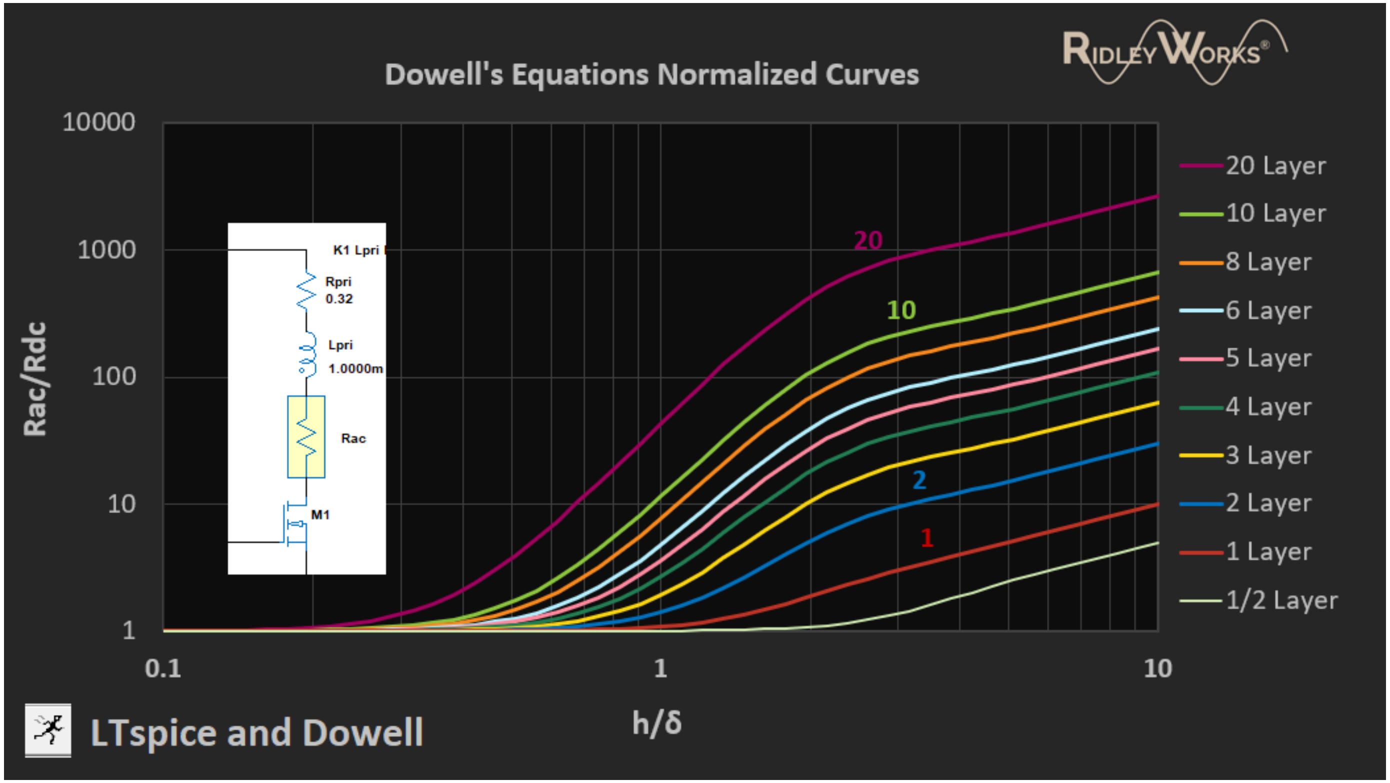
Magnetics Proximity Loss Models



Webinar Friday August 21, 2020 10:00 am PCT

Dr. Ray Ridley **Ridley Engineering**

Download magneticmodels.pdf

Ridley Engineering

Acknowledgements - References

P. L. Dowell, "Effects of eddy currents in transformer windings",

Proc. of the IEE, vol. 113, no. 8, pp. 1387-1394, Aug. 1966.

IEEE Transactions on Power Delivery, Vol. 8, No. 1, January 1993.

TIME DOMAIN MODELING OF EDDY CURRENT EFFECTS
FOR TRANSFORMER TRANSIENTS

Francisco de Leon*   Adam Semlyen

Nicola Rosano – 7th order RL network

Dr. Vatche Vorperian – Fractal Networks

Art Nace – Programming automation for LTspice data transfer

John Beecroft – technical discussions, testing and encouragement

Dr. Glenn Skutt – Dowell’s equation (patience in explaining it to me.)

Dr. Qichen Yang – algorithms for 5th order network solutions

Ridley Engineering

Dowell's Equations and Beyond

$$P_d = b_w \sum_{i=1}^{n} l_i \frac{1}{h_i \eta_i \sigma} H_i^2 \left[(1+\alpha_i^2) G_1(\Delta_i) - 4\alpha_i G_2(\Delta_i) \right]$$

$$G_1(\Delta_i) = \Delta \frac{\sinh 2\Delta + \sin 2\Delta}{\cosh 2\Delta - \cos 2\Delta}$$

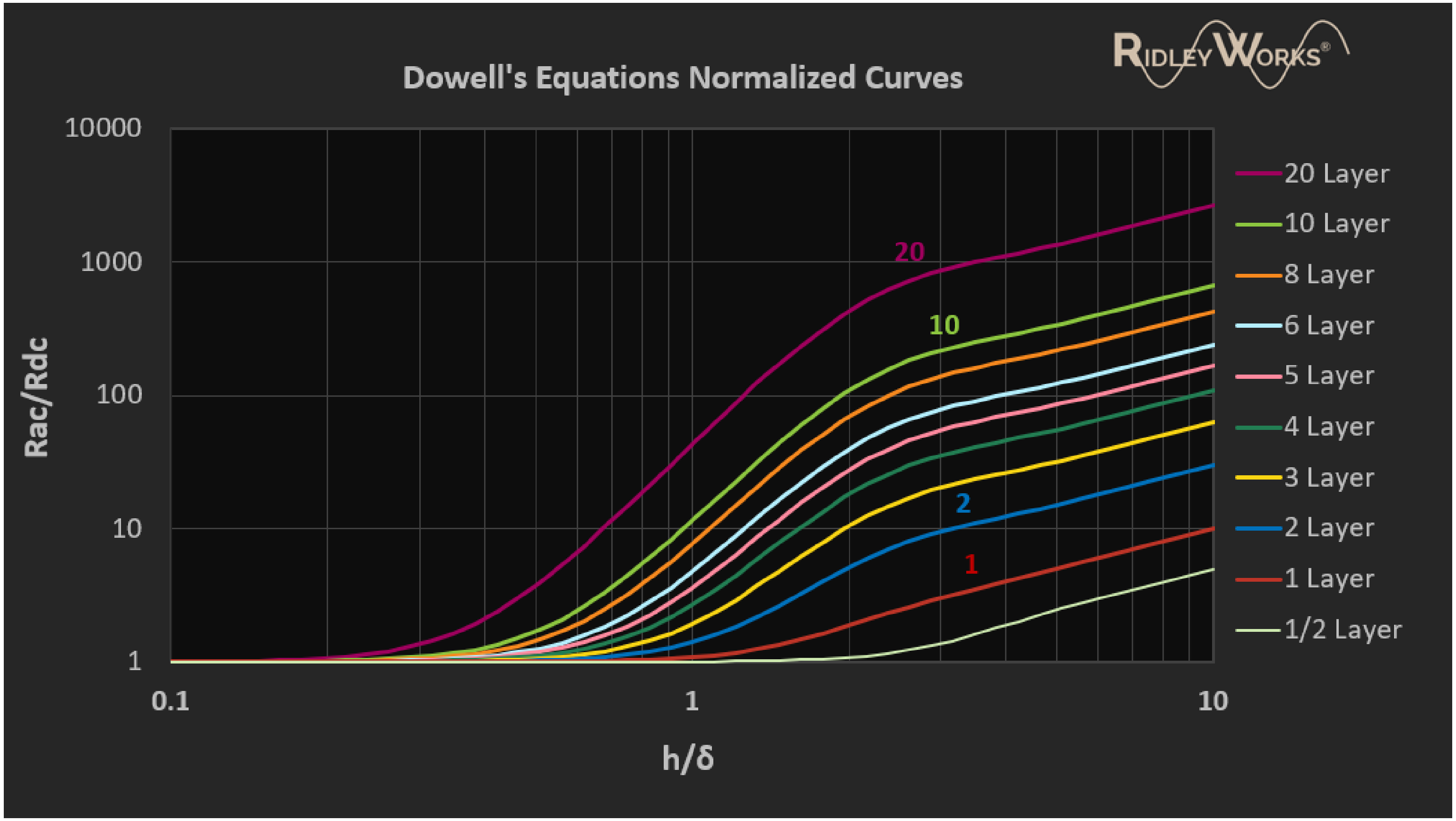
$$G_2(\Delta_i) = \Delta \frac{\sinh \Delta \cos \Delta + \cosh \Delta \sin \Delta}{\cosh 2\Delta - \cos 2\Delta}$$

$$\begin{aligned} P_n &= \int_0^{2\pi} \int_0^{w} E(r_{n_i}) H(r_{n_i}) r_{n_i} \, dz \, d\phi \\ &\quad - \int_0^{2\pi} \int_0^{w} E(r_{n_o}) H(r_{n_o}) r_{n_o} \, dz \, d\phi \\ &= 2\pi h P_{l_0} \Delta F_n \end{aligned} \tag{28}$$

$$\begin{aligned} F_n = \frac{\kappa}{\Psi_0(kr_{n_o}, kr_{n_i})} &\{ (n-1)^2 \overline{r}_{n_i} \Psi_1(kr_{n_o}, kr_{n_i}) \\ &- n(n-1) \left[\overline{r}_{n_i} \Psi_1(kr_{n_i}, kr_{n_i}) + \overline{r}_{n_o} \Psi_1(kr_{n_o}, kr_{n_o}) \right] \\ &+ n^2 \overline{r}_{n_o} \Psi_1(kr_{n_i}, kr_{n_o}) \} \end{aligned} \tag{29}$$

If you are a PhD student –
go for it – maybe…….

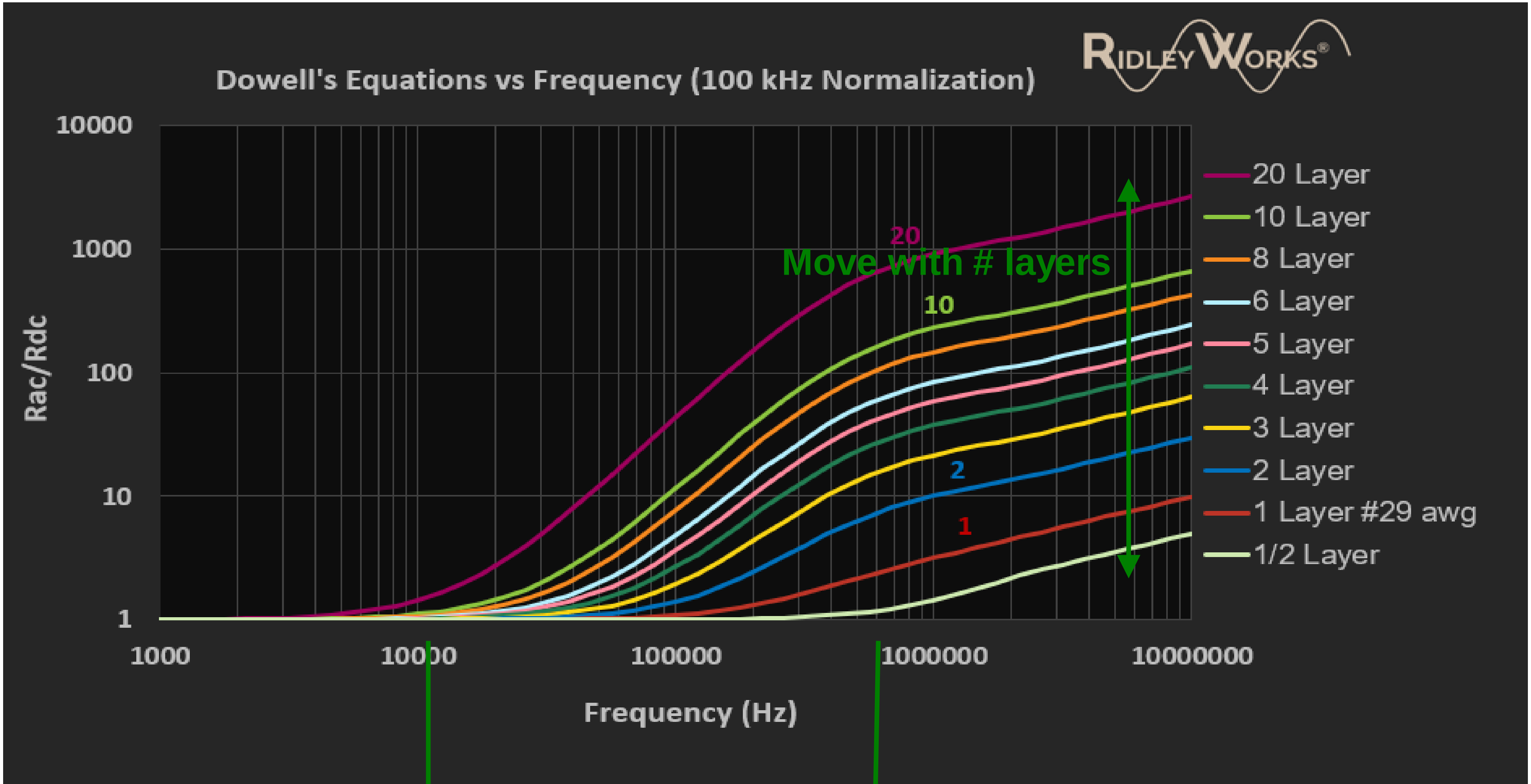
Normalized Curves for Dowell's Equations



Elegant curves explain everything about proximity – amazingly compact

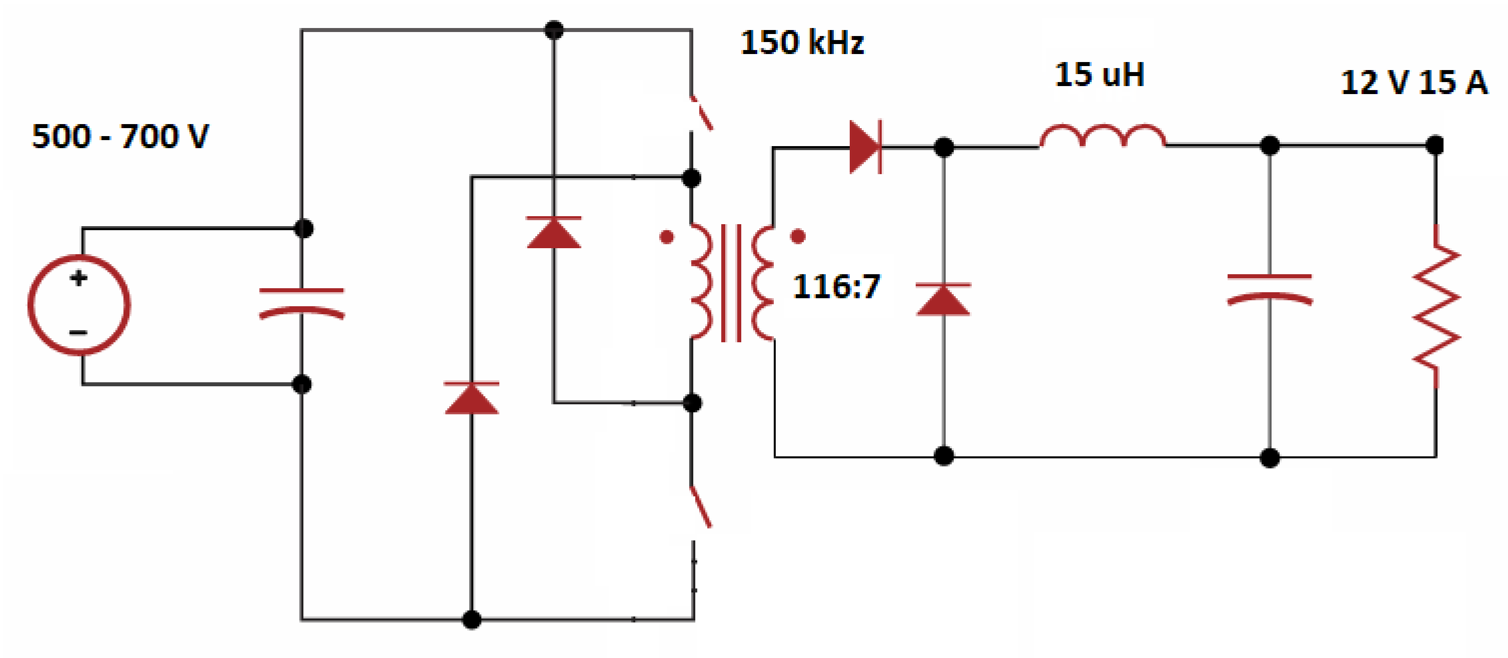
Overly elegant? Cannot see design direction on the surface:
No apparent advantage to multilayers, only penalty

Proximity Curves vs Frequency

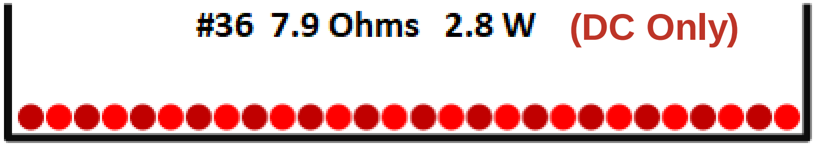


Move with:
 # layers
Layer thickness

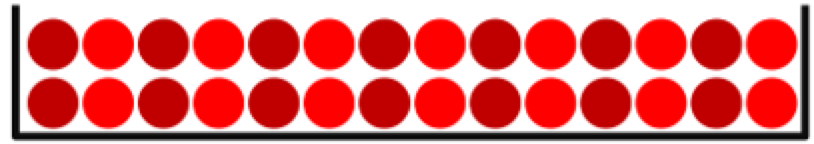
Bringing Dowell's to Life - 150 kHz Forward Converter

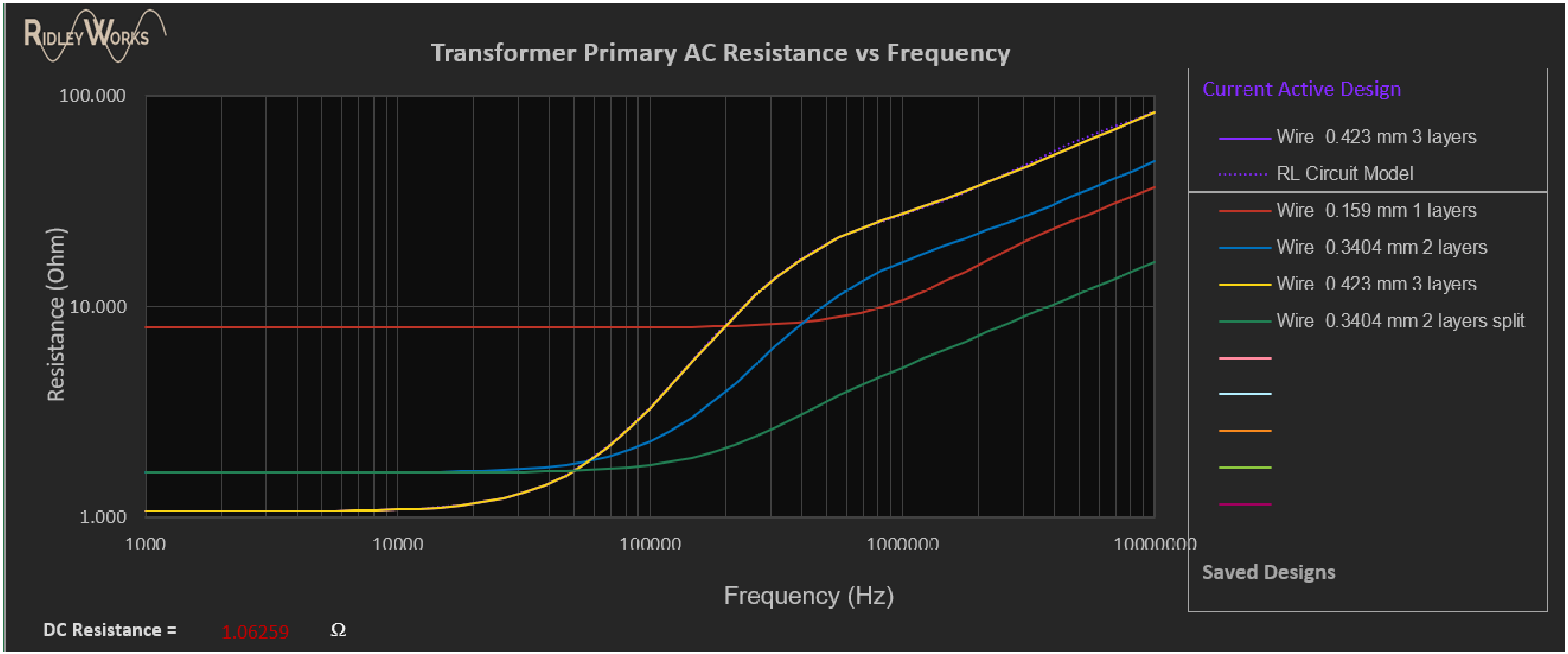


Different Transformer Primary Windings



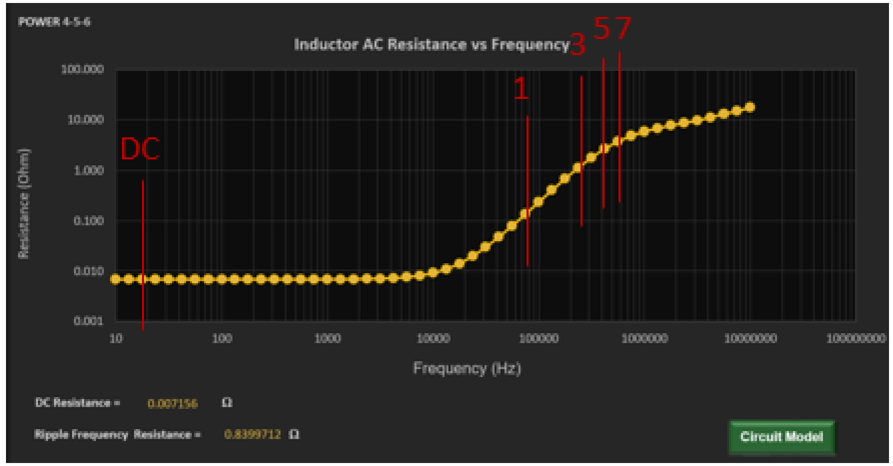
#29 1.6 Ohm 0.59 W (DC Only)



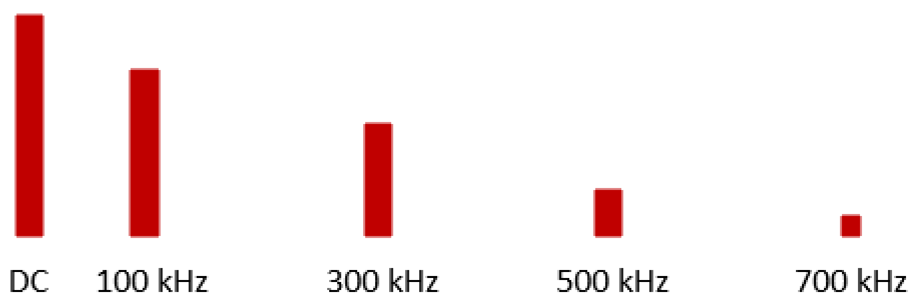


Solving for Losses – the Hard Way

Step 4
Dowell's Eqs for AC Resistance

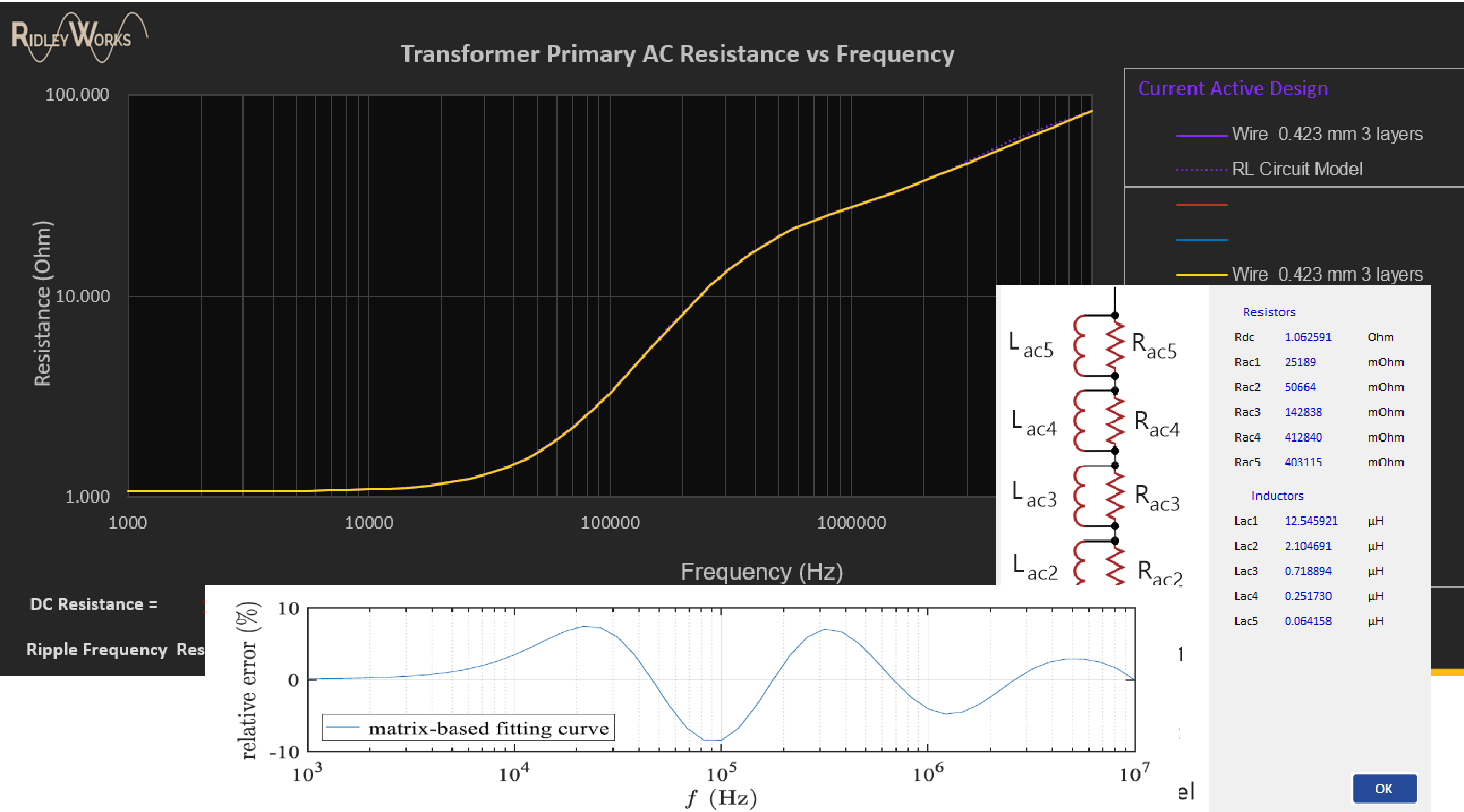


Step 3
Extract Harmonic Content – solve I^2R_{ac} for each



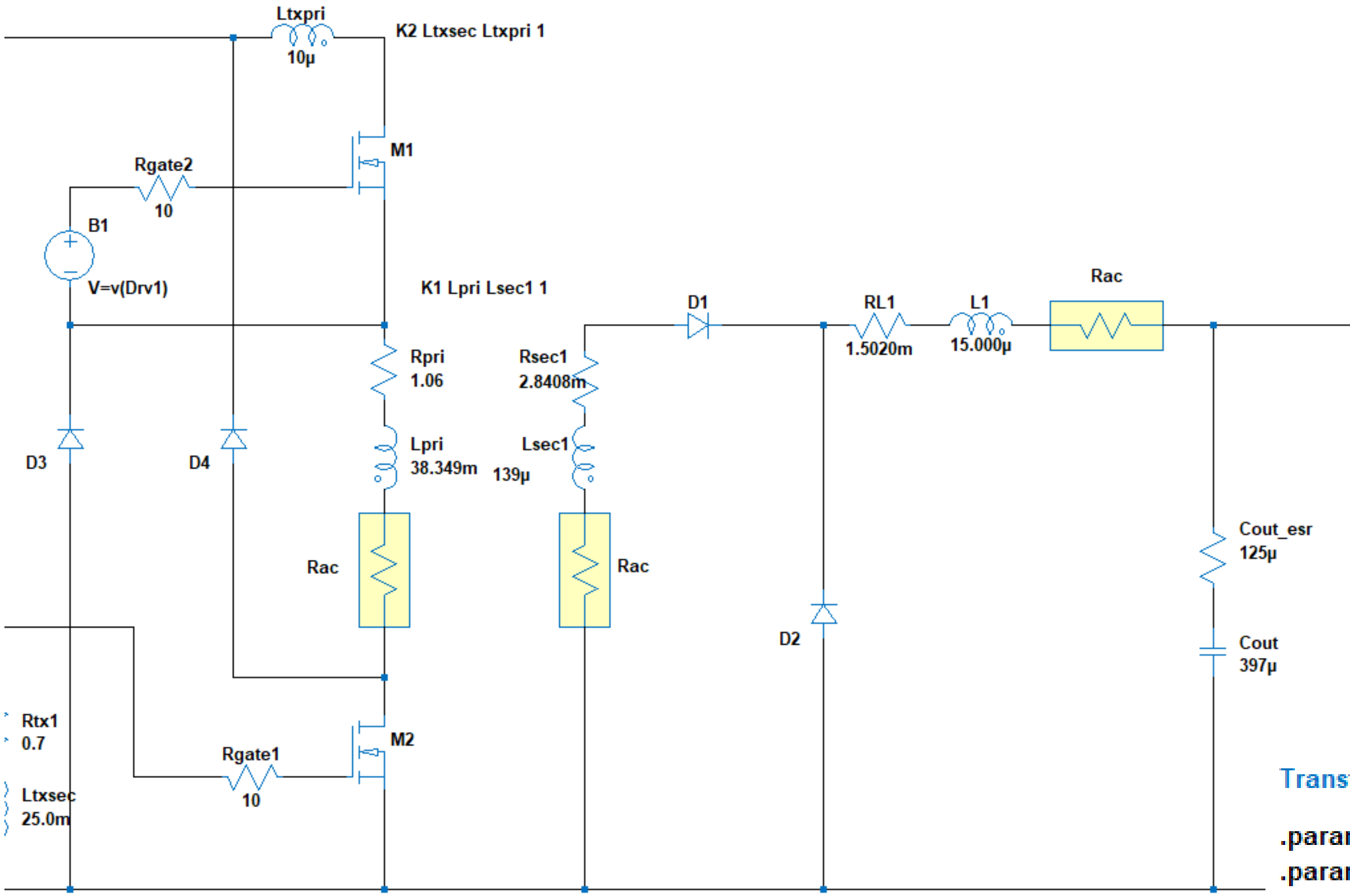
Ridley Engineering

Three Layer Design and Circuit Model



Ridley Engineering

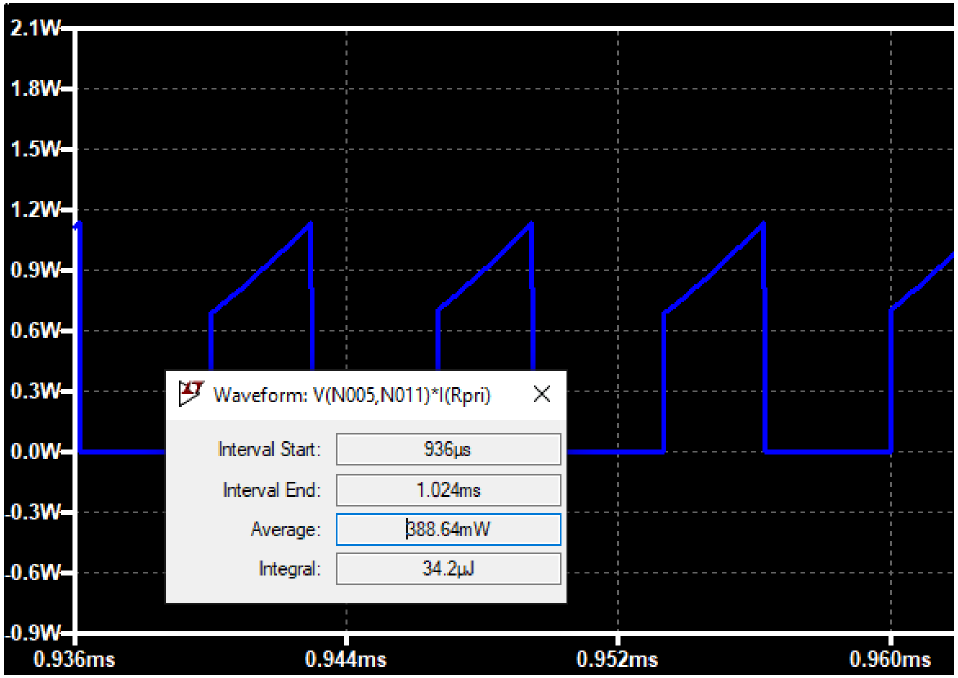
Make LTspice Do All the Hard Work!

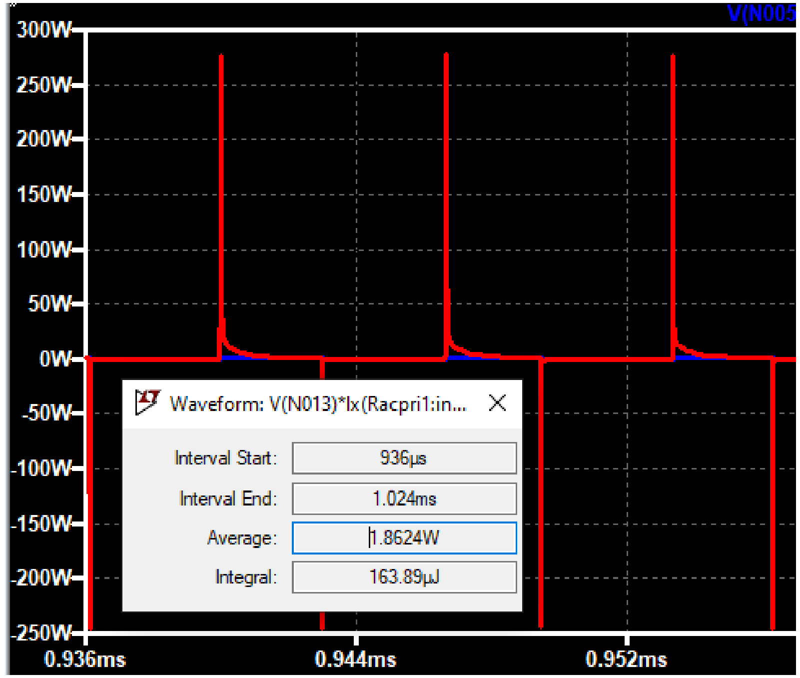


Transformer Proximity Loss Model

.param Racpri1=25189m
.param Racpri2=50664m
.param Racpri3=142838m
.param Racpri4=412840m
.param Racpri5=403115m
.param Lacpri1=12.5459212999537u
.param Lacpri2=2.10469084291543u
.param Lacpri3=0.718894325163756u
.param Lacpri4=0.251730301523891u
.param Lacpri5=6.41577510564919E-02u

Make LTspice Do All the Hard Work!



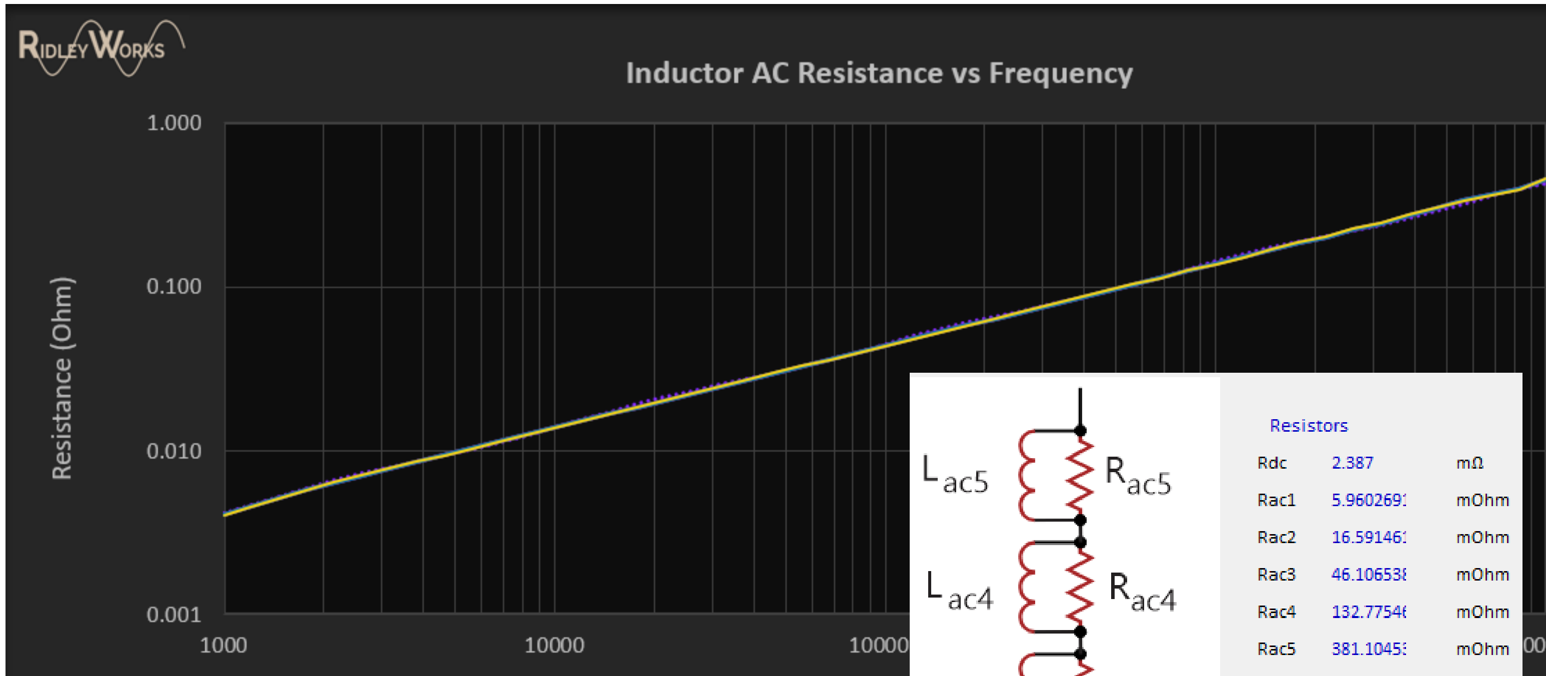


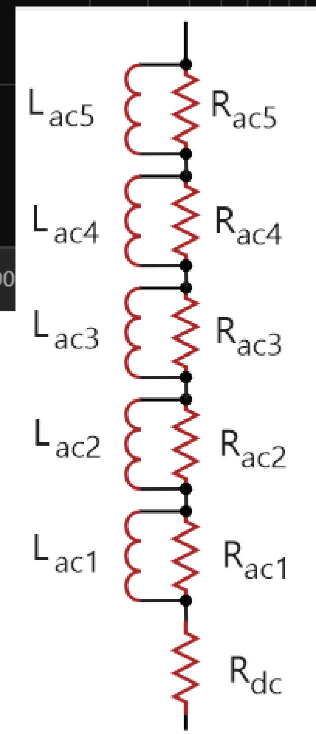
DC Calculation: 0.388 W

Proximity Calculation: 1.8 W

Ridley Engineering

Coilcraft SER2918-153 Inductor Design and Circuit Model



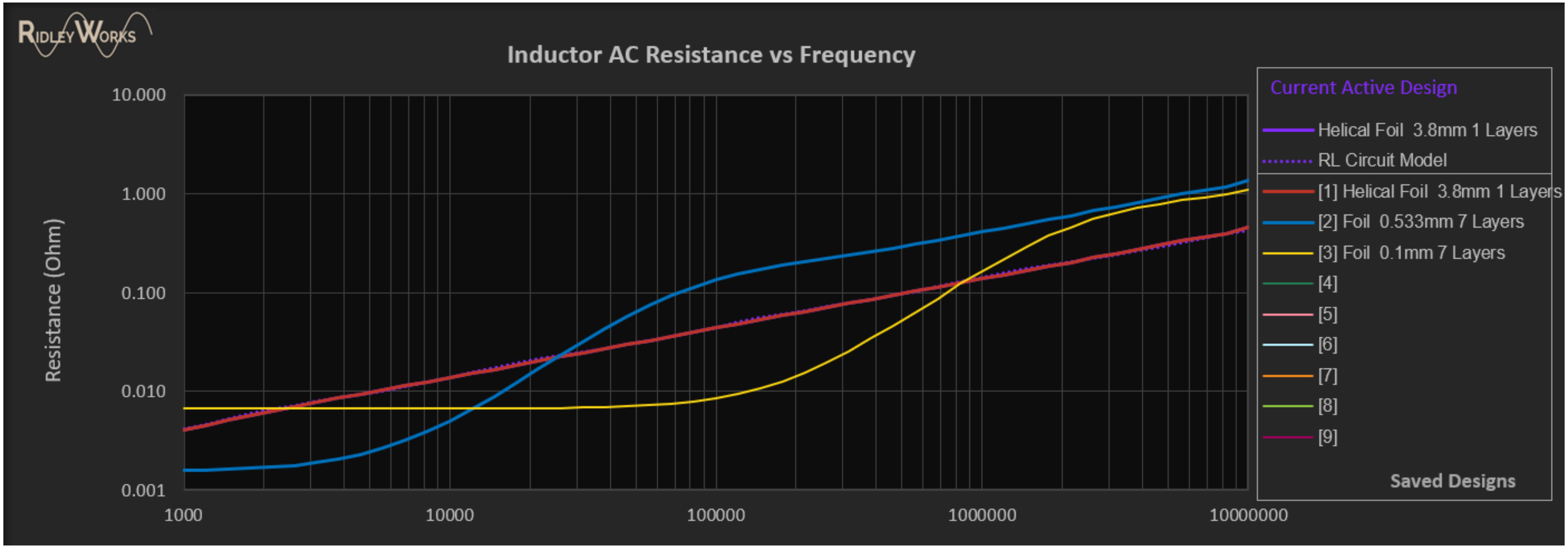


Resistors		
Rdc	2.387	mΩ
Rac1	5.960269	mOhm
Rac2	16.59146	mOhm
Rac3	46.10653	mOhm
Rac4	132.7754	mOhm
Rac5	381.1045	mOhm
Inductors		
Lac1	0.58734451	µH
Lac2	0.17991504	µH
Lac3	6.05692310	µH
Lac4	0.02113187	µH
Lac5	7.34848192	µH

Wouldn't this be useful to you?

5 minutes work to generate the model…..

Coilcraft SER2918-153 Core - Other Winding Possibilities



Yellow Option is Better for an LLC Inductor – AC component only

How to Learn More

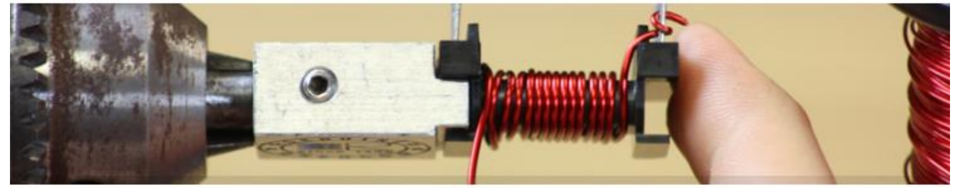
Email info@ridleyengineering.com
For full demo

Frequency Response Analyzers

A New Small-Signal Model for Current-Mode Control

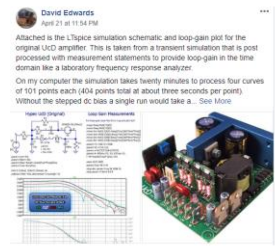
Raymond B. Ridley

Free Book



> Education > Power Design Workshop > Intro

POWER SUPPLY DESIGN WORKSHOPS



Power Supply Design Center Facebook Group

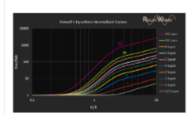
Power Supply Design Center Articles

[113] THE ADVENTURES OF 'OHM

This custom-designed comic strip is for all the electrical engineers who are suddenly working from home.

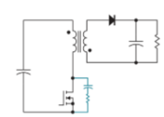
[112] THE POWER OF DOWELL'S EQUATIONS AND CURVES

The standardized curves of Dowell's equations are a superb tool for designing better high-frequency magnetics. A careful balance of layer count and wire or foil count is needed to reach an optimum design.



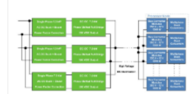
[A24] FLYBACK CONVERTER SNUBBER DESIGN

In this article, we will talk about practical design techniques for the most commonly used snubber and clamp circuits for the flyback converter.



[111] ZVS FULL-BRIDGE CONVERTER EMPLOYING AN ACTIVE SNUBBER

The ZVS full bridge converter can be enhanced greatly by implementing an active snubber on the secondary side of the transformer.

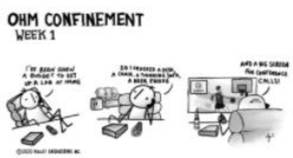


Ridley Engineering

How to Learn More – Recent Webinar Series

ADVENTURES OF 'OHM

This custom-designed comic strip is for all the electrical engineers who are suddenly working from home.



BUILD A CURRENT MODE CONTROLLER IN ONE HOUR - WEBINAR

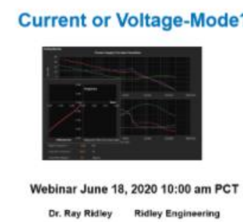
Design and Build a Current Mode Controller in One Hour and learn the 7 secrets of current-mode control

BUILD A VOLTAGE-MODE CONTROL LOOP IN ONE HOUR - WEBINAR

In this video Dr. Ray Ridley measures a working power stage, designs the compensator, inserts compensation components, and measures the loop gain.

VOLTAGE-MODE OR CURRENT-MODE CONTROL? - WEBINAR

Watch Dr. Ridley's webinar on voltage and current mode control. Get the definitive answer on which you should be using.



POWER SUPPLY DESIGN ESSENTIALS - WEBINAR

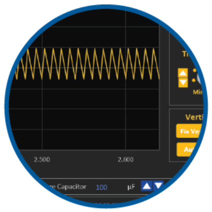
In this webinar we will go deep into the design of a converter and many of the aspects that need to be considered.

MAGNETICS ESSENTIALS - WEBINAR

In This video Dr. Ray Ridley talks about Magnetics Essentials

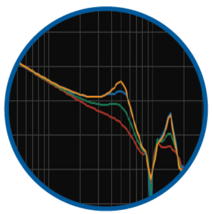
LINK FROM RIDLEYWORKS TO PSIM - WEBINAR

In This video Dr. Ray Ridley talks about the link between RidleyWorks and PSIM



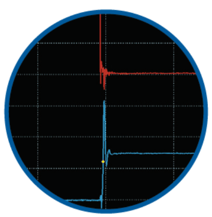
RidleyWorks® Lifetime License

- Power Stage Designer
- Power Stage Waveforms
- Magnetics Designer
- Transfer Function Bode Plots
- Closed Loop Design
- Automated FRA Control
- LTspice® Automated Link
- PSIM® Automated Link



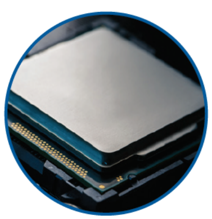
4-Channel Frequency Response Analyzer

- 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
- Intel® HD Graphics 620
- Integrated Dual Band Wireless, Bluetooth 4.2
- Dual HDMI and USB Ports, Ethernet

Ridley Engineering