RIDLEY WEBINAR SERIES: 9

CORE LOSS MODELING

Webinar November 12, 2020 10 am PDT

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Core Loss Modeling – the Players

Charles Proteus Steinmetz – great GE engineer working from the late 1890s.

Dr. Vatché Vorpérian – one of the best minds in our industry taught me about fractal mathematics.

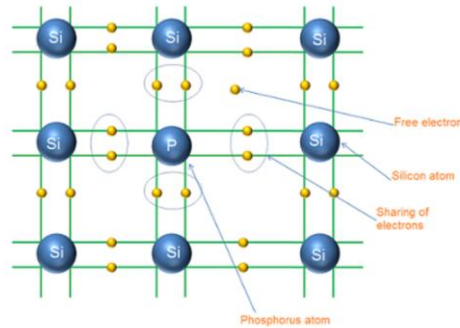
Dr. Qichen Yang – solved complex mathematical problems for me involving 6th order circuit optimization.

Dr. Shilpa Marti – spent 3 weeks reading and transcribing core loss data for us so that you don't have to do that anymore.

Arthur Nace – retired aerospace engineer and programmer who automated LTspice models for us.

John Beecroft – Primary tester and proponent of RidleyWorks for over 20 years.

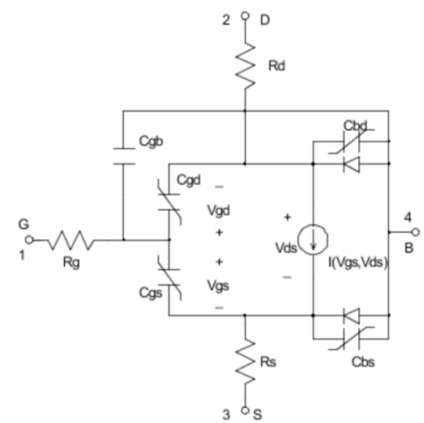
Semiconductor Devices and Models



$$
\begin{aligned}
&\frac{\lambda^2\left(1-y^2\right)}{2}\Biggl\{\Biggl[n\left(y+\frac{\nu-\mu}{2n+\mu+\nu}\right)\left(\frac{\mu-2\beta}{1-y}-\frac{\nu-2\alpha}{1+y}\right)\\
&\quad+n\,(n+\mu+\nu+1)+(2\alpha\beta+\alpha+\beta)\\
&\quad-\alpha^2\frac{1-y}{1+y}-\beta^2\,\frac{1+y}{1-y}+\frac{2}{\lambda^2\left(1-y^2\right)}\\
&\quad\times\left[\frac{V_0}{q}\,(y+\gamma)\left(1-y^2\right)-E\right]\Biggr]\varphi_n\\
&\;-2\frac{(n+\mu)\,(n+\nu)}{2n+\mu+\nu}\left(\frac{\mu-2\beta}{1-x}-\frac{\nu-2\alpha}{1+x}\right)\frac{A_n}{A_{n-1}}\varphi_{n-1}\Biggr\}=0,
\end{aligned}
\qquad (35)
$$

These are impossibly complex structures to build and understand.

Yet they usually come with a spice model that's pretty useful.



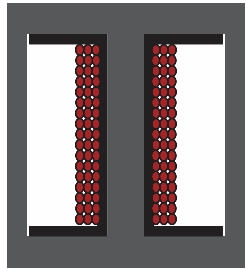
Magnetics Devices and Models

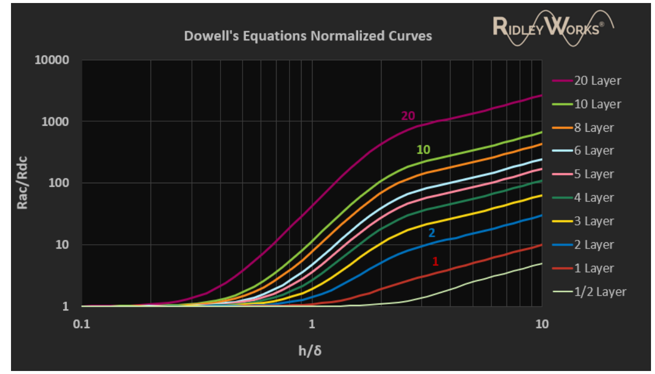
Not so hard to build, although maybe hard to understand.

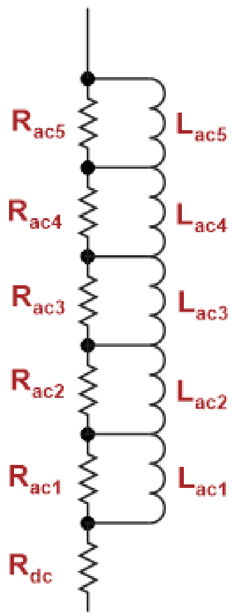
Doesn't compare to Schroedinger's equations…..

Where is the spice model ?

Magnetics Winding Loss Models

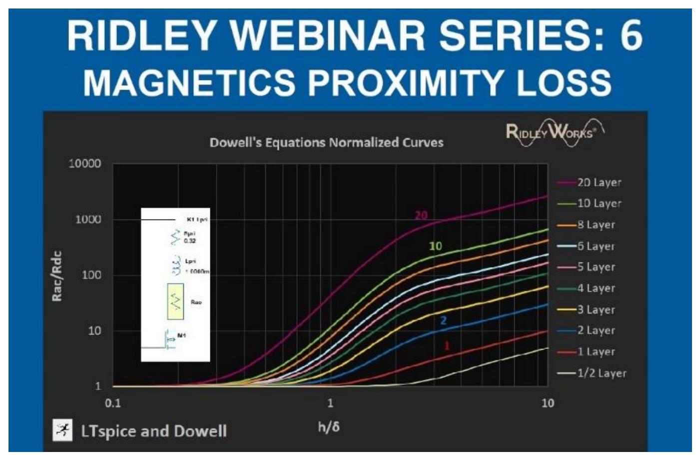






New Rac Model

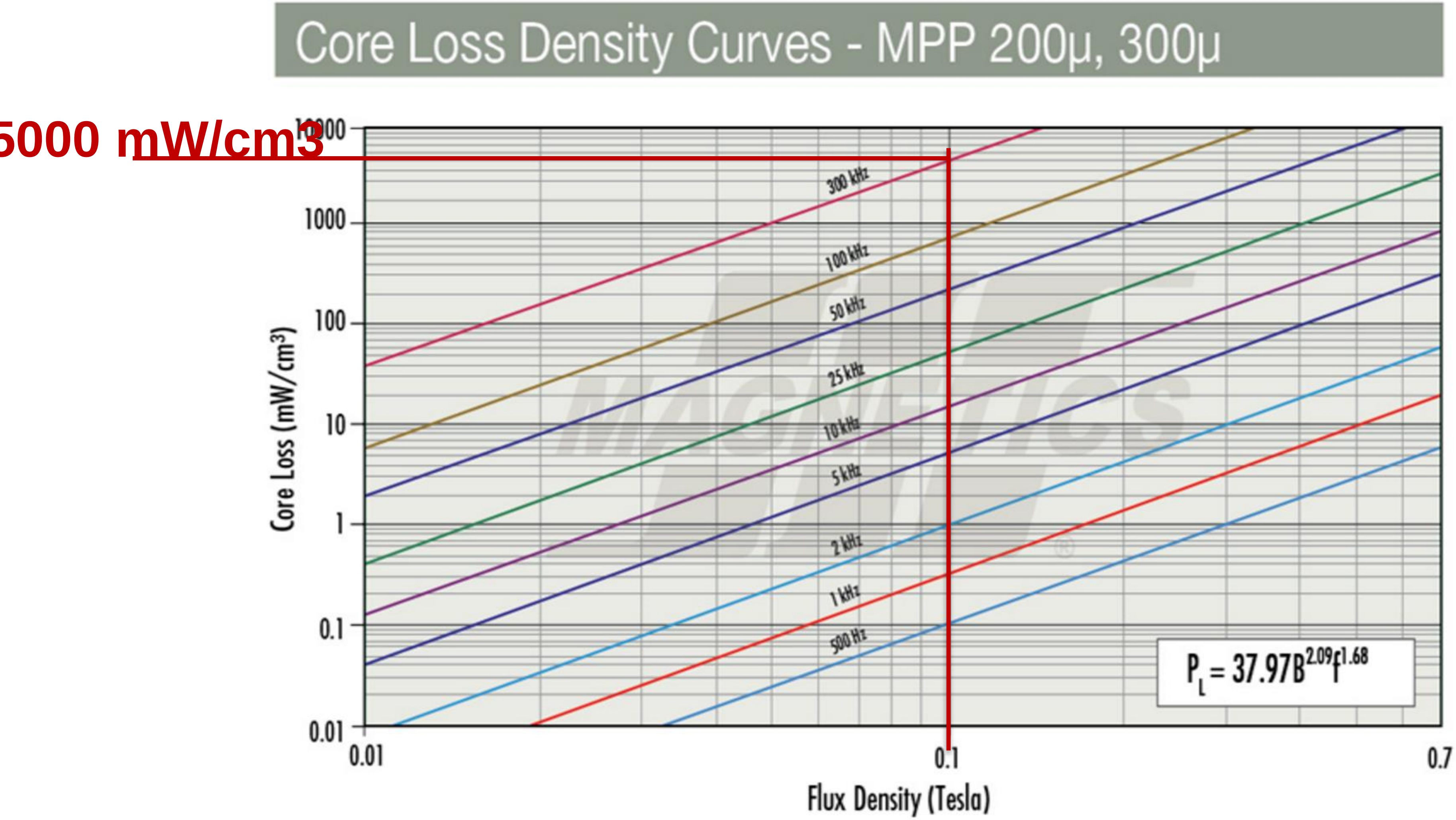
Complex proximity loss models covered in this webinar



https://ridleyengineering.com/videos-e/304-magnetics-proximity-loss-webinar.html

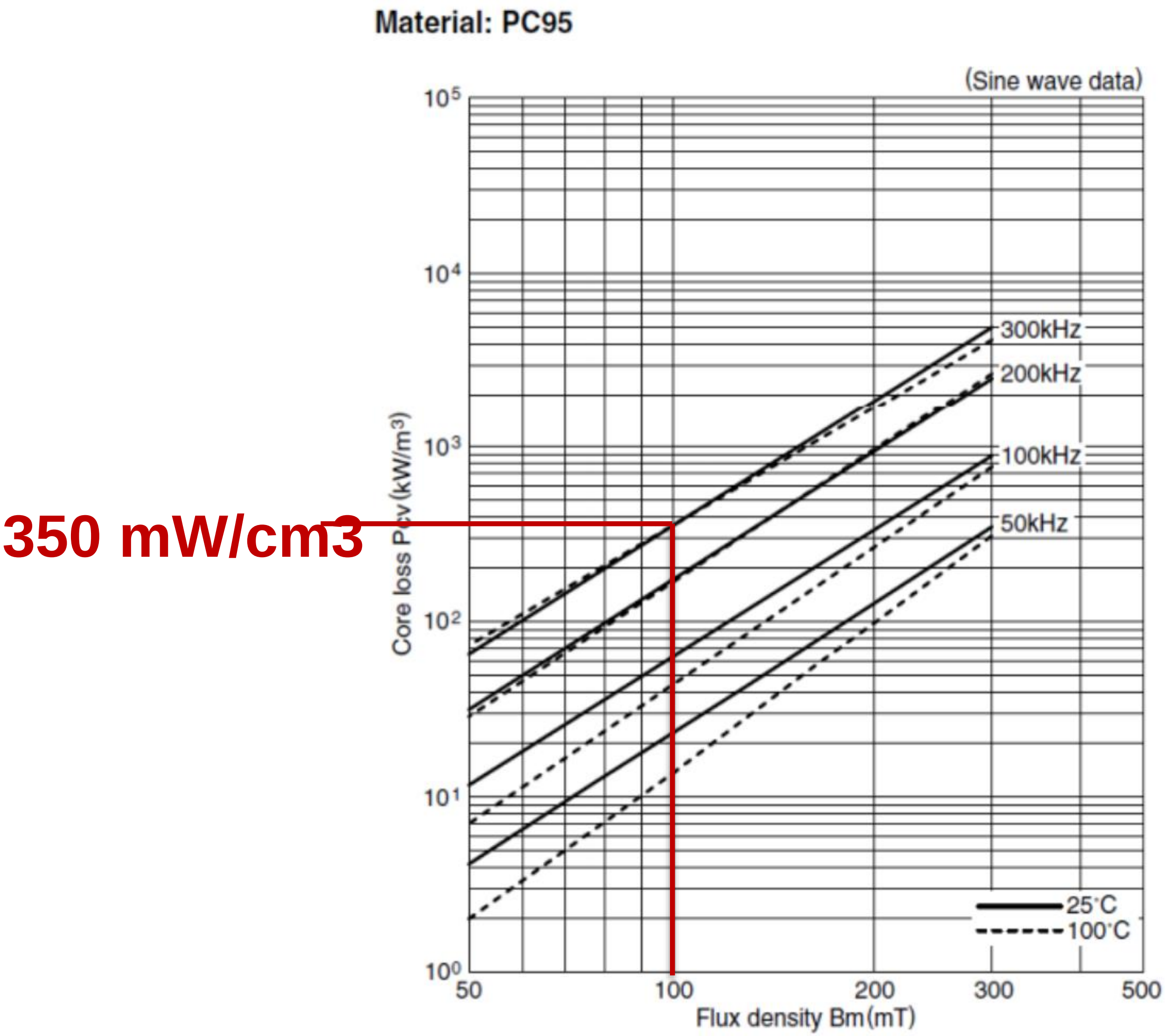
Ridley Engineering

Core Loss MPP 200u



300 kHz 0.1 T 5 W/cm3

Core Loss PC95



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

Steinmetz Equation

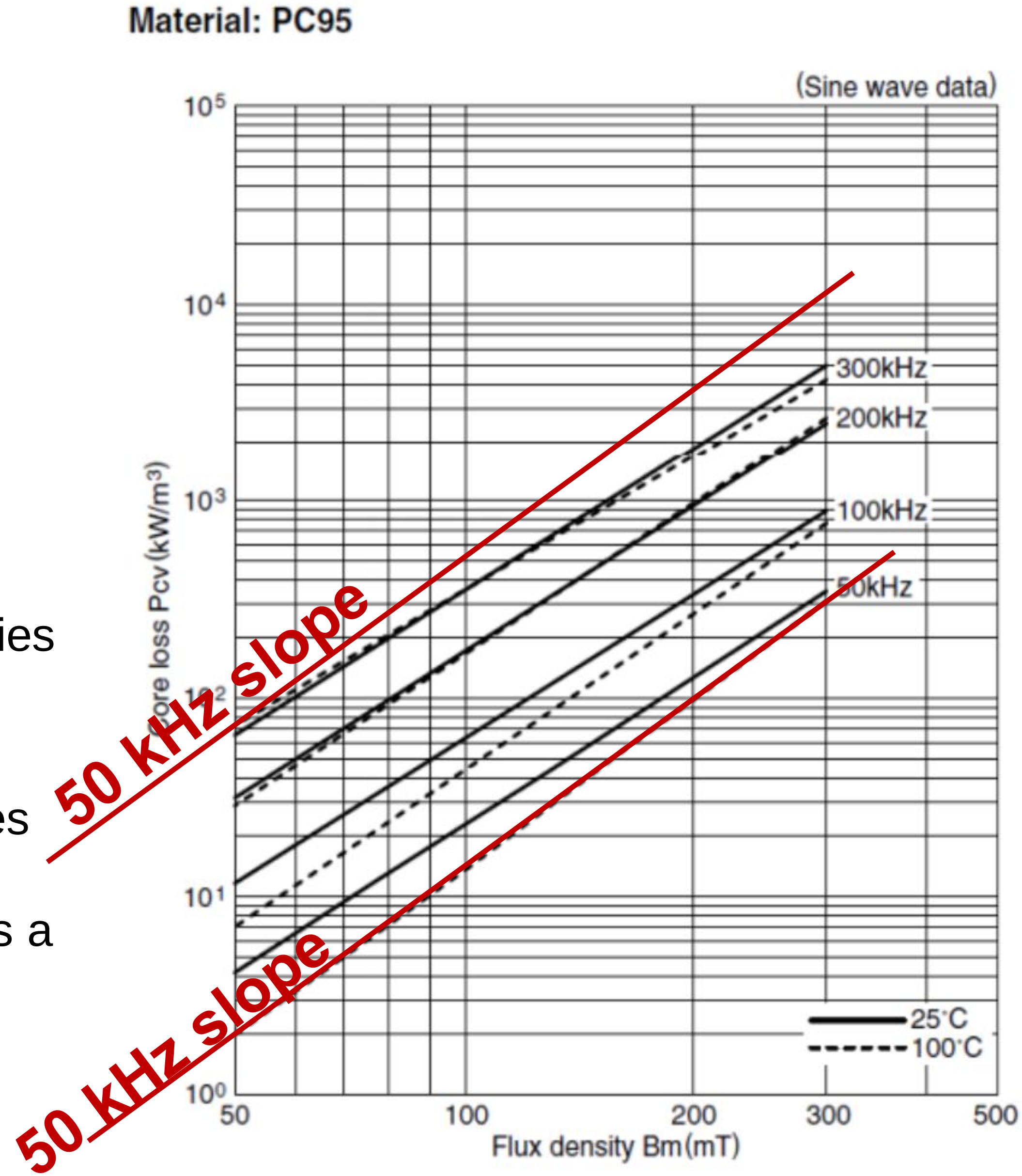
$$P_c = kf^x \Delta B^y$$

Equation assumes curves are

1) Equally spaced with frequency

2) Equal slopes at different frequencies

Steinmetz Equation named for Charles Steinmetz, he introduced a form of this equation in **1892**. Core loss was a problem even at 50/60 Hz



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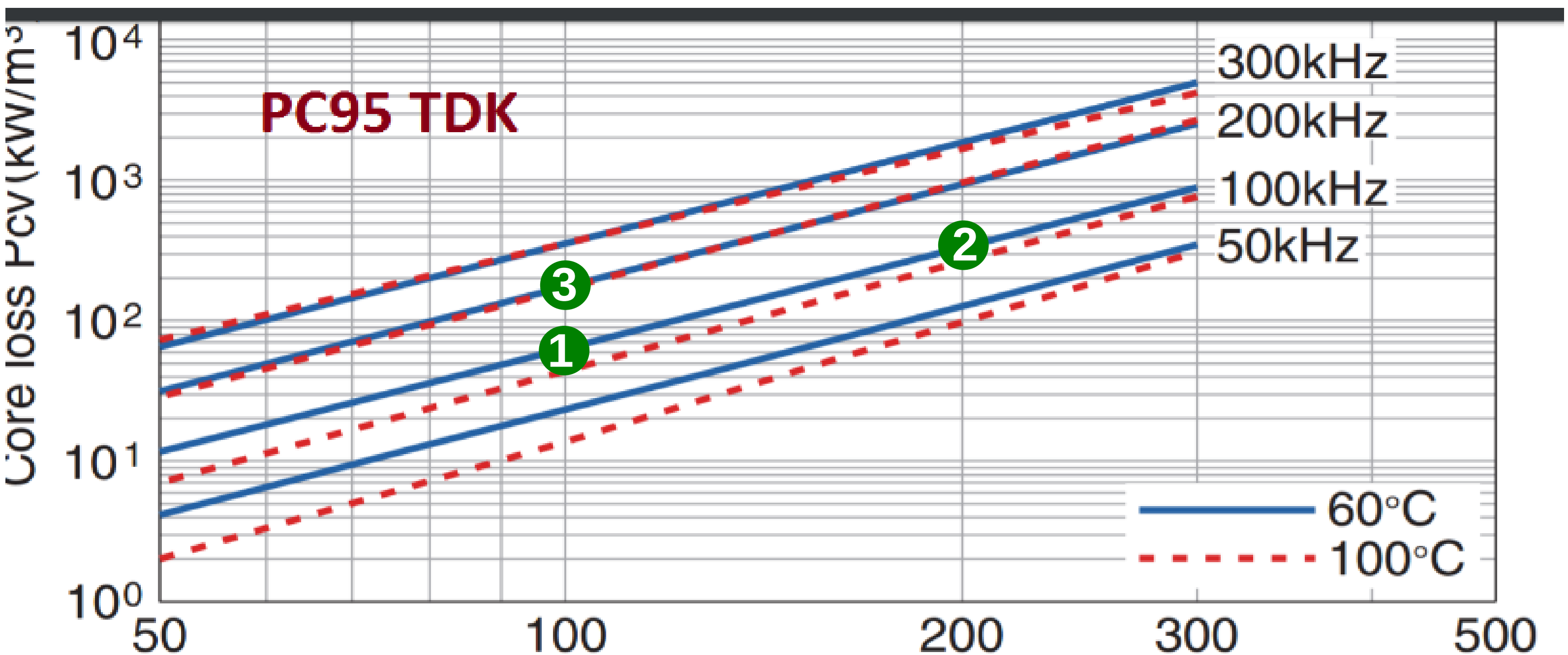
Use Excel to Calculate Coefficients

Vendor	Material	Core Data 0.2 T 100 kHz mW/cm3	Core Data 0.1 T 100 kHz mW/cm3	Core Data 0.1 T 200 kHz mW/cm3	Delta B Exponent	f Exponent	k
TDK	PC95	**350**	**64**	**180**	**2.451211112**	**1.4918531**	**18.77954**



Constant	k = 18.7795
Frequency Exponent	x = 1.4918
Flux Exponent	y =2.45

Ridley Engineering

Early Transformer Core Loss Model

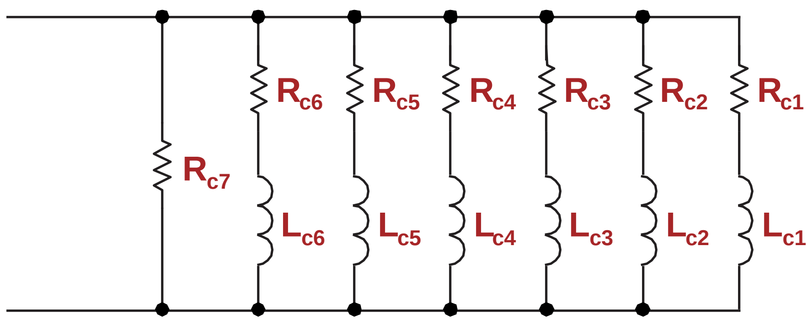
Simple resistor captured some of the loss characteristics

Frequency was fixed to line distribution frequency (change resistor value for different frequency)

Hysteresis losses captured for sinewave excitation – flux exponent assumed to be 2

Parallel Ladder Network - Frequency Dependence

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



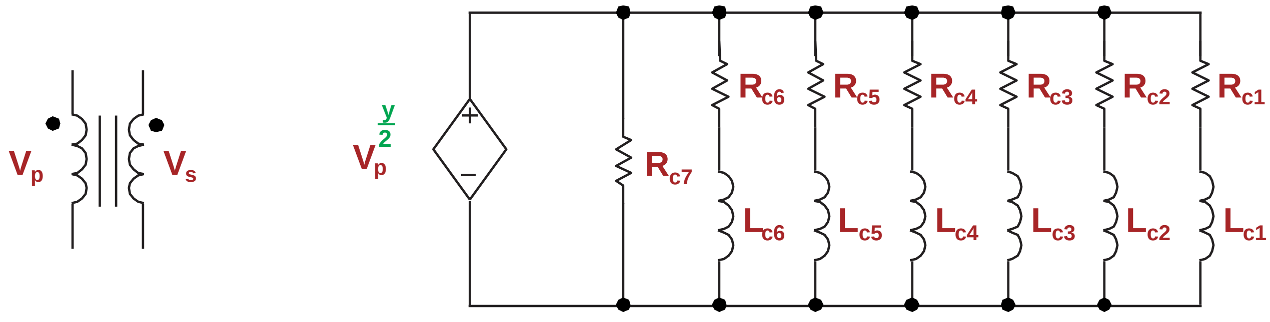
Parallel ladder driven by the inductor or transformer voltage

Frequency dependent dissipation matches frequency exponent

This will give a flux exponent of 2, like the early core loss models

Parallel Ladder Network – Adding y Exponent

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



Parallel ladder driven by the inductor or transformer voltage

Magnetic winding voltage is raised to the y/2 power

Waveform sign must stay the same

Data Entry and Model Generation

TRANSFORMER CORE MATERIAL SELECTION

Ferroxcube		TDK		Magnetics	Any	
○ 3C90	○ 3C91	○ PC40	○ PC47	○ P	○ MPP 200u	○ New 11
○ 3F3	○ New	○ PC90	○ New	● F	○ New 8	○ New 12
○ 3C96	○ New	○ PC44	○ New	○ R	○ New 9	○ New 13
		○ PC95		○ New	○ New 10	○ New 14

EDIT LOSS DATA

Temperature data used: 100 degrees C


Steinmetz

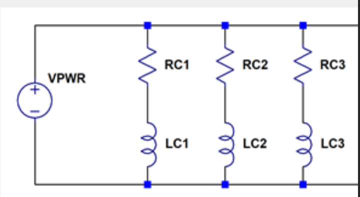
CHARACTERISTICS FOR SELECTED MATERIAL

Permeability 3000 Magnetizing Inductance 0.3311 mH Core Loss 0.476 W

PSIM/LTSPICE CORE LOSS MODEL

Inductors				Resistors			
LC1	6.561 mH	LC4	22.544 mH	RC1	20.13 Ω	RC5	138.66079 kΩ
LC2	9.907 mH	LC5	34.865 mH	RC2	182.42 Ω	RC6	999.41181 kΩ
LC3	14.963 mH	LC6	41.882 mH	RC3	1.65307 kΩ	RC7	10.67 MΩ

Voltage Exponent 2.538



Core Material Loss Data

	New Value	Current Value
Core Manufacturer	Magnetics	Magnetics
Core Material	F	F
60 Degrees C	Loss Data (mW/cm3)	
100 kHz 0.1 T	140	140
100 kHz 0.2 T	760	760
200 kHz 0.1 T	363	363
100 Degrees C		
100 kHz 0.1 T	105	105
100 kHz 0.2 T	610	610
200 kHz 0.1 T	260	260

OK

Steinmetz Coefficients

Core Material F

Core Manufacturer Magnetics

$$P_{core} = K \Delta B^{x} f^{y}$$


Steinmetz

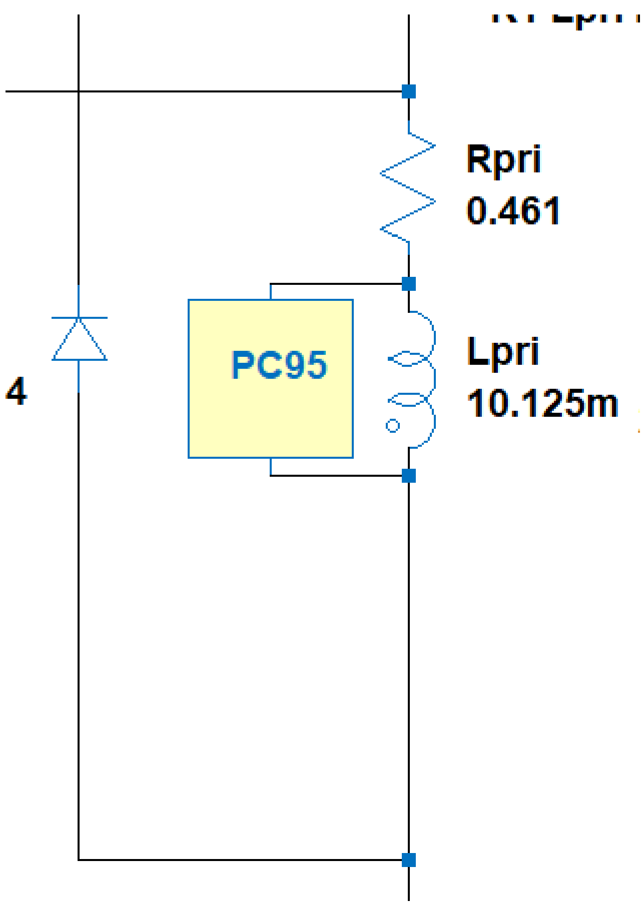
Constant K 87.738

Flux exponent x 2.538

Frequency Exponent y 1.308

OK

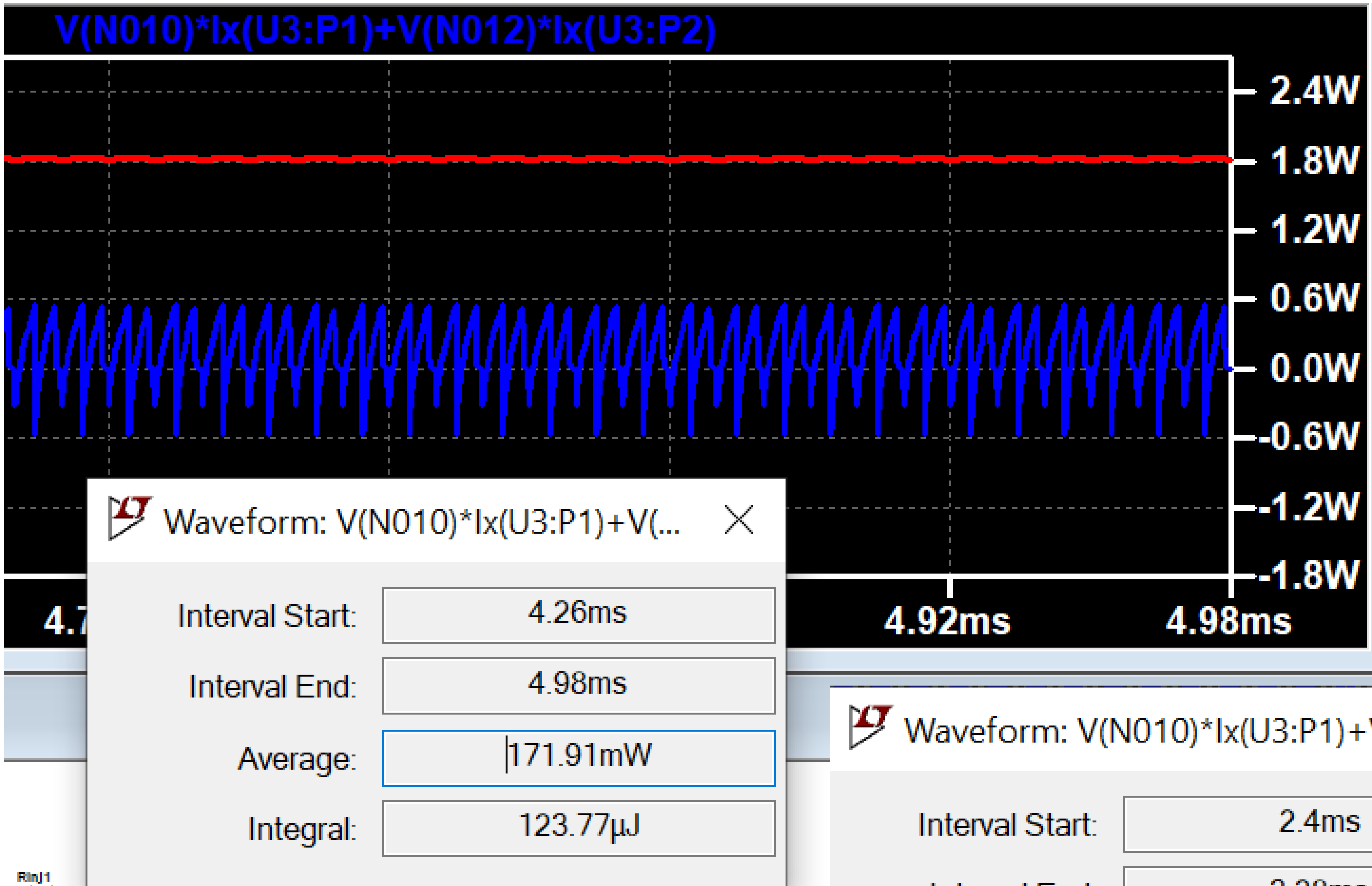
Fully Automated PSIM and LTspice Models



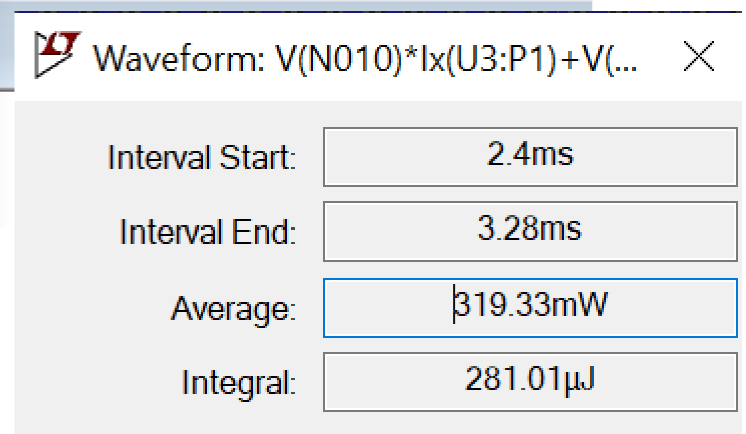
Transformer Core Loss Model

.param CLexp=2.160964
.param Rc1=40705.33
.param Rc2=139656.09
.param Rc3=479205.38
.param Rc4=1640976.57
.param Rc5=5814347.47
.param Rc6=12931115.75
.param Rc7=117724615.34
.param Lc1=7.600474
.param Lc2=4.346083
.param Lc3=2.48547
.param Lc4=1.418528
.param Lc5=0.837693
.param Lc6=0.310505
.param Coupling=0.007820

LTspice Simulation Results



Low Line Input



High Line Input

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NEW! 4-Day Workshop

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Online 4-Day Workshop: DEC 7-10, 2020 - TWO Colleagues

$5,000.00

2021 Dates

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This is our brand-new workshop format where we ship you everything you need to design, test, and learn. Magnetics kits with cores, bobbins and wire, custom computer and software, oscilloscope, frequency response analyzer, power supplies, load banks, test boards and parts kits are included. It's a learning experience like no other where we teach real-time and monitor each of your individual test stations from our base in California.

All attendees receive course notes and their personal copy of RidleyWorks to greatly accelerate your design process.

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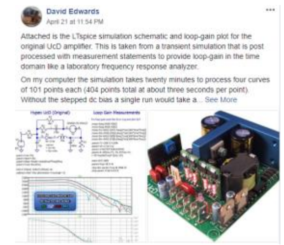
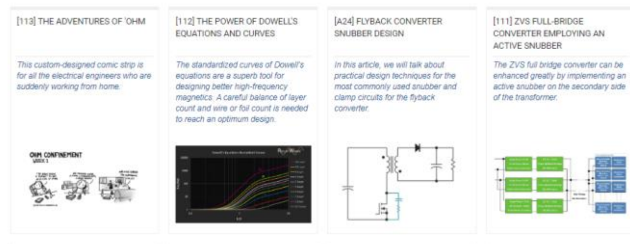
Power Supply Design Center Facebook Group

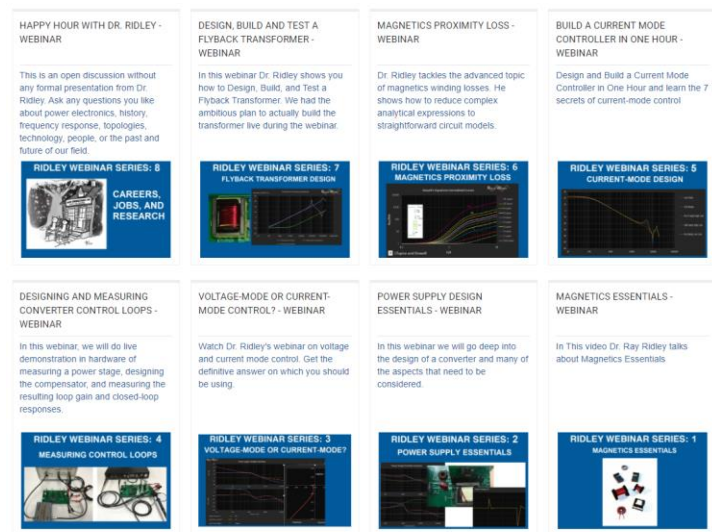




Power Supply Design Center Articles

Frequency Response Analyzers

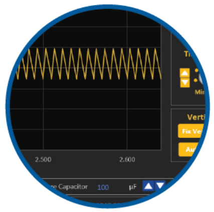
Webinar Series



A New Small-Signal Model for Current-Mode Control

Raymond B. Ridley

Free Book



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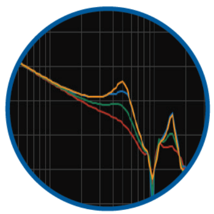
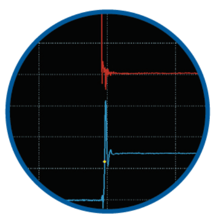


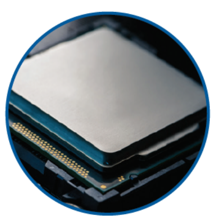
4-Channel Frequency Response Analyzer

Frequency Range 1 Hz - 20 MHZ
Source Control from 1 mV - 4 V P-P
Built-In Injection Isolator
Bandwidth 1 Hz - 1 kHz
Automated Setup from RidleyWorks®
Drect Data Flow into RidleyWorks®



4-Channel 200 MHz Oscilloscope

Picoscope® 5444D 4-Channel Oscilloscope
200 MHz Bandwidth
1 GS/s at 8-bit res; 62.5 MS/s at 16-bit res
Signal Generator up to 20 MHZ
Computer Controlled



Embedded Computer

Intel® Computer with 32 GB RAM, 256 GB SSD
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Integrated Dual Band Wireless, Bluetooth 4.2
Dual HDMI and USB Ports, Ethernet