What is Next in Magnetics?

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www.ridleyengineering.com

APEC 2018 Seminar

Ridley Engineering

Magnetics Modeling Software

ANSYS

Maxwell

Ansoft

Maxwell 3D

Electromagnetic and Electromechanical Analysis

Coilcraft

Power Inductor Analysis & Comparison Tool

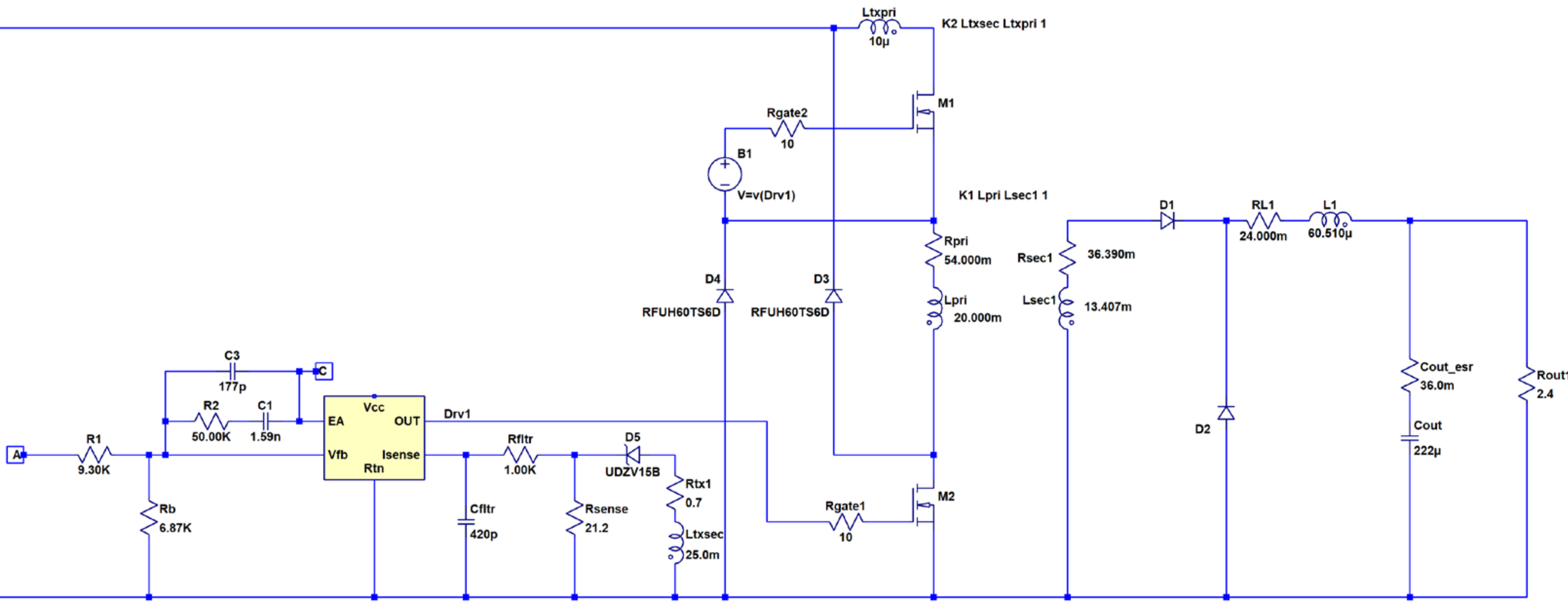
MAGNETICS® Inductor Design

TDK EPCOS Ferrite Magnetic Design Tool

REDEXPERT®

RidleyWorks™ Release 11

Spice Simulation Software



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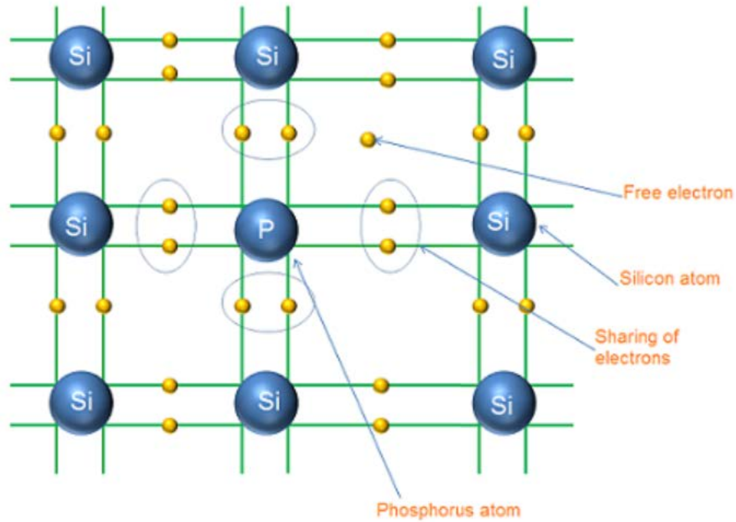
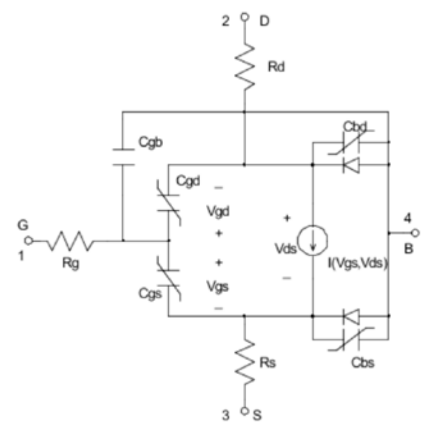
Semiconductor Devices and Models



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

These are impossibly complex structures to build and understand.

Yet they come with a spice model that’s pretty useful and accurate



Magnetics Devices and Models

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

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

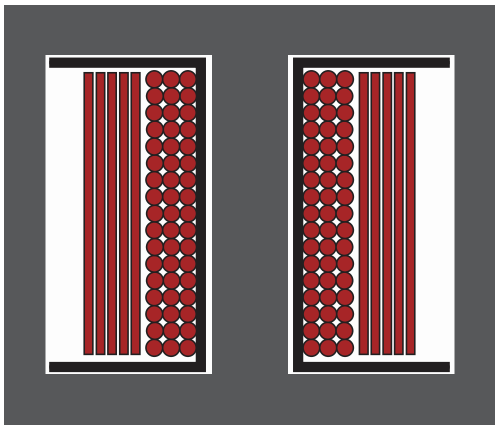
Where is the Spice model ?

The Biggest Problem with Magnetics Design

The magnetics get too **HOT!**

99.9% of designs don’t apply proximity loss properly.

Example: Forward converter transformer



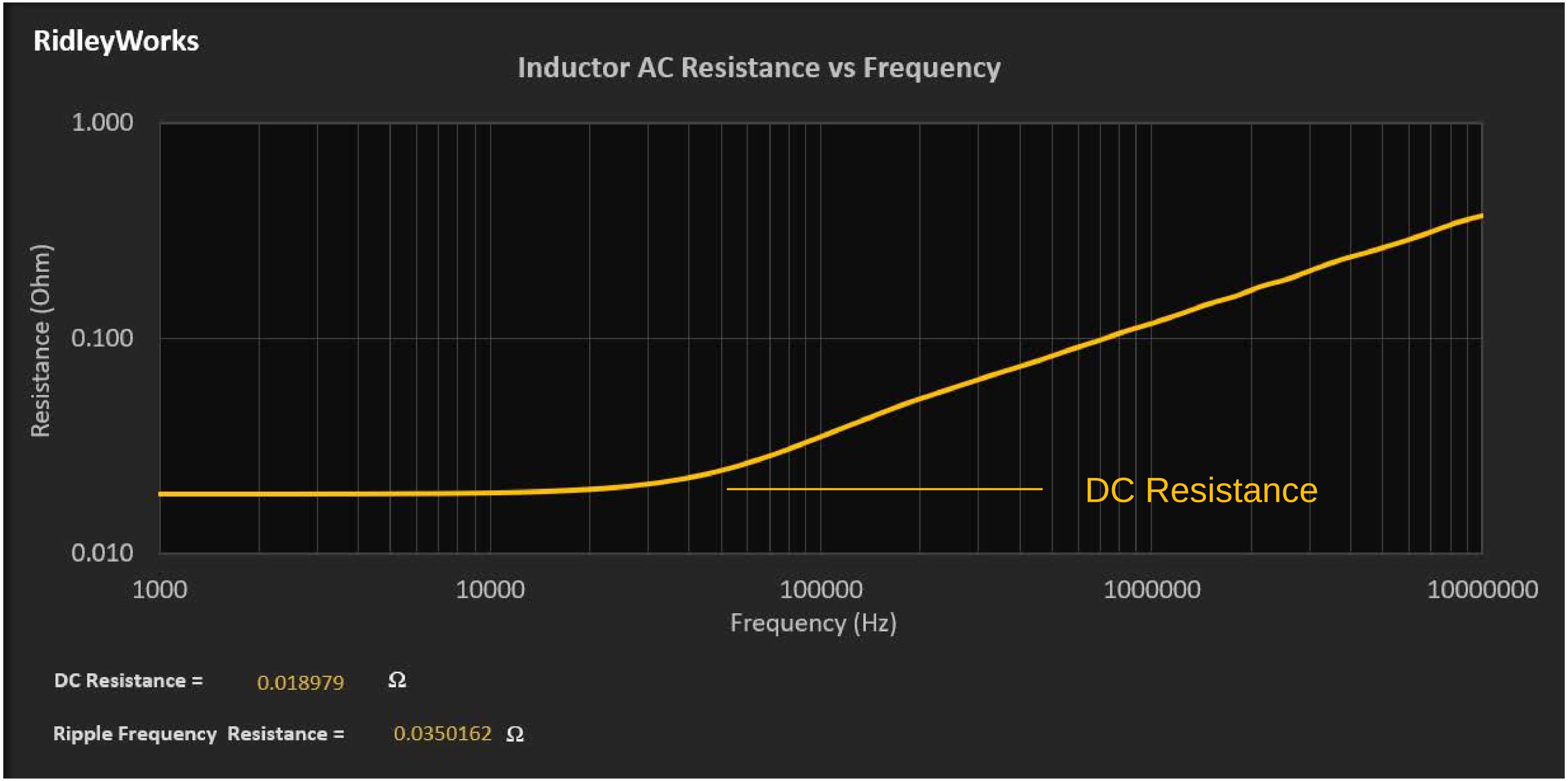
Winding loss if you don’t do proximity analysis:

1.04 W

Winding loss with full harmonic proximity analysis

10.77 W

Every Magnetic Winding Has a Unique Frequency-Dependent Resistance



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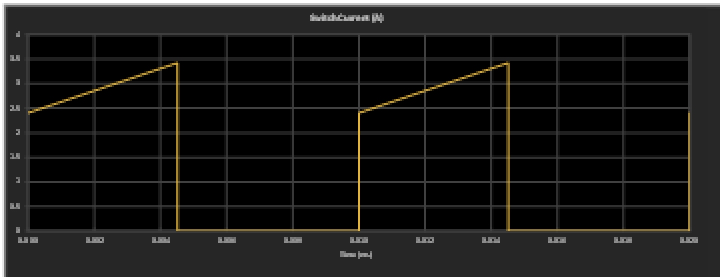
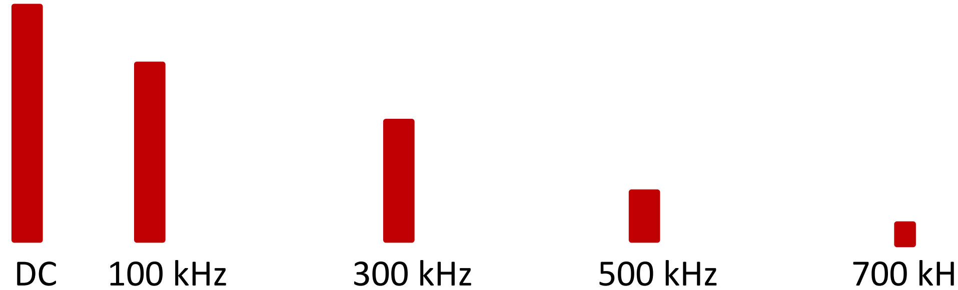
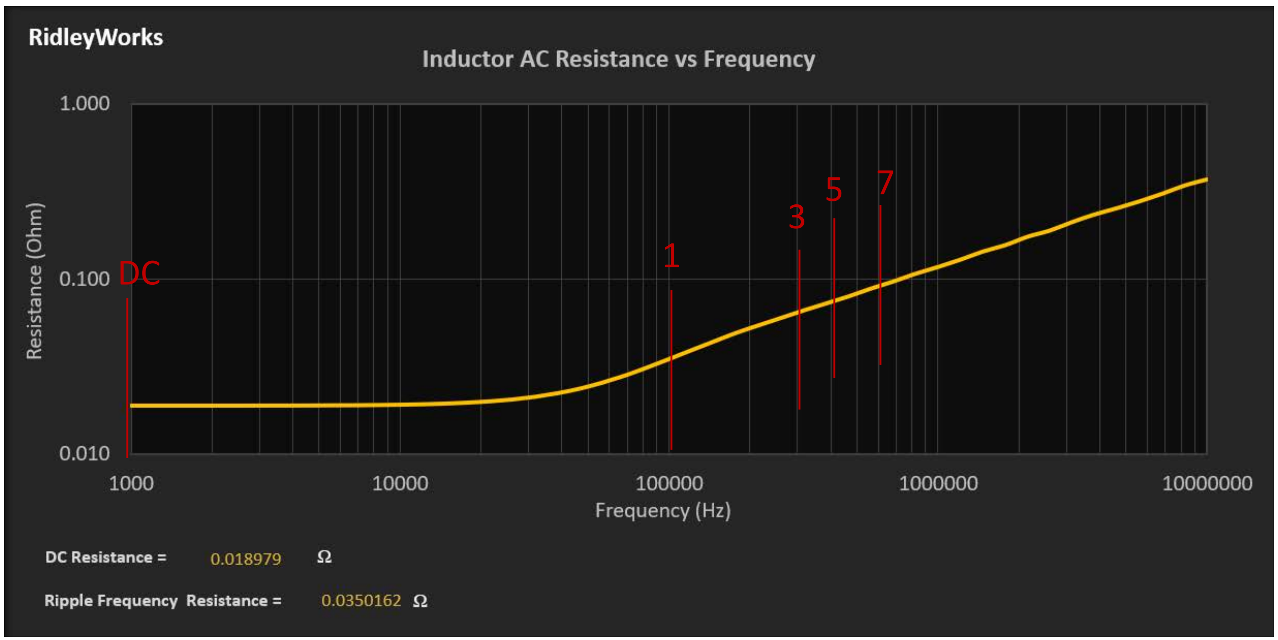
Every Circuit Waveform Has a Unique Frequency Content







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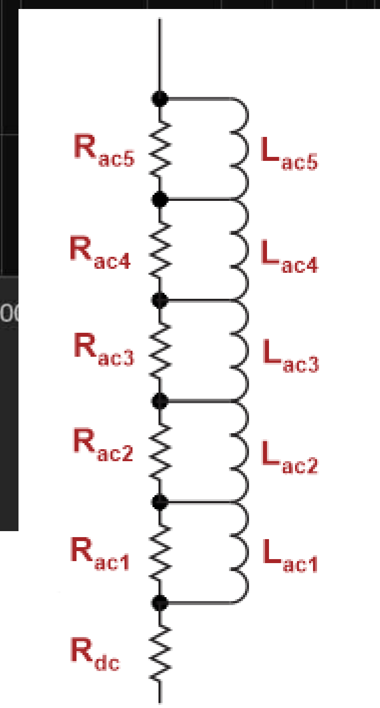
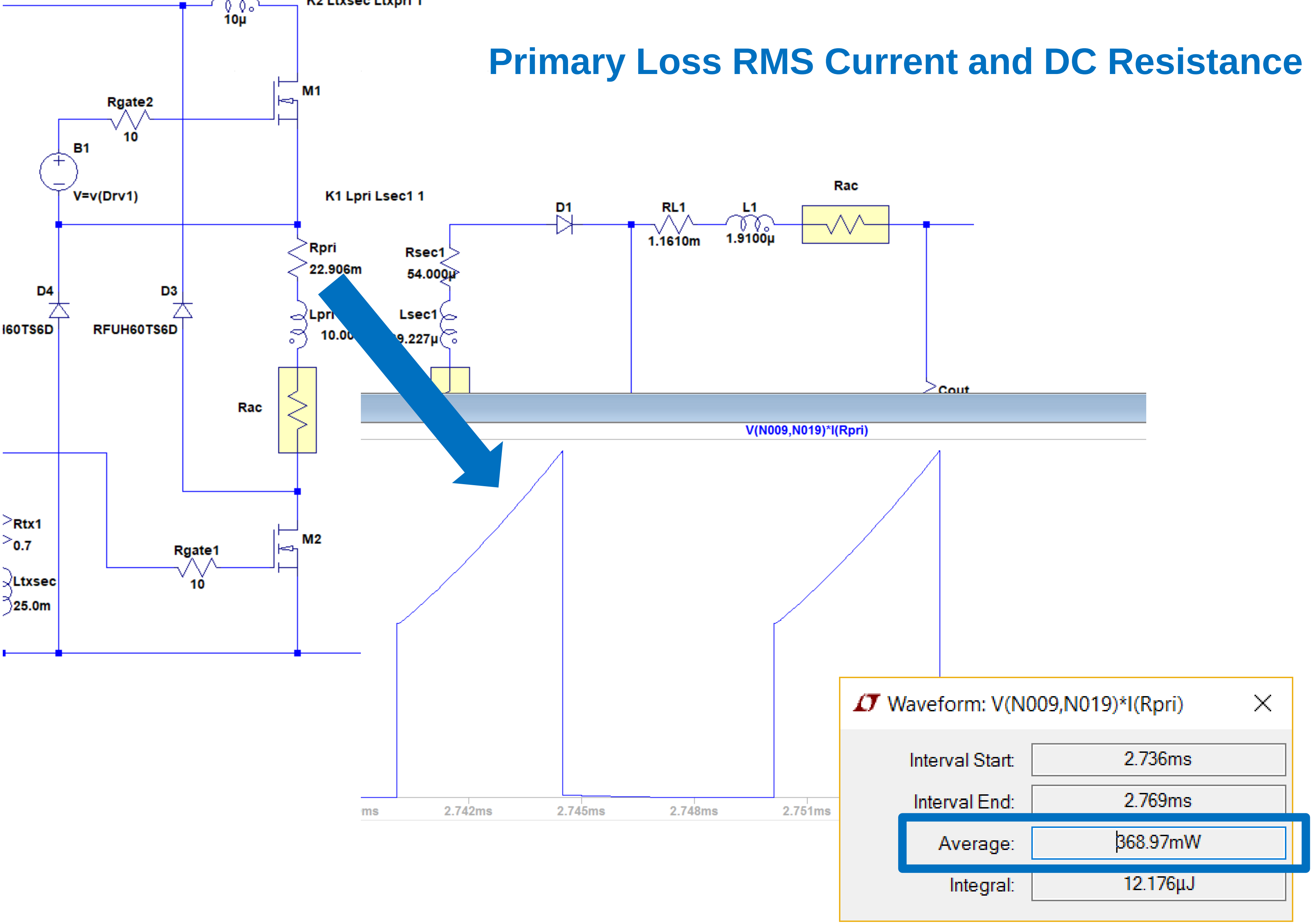
Spice Model for AC Resistance



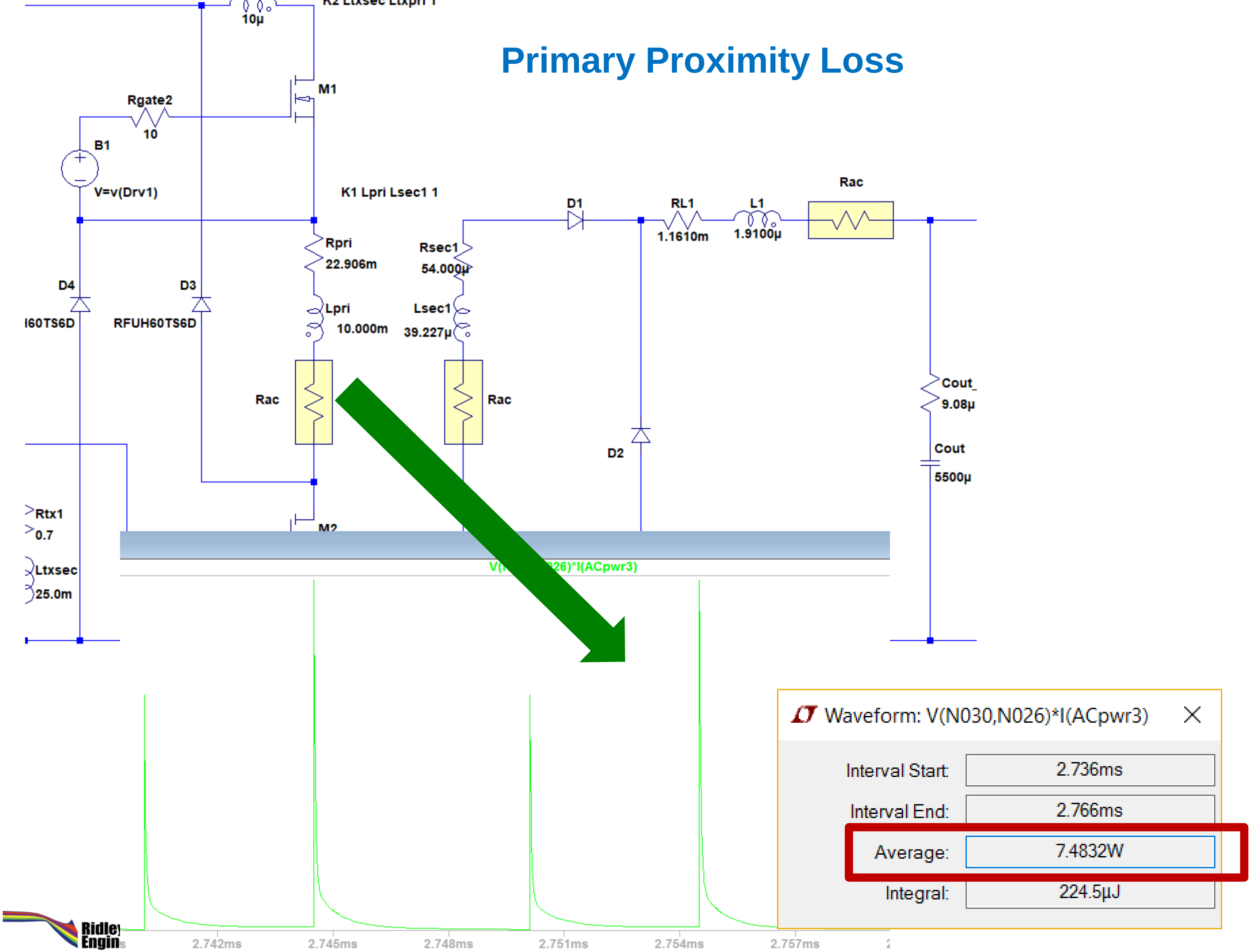
Set each Rac to be incremental resistance between sample frequencies

New Rac Model

Primary Loss RMS Current and DC Resistance



Primary Proximity Loss



The Winding Loss Modeling Problem is Solved. It works better than expected. So we are left with -

Magnetics Core Loss

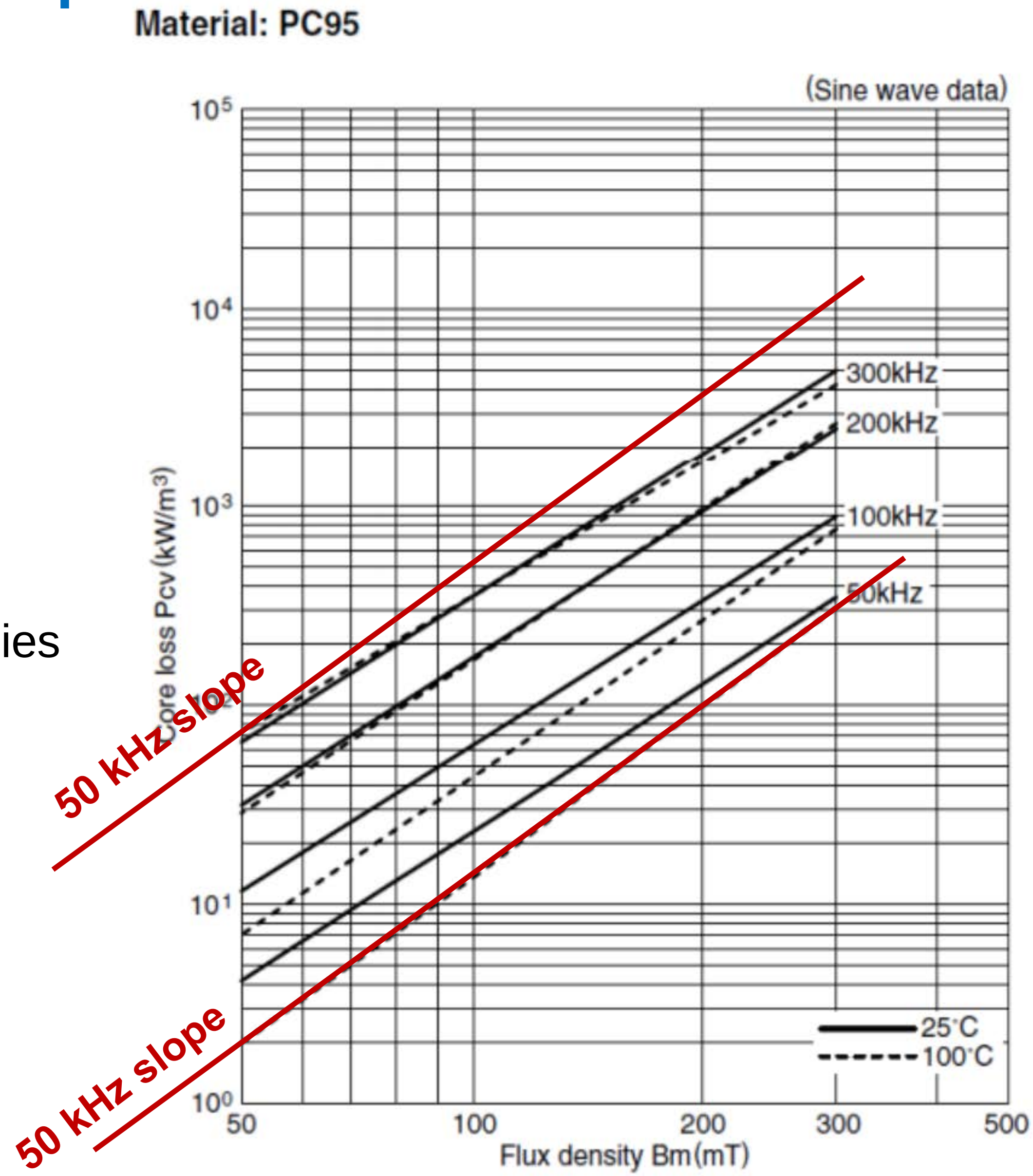
Steinmetz Equation Limitations

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

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

We, and others, have done extensive work on better modeling techniques but run into problems:

1) There are no standards of data presentation

2) There are big holes in the data measurements that need to be filled.

3) None of the core manufacturers are interested

Early Transformer Core Loss Model

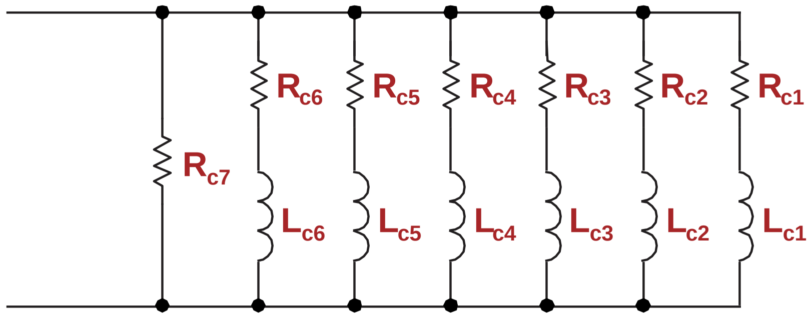
Simple resistor captured some of the loss characteristics

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

A Frequency Dependent Core Loss Model

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

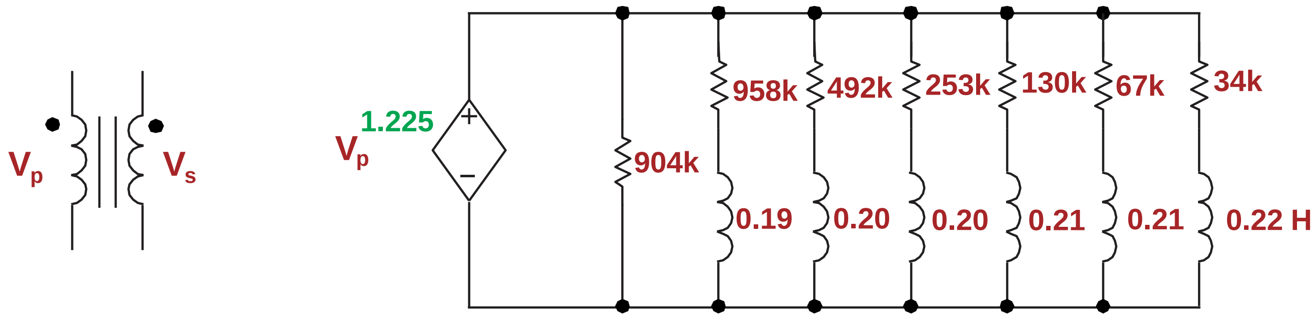


Parallel ladder driven by the inductor or transformer voltage

Frequency dependent dissipation matches frequency exponent

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

Features of Core Loss Network



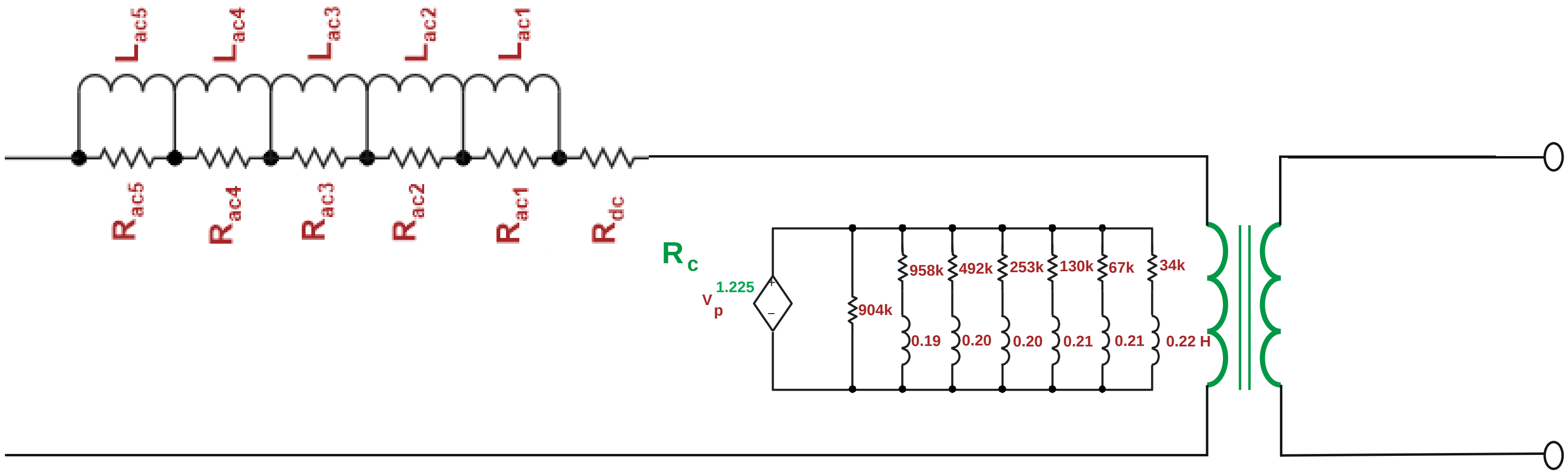
Recommended to base model on **square wave measurements - its much easier!** Could be a widespread effort with standard tester.

Sinewave application will give results somewhat higher than reality

50% duty cycle will have good accuracy - shorter duty cycles will show increased loss – probably more than reality

We still seriously lack comprehensive data with different duty cycles

Transformer Model with Core Loss and Proximity Loss



To get this model is easy:

Winding structure generates proximity model in a few seconds (see our demo)

Core model needs just three data points for the material used

Models are ready now. Refinements when better data problem is solved.

Free Software to Generate LTspice Models

ridleyengineering.com/software-ridley/ridleyworks/ridleyworks-software.html

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