not go away (however much it is wished for)

Isolation transformers will creep back into PoL applications to boost efficiency – **More magnetics!**

Multi-converter processing will continue to proliferate.

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Some References

Cliff Jamerson: Targeting Switcher Magnetics Core Loss Calculations, Power Electronics Technology, Jan 2001.

Ed Herbert: http://www.psma.com/technical-forums/magnetics/core-loss-studies

Christopher Oliver: www.micrometals.com/appnotes/appnotedownloads/coreloss update.pdf

Power Supply Design Center Articles http://www.ridleyengineering.com/design-center.html

[89] Core Loss Modeling
[90] Core Loss Modeling with Non-Sinusoidal Waveforms - Part II
[91] Core Loss Modelling - Sinewave Versus Triangle Wave - Part III

Ray Ridley and Art Nace
[A03] Modeling Ferrite Core Losses

Christopher Oliver
[A06] Core Loss Modeling & Measurement

Power Supply Design Software http://www.ridleyengineering.com/software.html

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