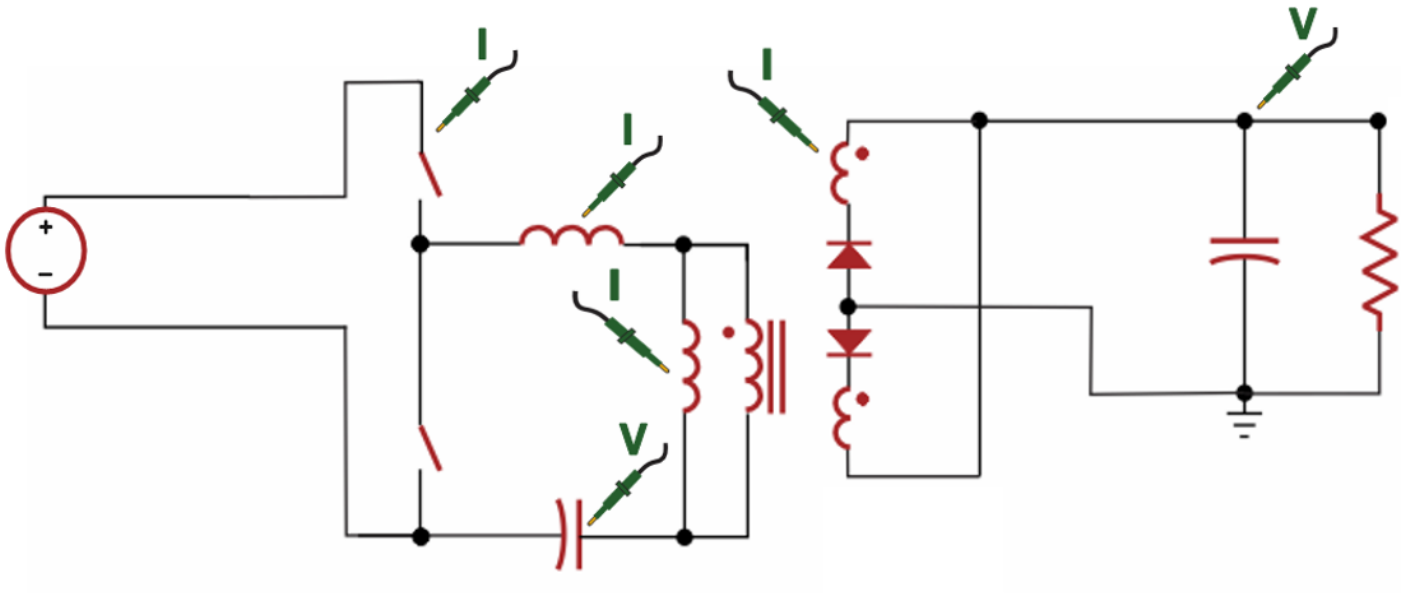
LLC Converter Design Using RidleyWorks



Webinar Thursday, November 17, 2022 10 am PDT

Presented by: Dr. Ray Ridley

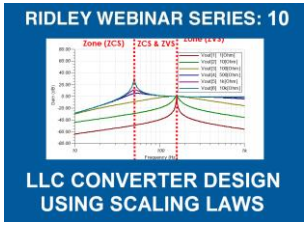
Ridley Engineering

LLC Converter Design - Acknowledgements

Arthur Nace – retired aerospace engineer and programmer who automated LTspice models for us. Our longest user of RidleyWorks.

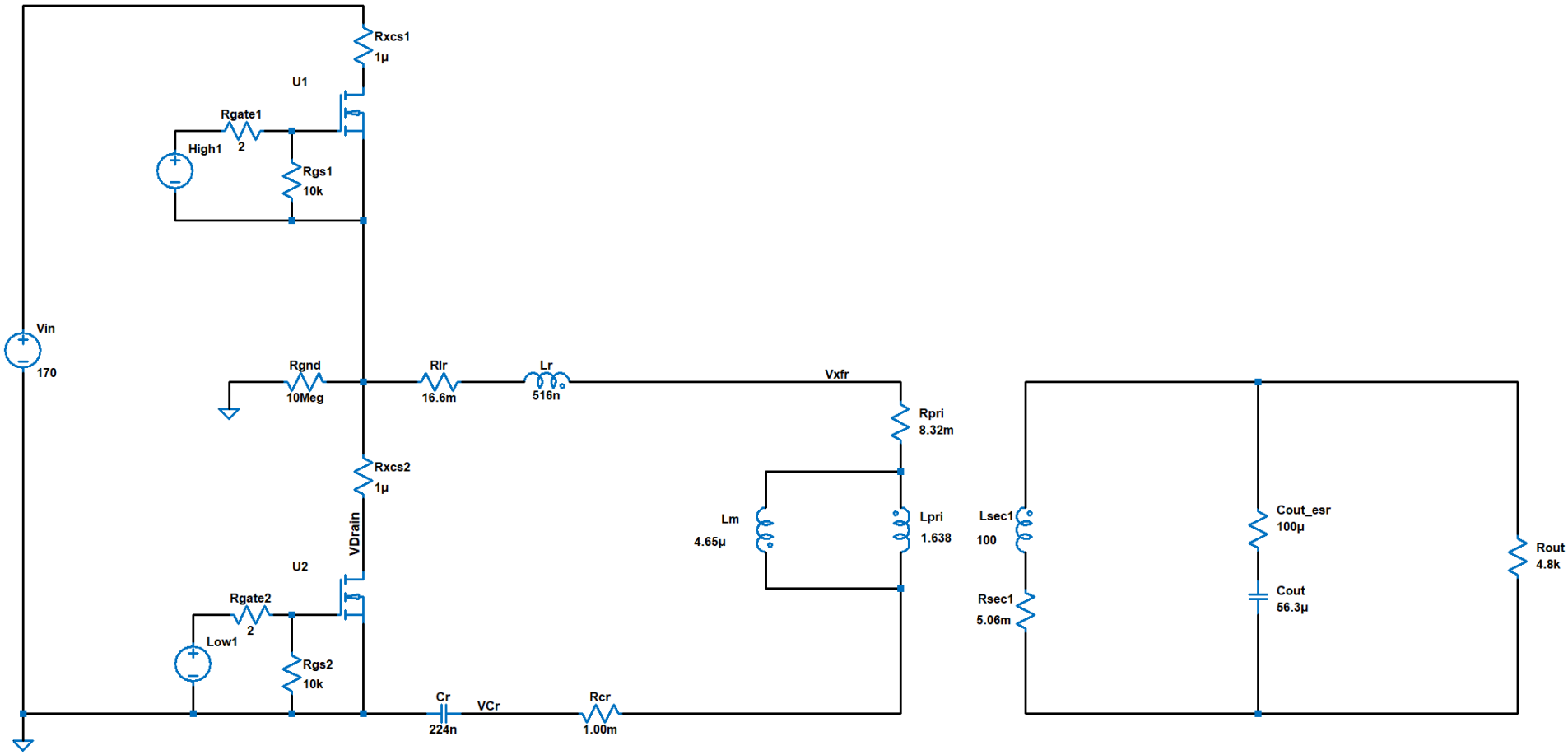
Nicola Rosano – Developed the Rosano impedance curves for designing the LLC the easy way.

No complex math - take one solid design, and scale it for frequency, voltage and power.

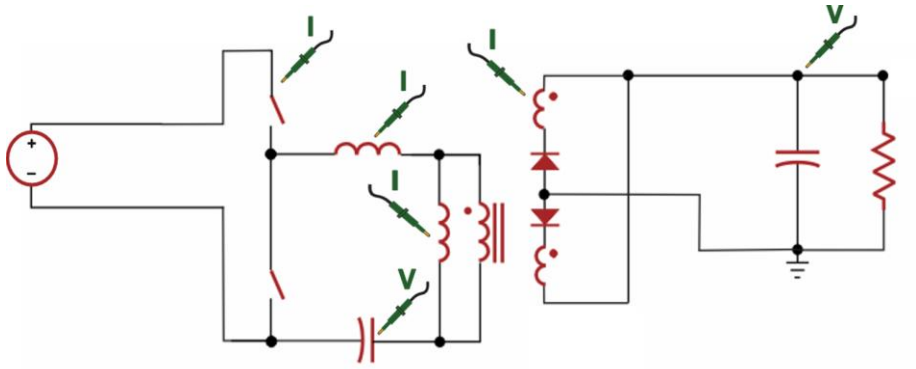


Watch this video for the theory on LLC design with scaling laws

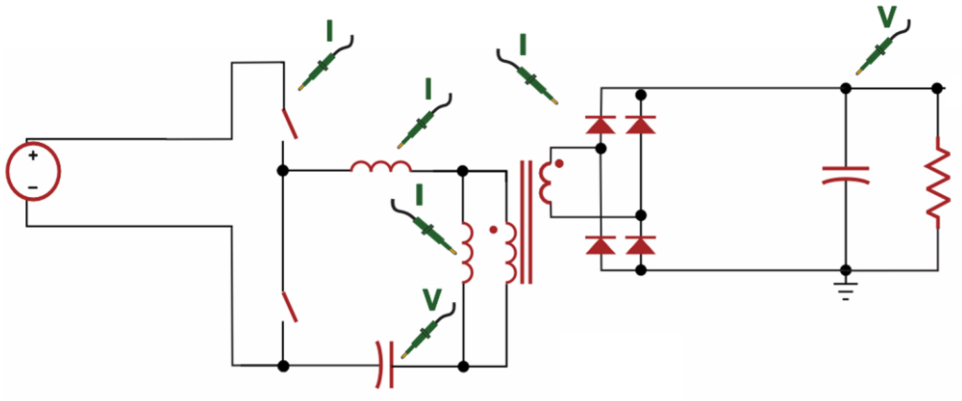
My First LLC (1980)



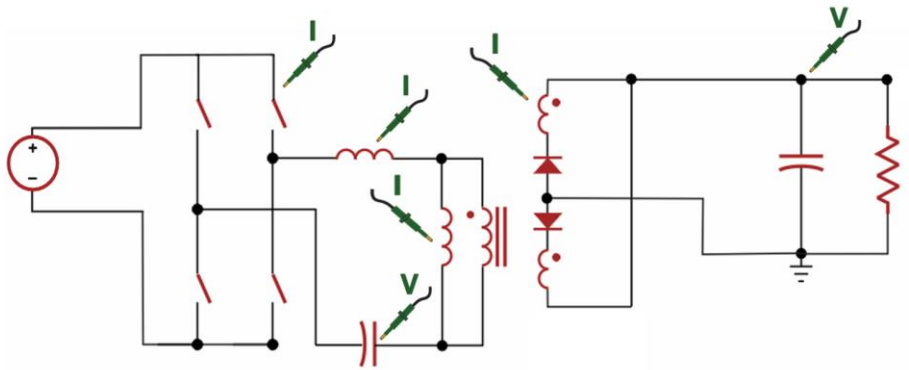
LLC Circuit Variations in RidleyWorks



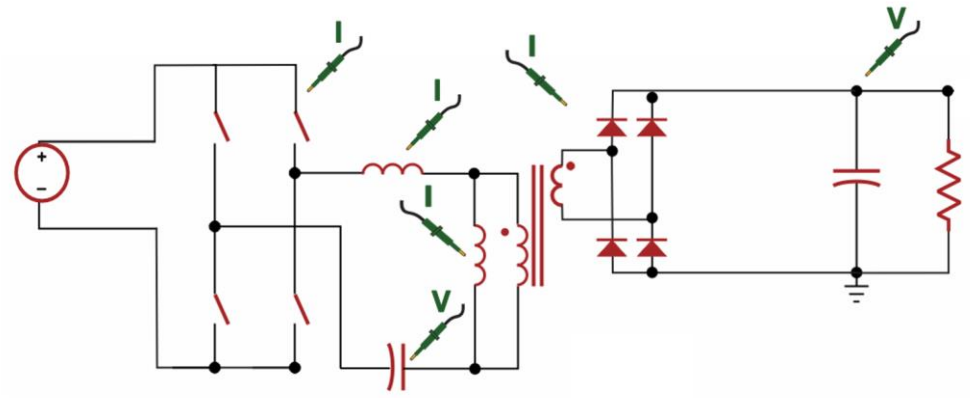
Half-bridge Inverter Half-wave Rectifier



Half-bridge Inverter Full-wave Rectifier



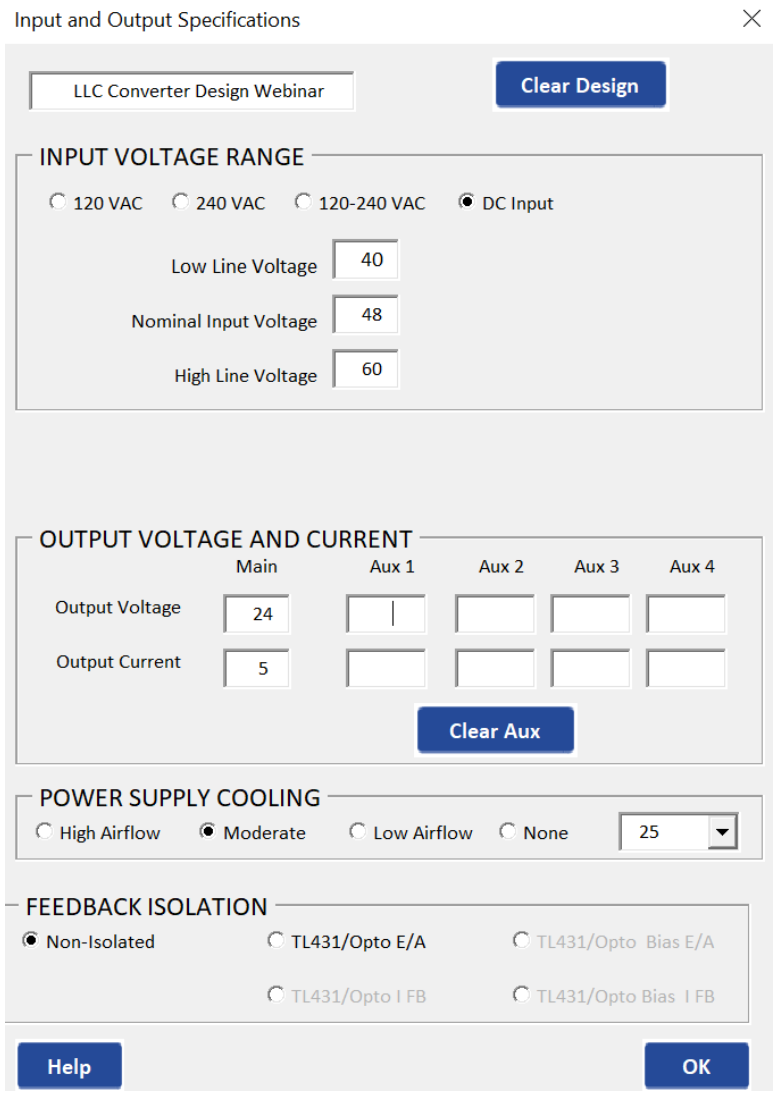
Full-bridge Inverter Half-wave Rectifier

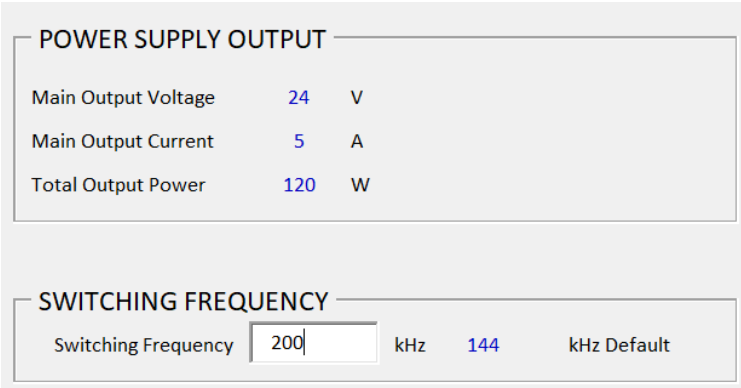


Full-bridge Inverter Full-wave Rectifier

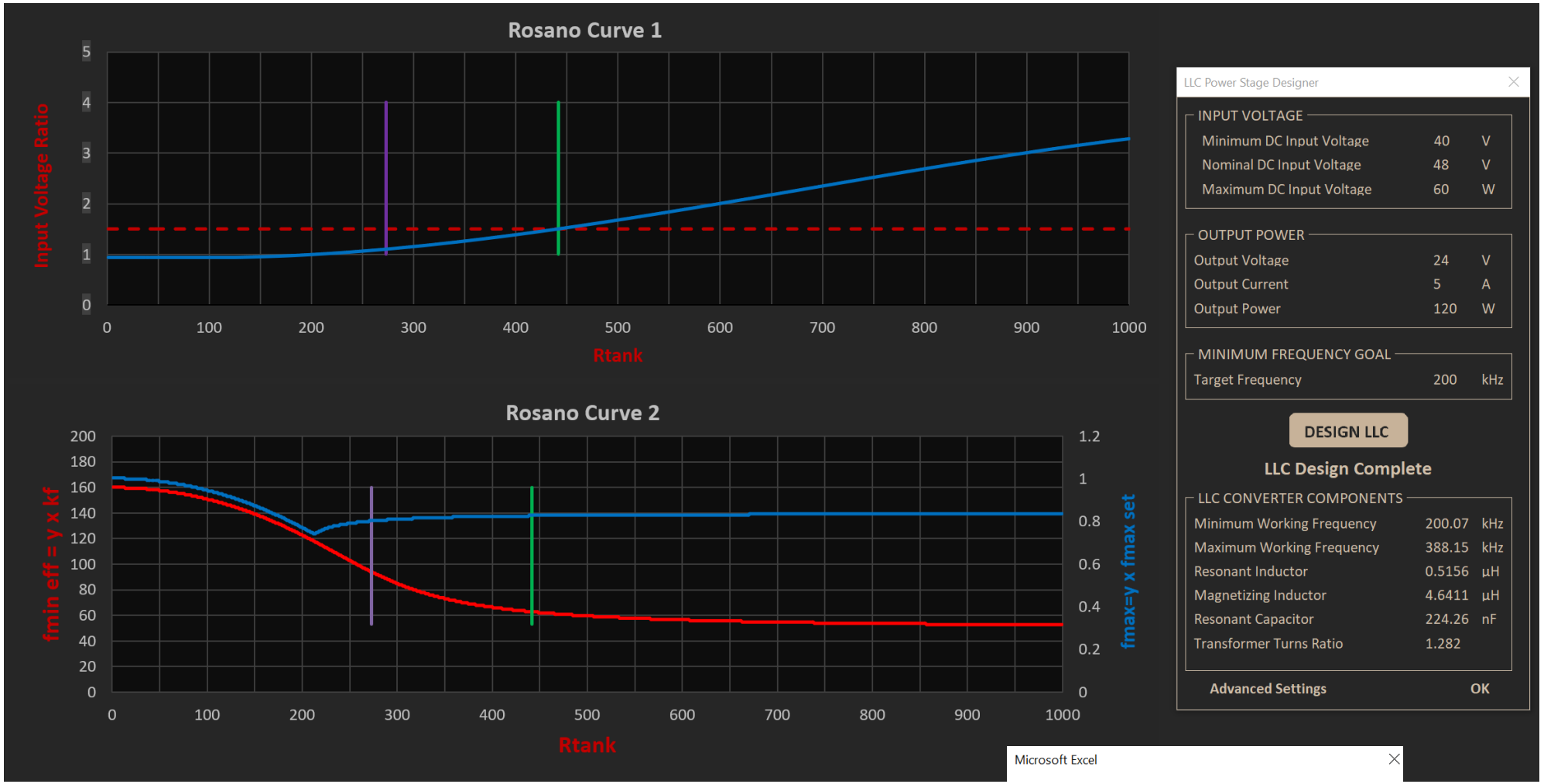
A Few Words About First Harmonic Analysis

Specification Input in RidleyWorks





Designing with Scaling Laws – Rosano Curves



LLC Power Stage Designer

INPUT VOLTAGE

Minimum DC Input Voltage	40	V
Nominal DC Input Voltage	48	V
Maximum DC Input Voltage	60	W

OUTPUT POWER

Output Voltage	24	V
Output Current	5	A
Output Power	120	W

MINIMUM FREQUENCY GOAL

Target Frequency	200	kHz

DESIGN LLC

LLC Design Complete

LLC CONVERTER COMPONENTS

Minimum Working Frequency	200.07	kHz
Maximum Working Frequency	388.15	kHz
Resonant Inductor	0.5156	µH
Magnetizing Inductor	4.6411	µH
Resonant Capacitor	224.26	nF
Transformer Turns Ratio	1.282	

Advanced Settings OK

Microsoft Excel

5 LTspice files are in the folder 'RidleyWorks LTspice' on your desktop

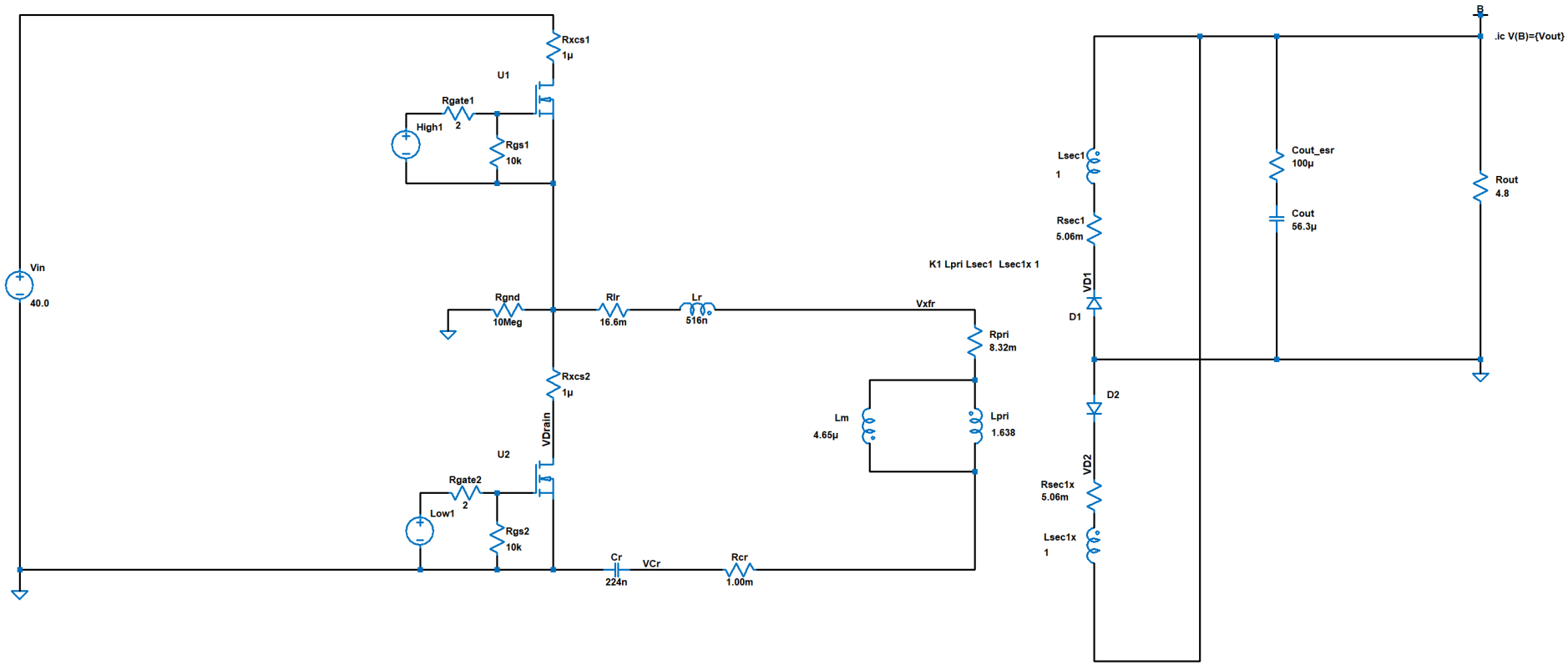
OK

Automatic LTspice Schematic Generation from RidleyWorks

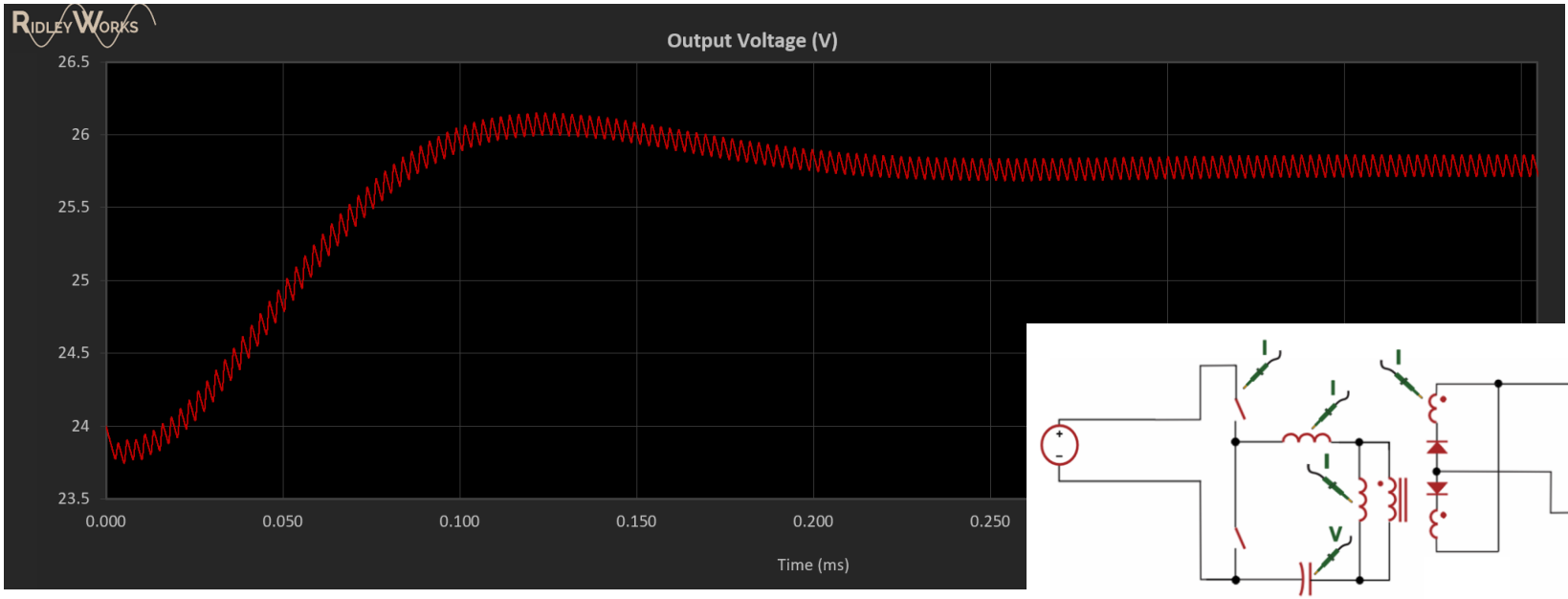
RidleyWorks LTspice Schematic

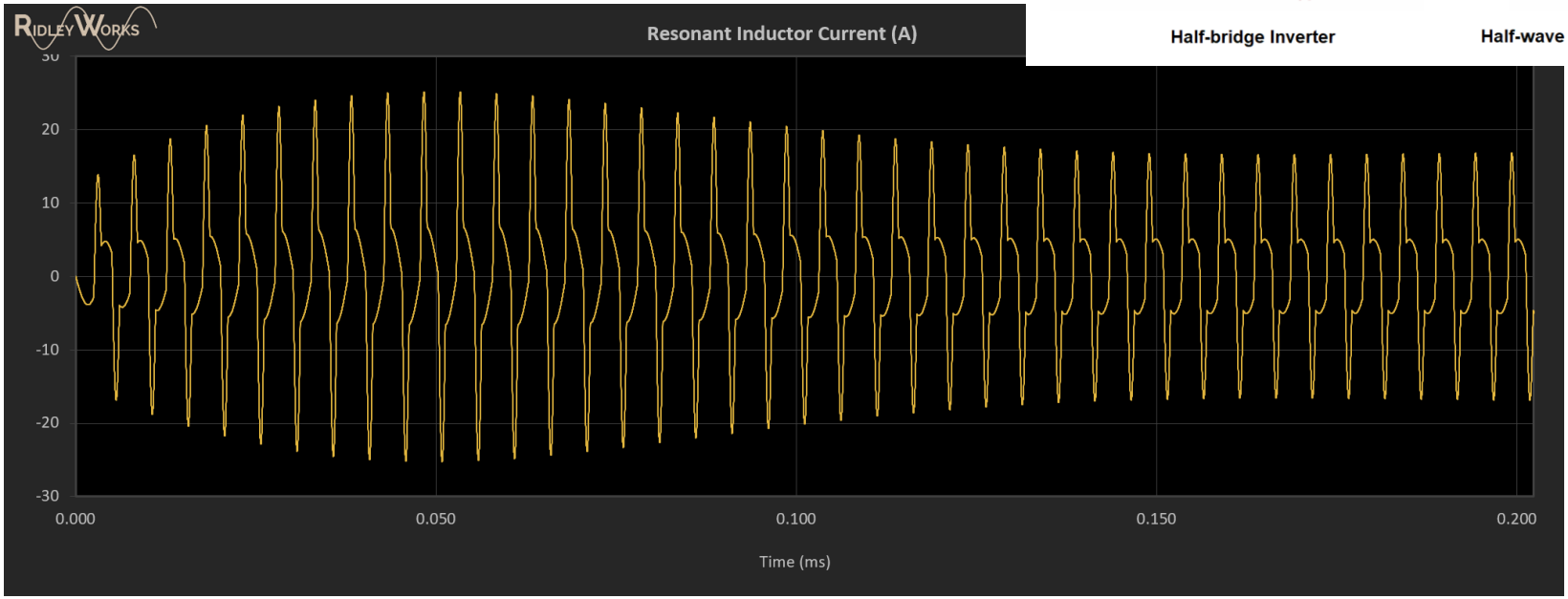
LLC CONVERTER DESIGN WEBINAR

Vin = 40.0, Vout1 = 24.0V @ 5A, llc steady state, voltage-mode



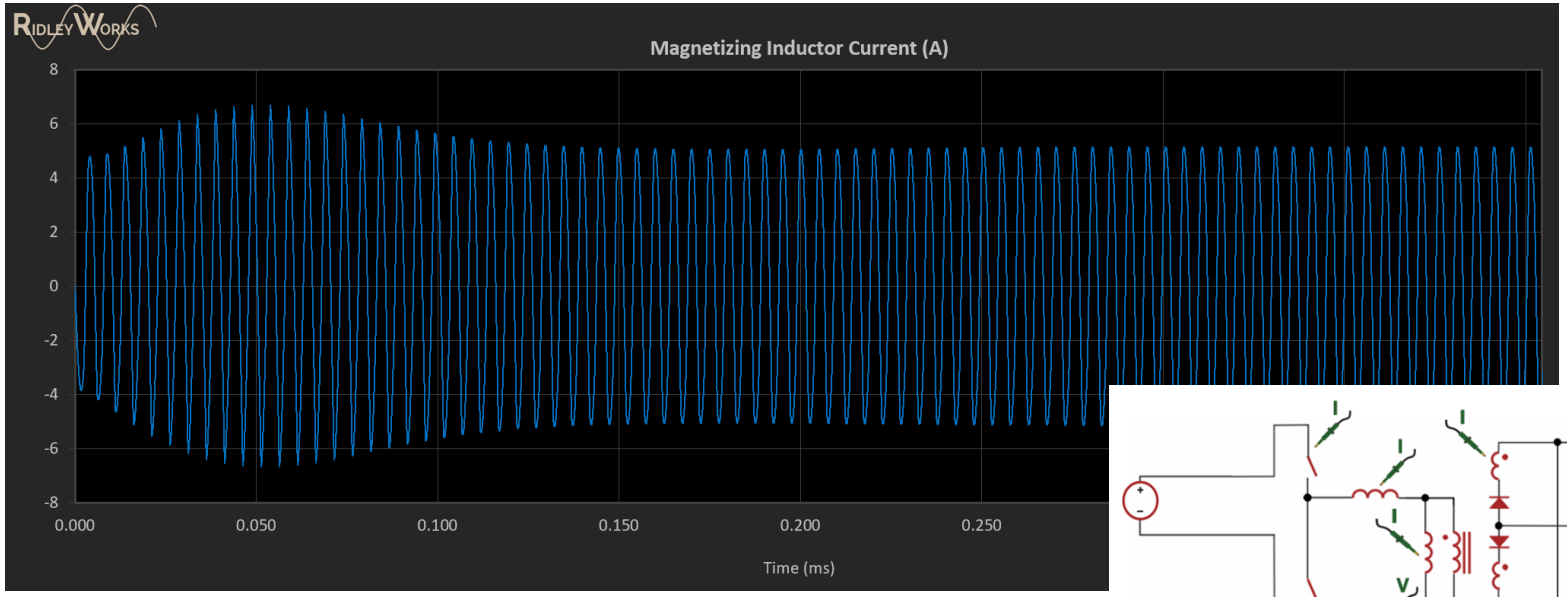
LLC Waveforms in RidleyWorks

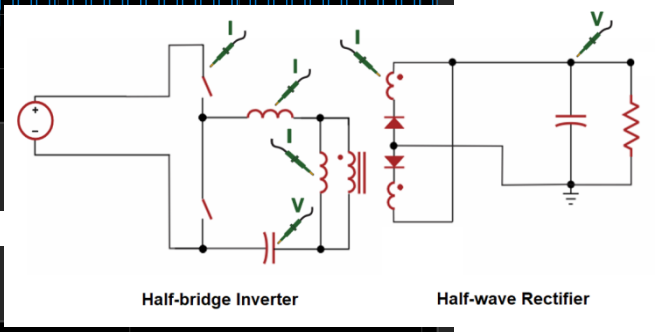


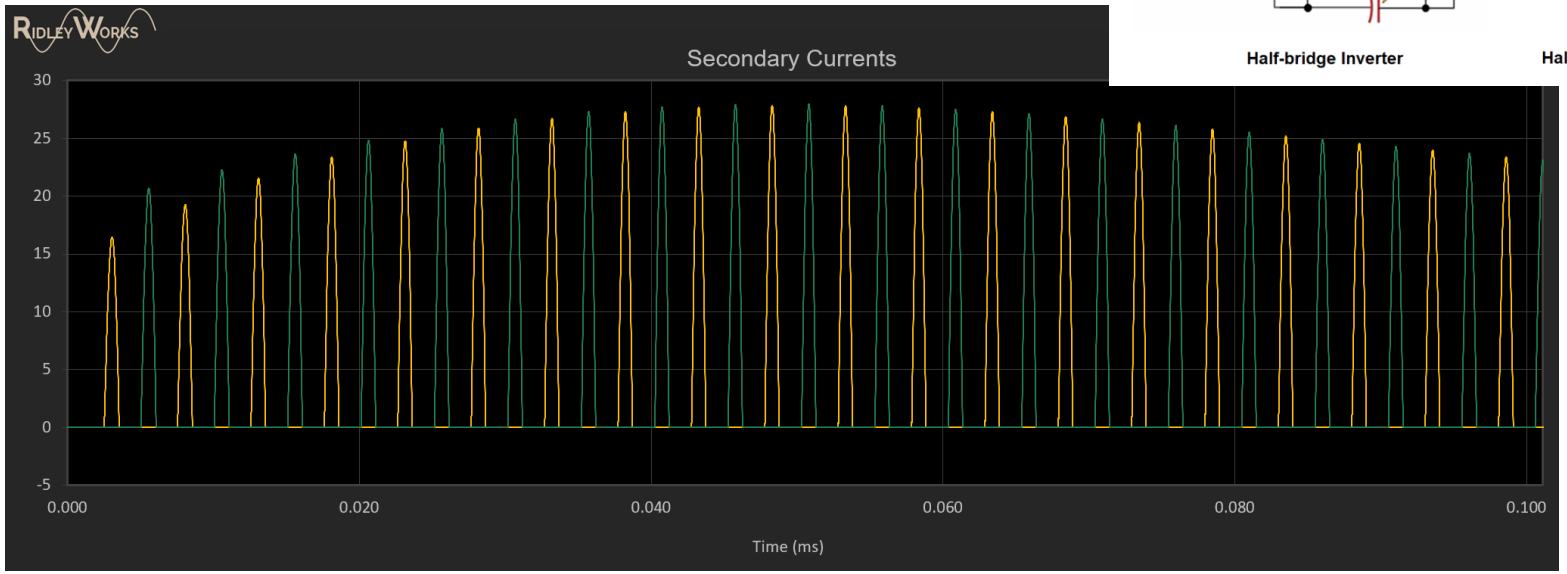


1 LLC STEADY STATE.asc

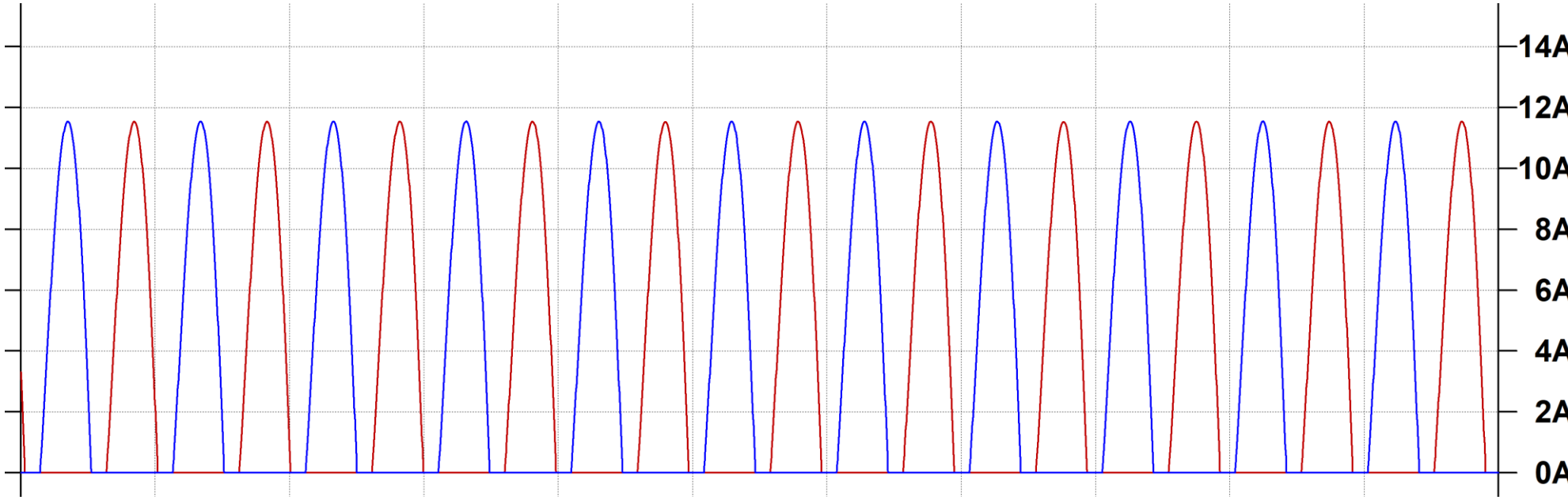
LLC Waveforms in RidleyWorks



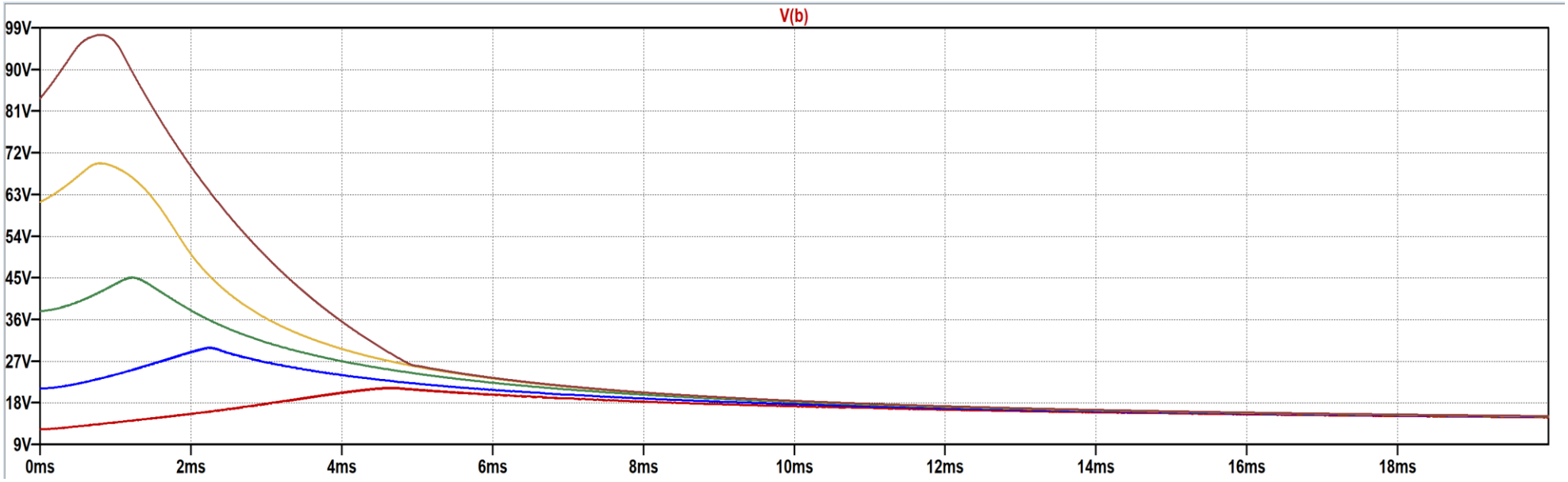




High-Line Secondary LLC Waveforms



LLC Gain Curves

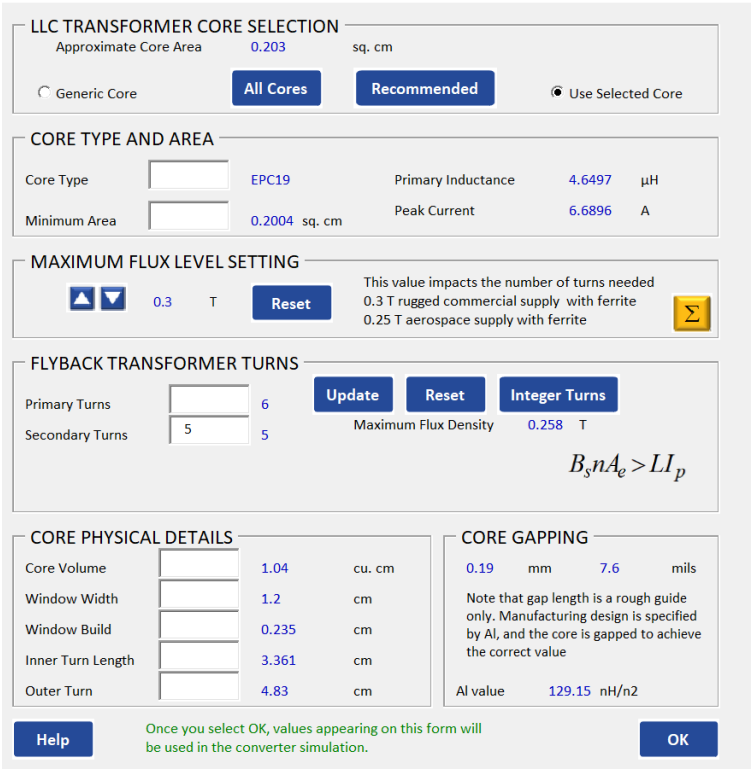


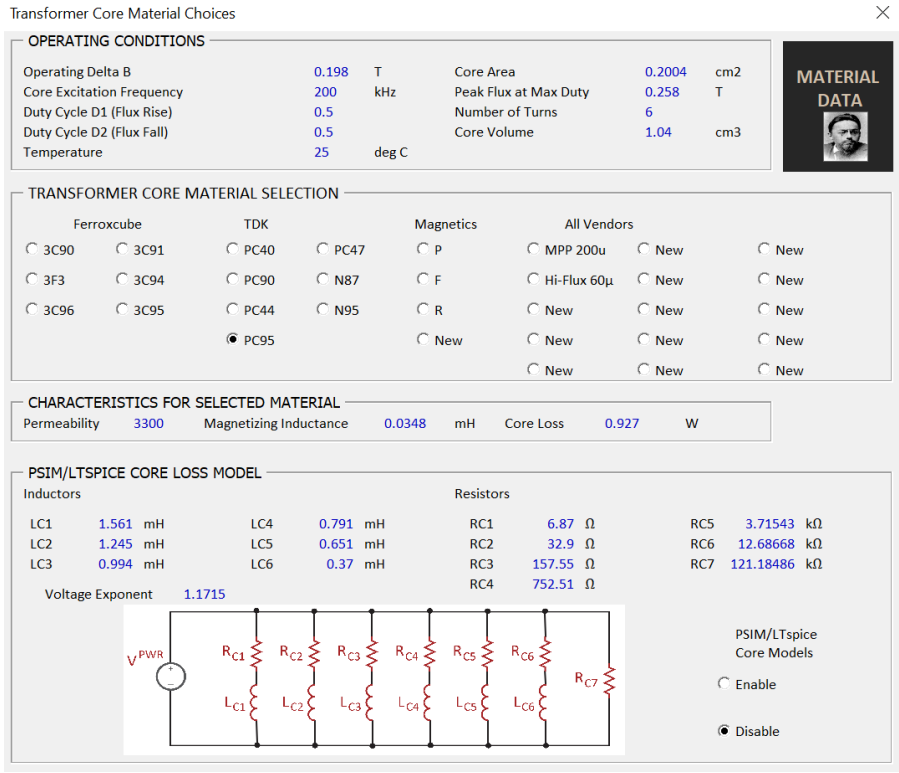
Load from RL/2 (overload) to 8RL

Sweep from Fmin to Fmax

2 LLC CURVE TRACER.asc

Transformer Core Design in RidleyWorks





Core loss is high – add more turns, but check Winding loss first.

Transformer Primary Winding Design in RidleyWorks

Transformer Primary Winding Design

PRIMARY WINDING ALLOCATION

Window Allocation 0.5

Number of Turns 6

AVAILABLE WINDOW

Margin Required 0 mm each end 1.2 cm Available Window

Insulation Required 0 mm total 0.1175 cm

WINDING STRUCTURE

Magnet Wire | Triple Insulated Wire | Foil

Number of Layers 6 Number of Parallel Wires 1

Maximum Conductor Size That Will Fit Exactly is 0.185 mm = 7.28 mils

Your Choice of Conductor Size 0.1111 mm = 4.37 mils

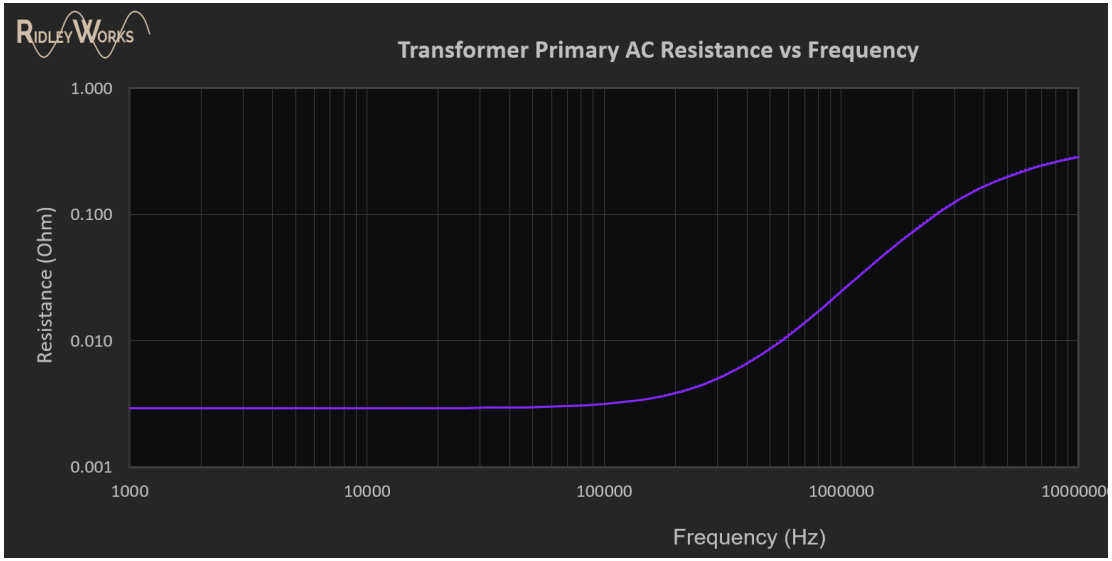
Update Minimize Loss

Split Primary Winding Leakage Inductance 0.091 µH

WINDING LOSS DETAILS

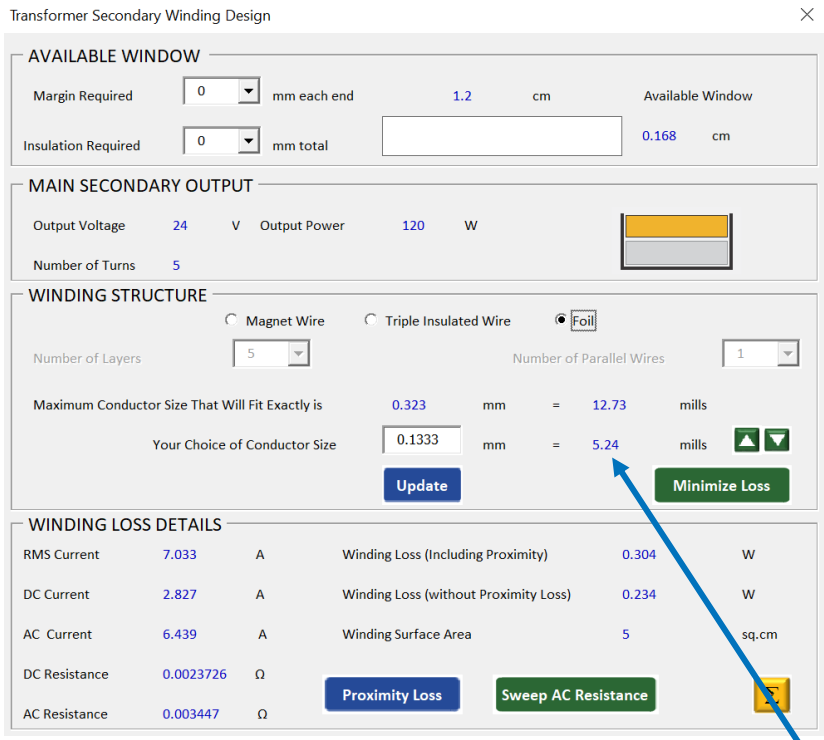
RMS Current	9.484	A	Winding Loss (Including Proximity)	0.346	W
DC Current	0	A	Winding Loss (without Proximity Loss)	0.263	W
AC Current	9.484	A	Winding Surface Area	5.4	sq.cm
DC Resistance	0.00293	Ω			
AC Resistance	0.003857	Ω			

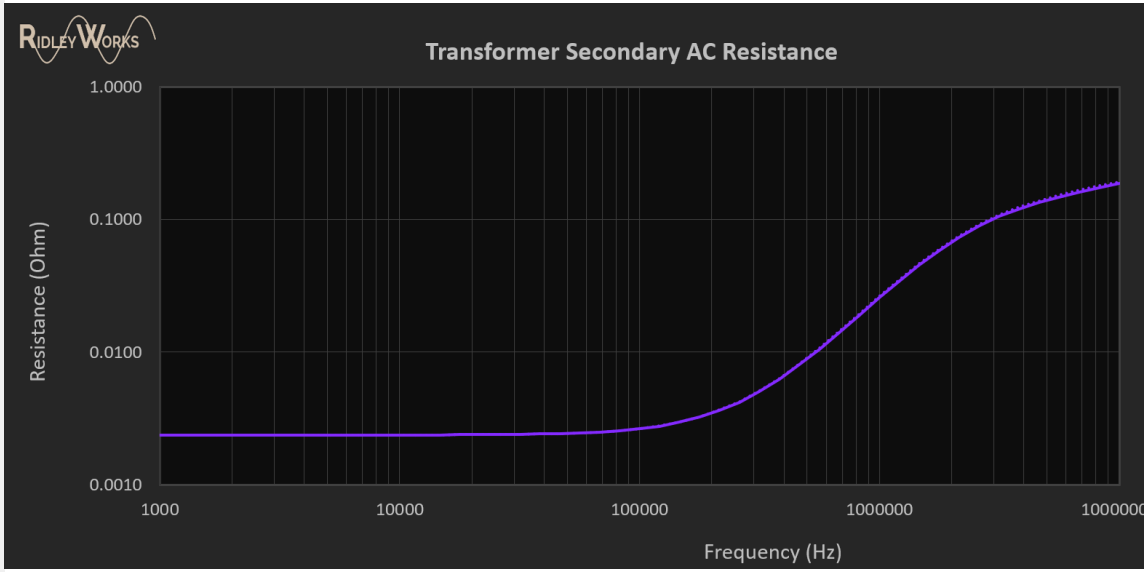
Proximity Loss Sweep AC Resistance Σ



Note – thin value of foil gives best results.

Transformer Secondary Winding Design in RidleyWorks





Note – thin value of foil gives best results.

Alternate Secondary Winding Design in RidleyWorks

Transformer Secondary Winding Design

AVAILABLE WINDOW

Margin Required 0 mm each end 1.2 cm Available Window

Insulation Required 0 mm total 0.168 cm

MAIN SECONDARY OUTPUT

Output Voltage 24 V Output Power 120 W

Number of Turns 5

WINDING STRUCTURE

Litz Wire Magnet Wire Triple Insulated Wire Foil

Number of Layers 1 Minimize Loss Number of Parallel Wires 2

Maximum Conductor Size That Will Fit Exactly is 20 awg

Your Choice of Conductor Size 20 awg

Update

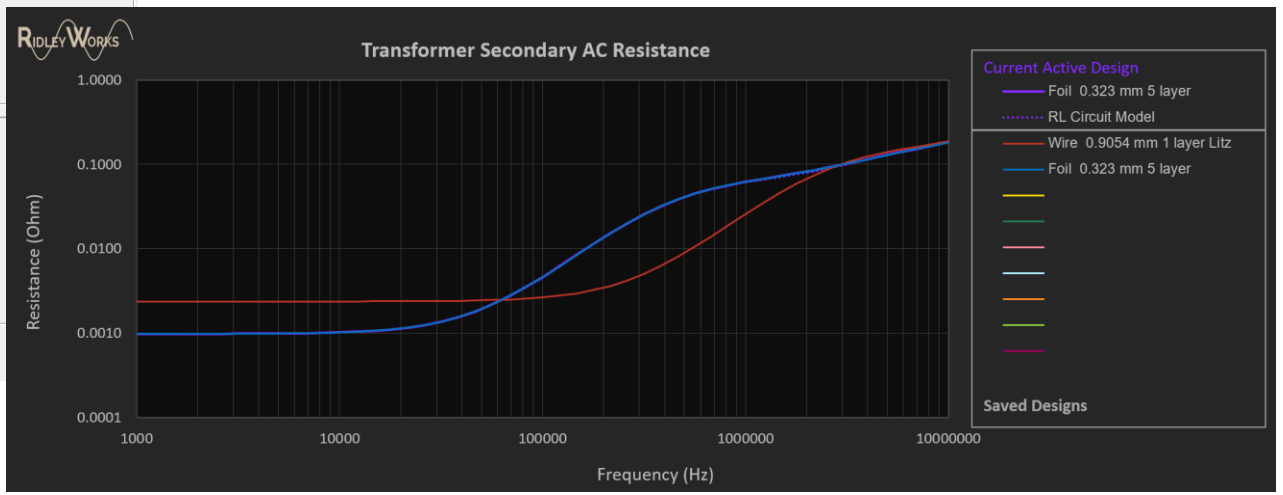
WINDING LOSS DETAILS

RMS Current	7.033	A	Winding Loss (Including Proximity)	0.377	
DC Current	2.827	A	Winding Loss (without Proximity Loss)	0.346	
AC Current	6.439	A	Winding Surface Area	5.2	
DC Resistance	0.0035138	Ω			
AC Resistance	0.004213	Ω			

Proximity Loss Sweep AC Resistance

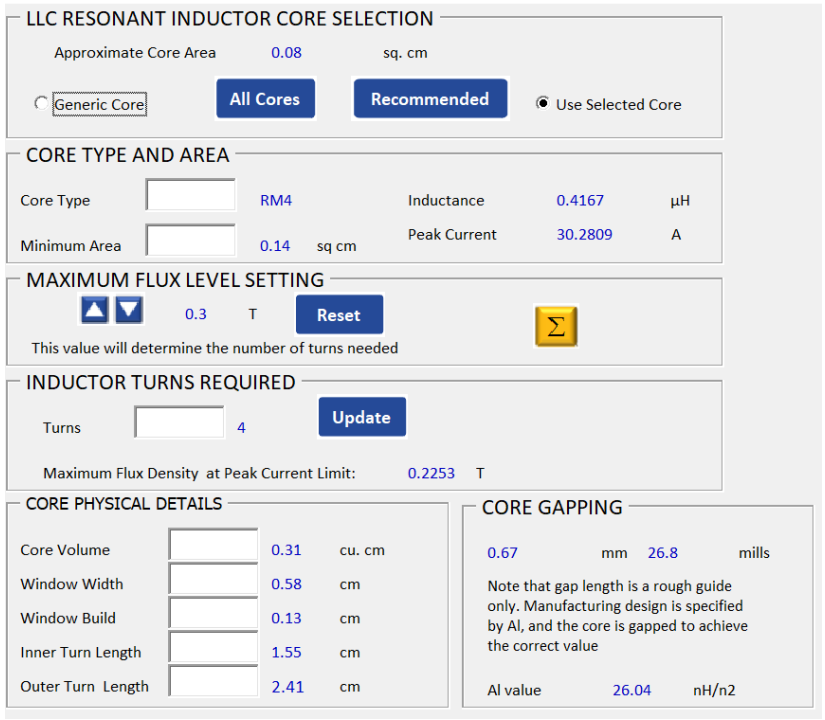
Help

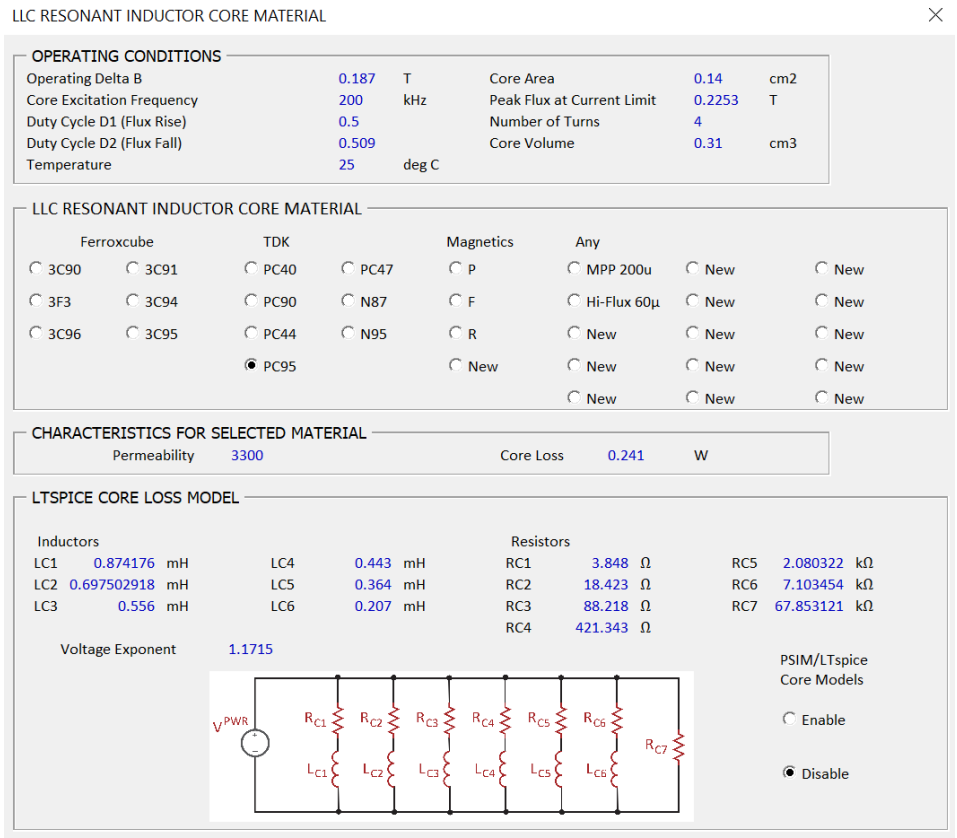
Once you select OK, values appearing on this form will be used in the converter simulation.



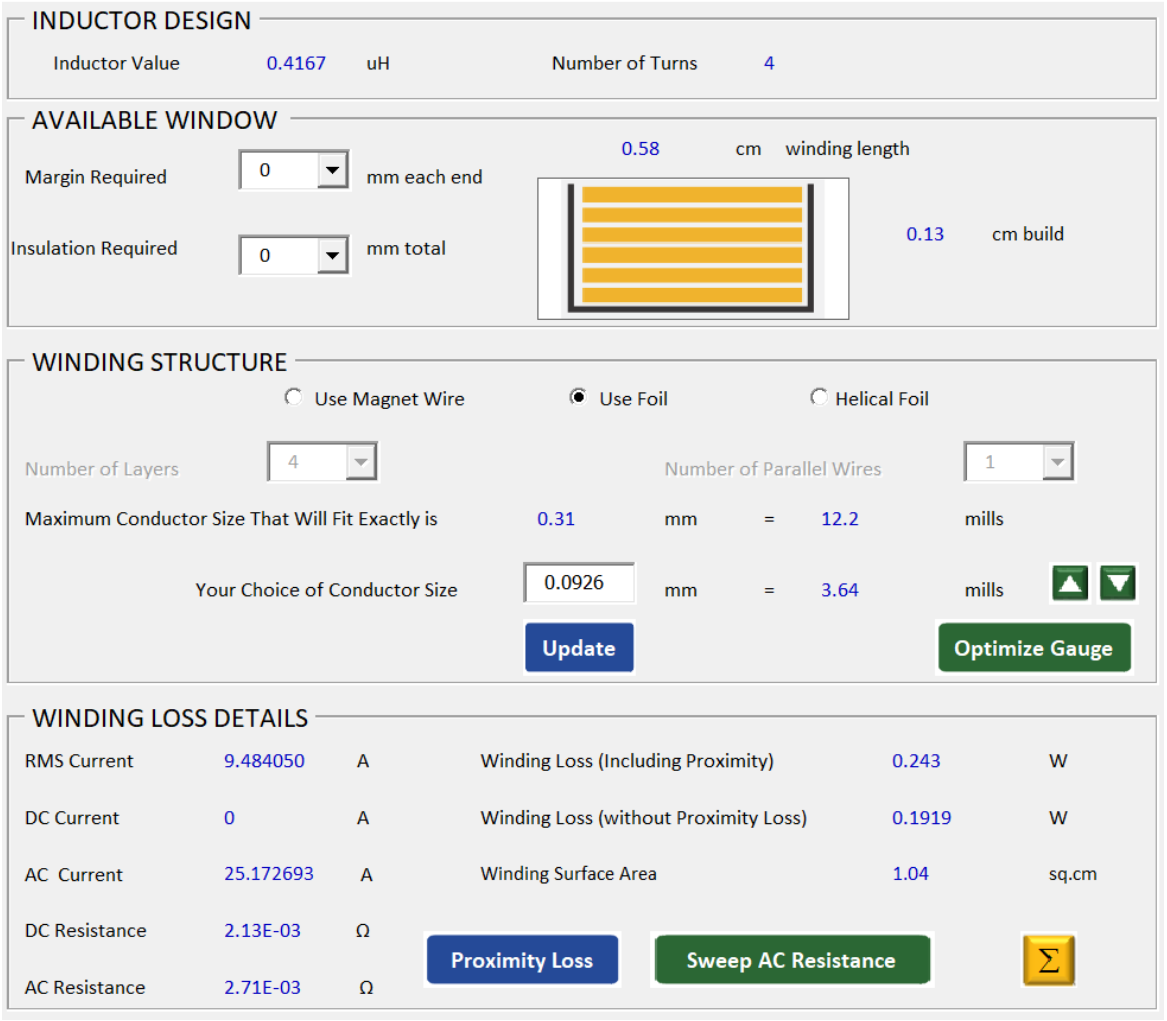
Note – there are lots of choices for winding design

Resonant Inductor Core Design in RidleyWorks

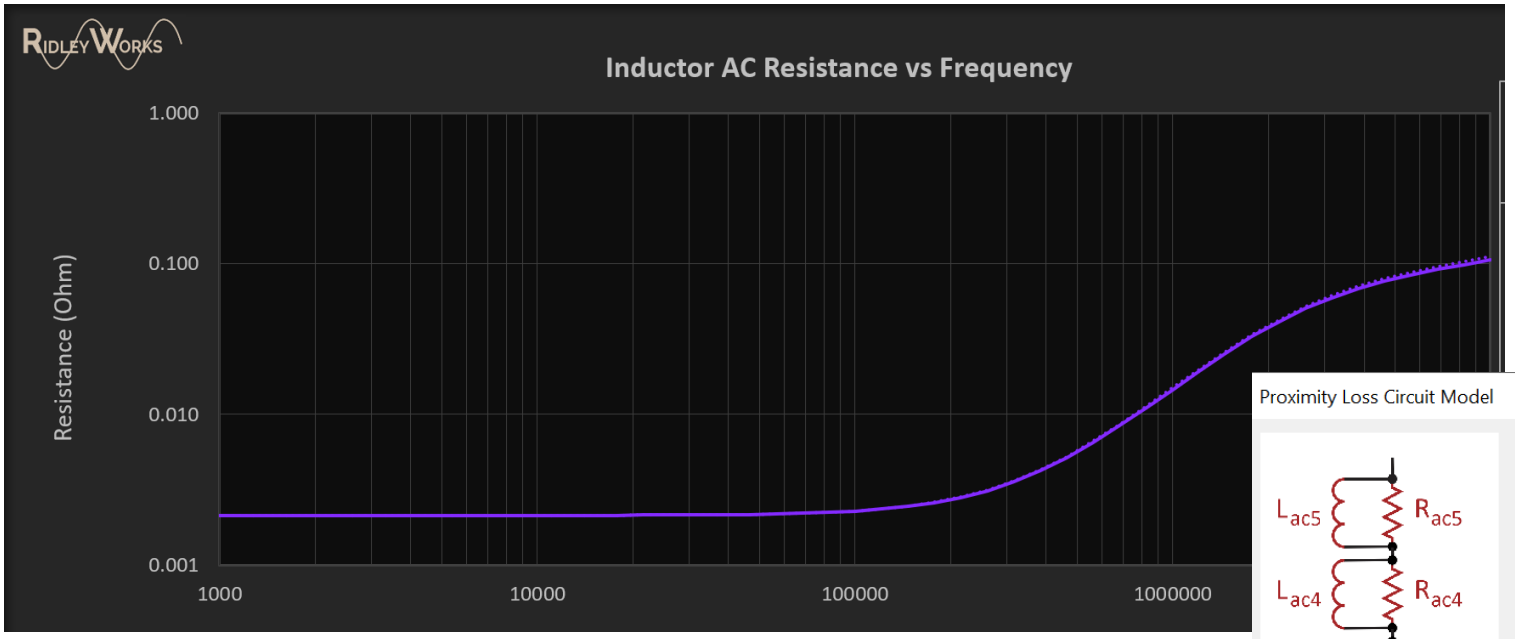


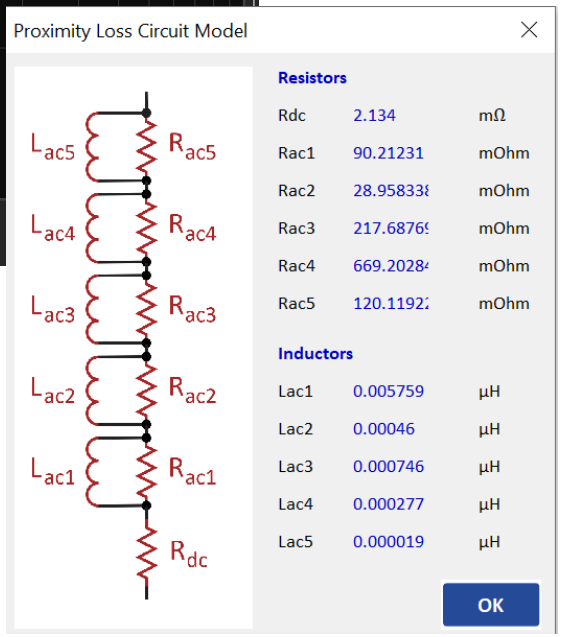


Resonant Inductor Winding Design in RidleyWorks

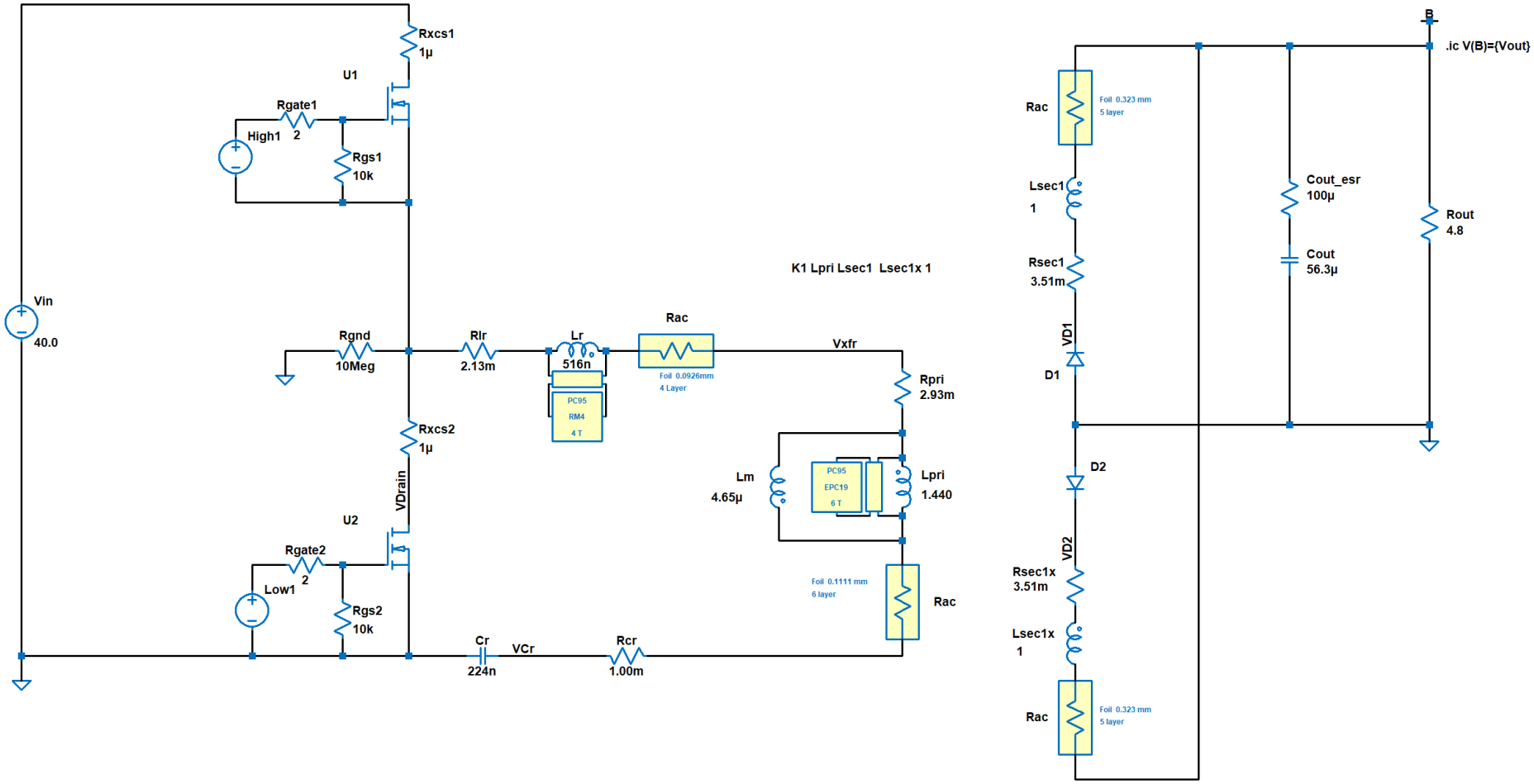


Resonant Inductor AC Resistance from RidleyWorks



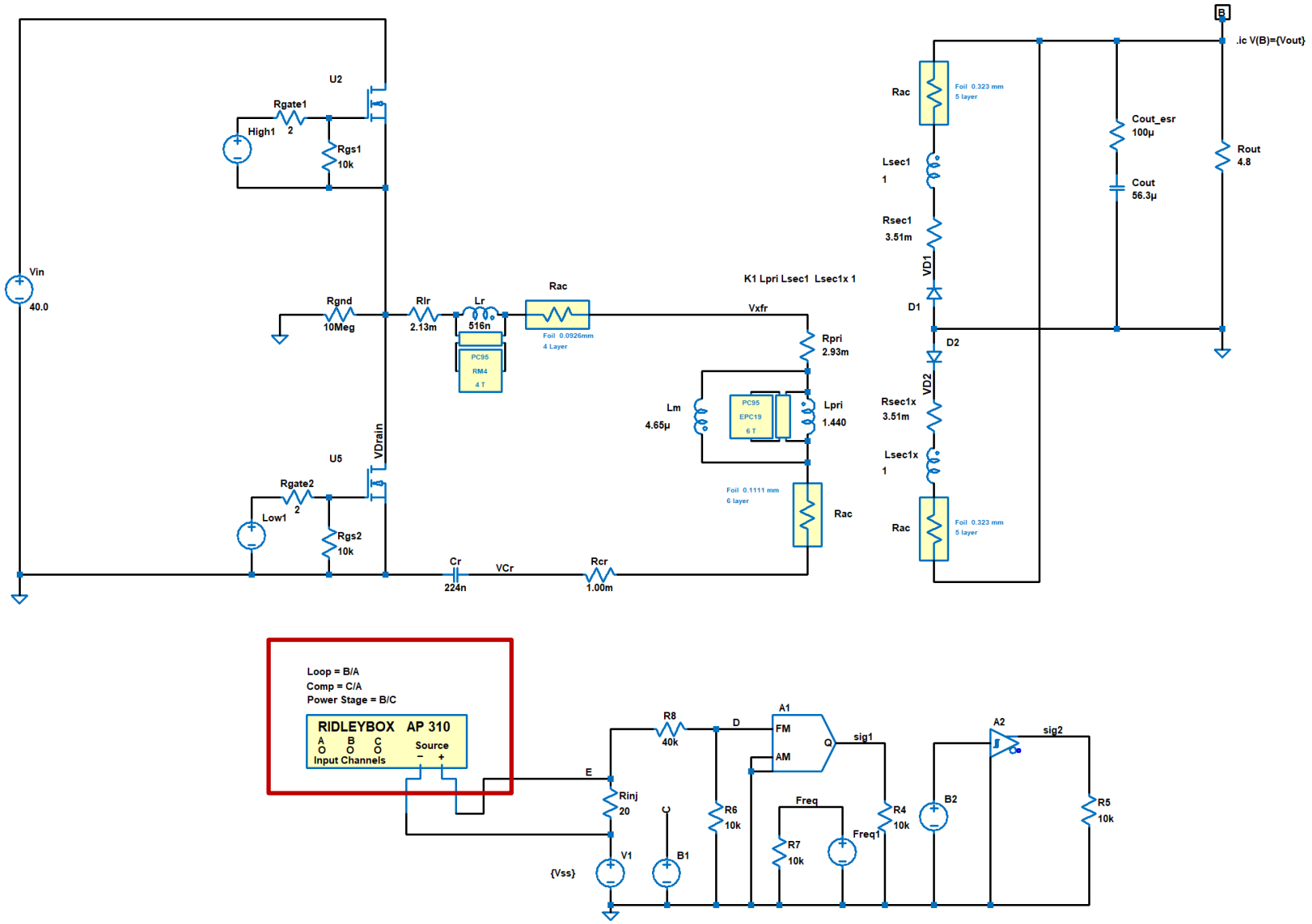


LTspice Simulation with Full Inductor and Transformer Proximity and Core Loss Models



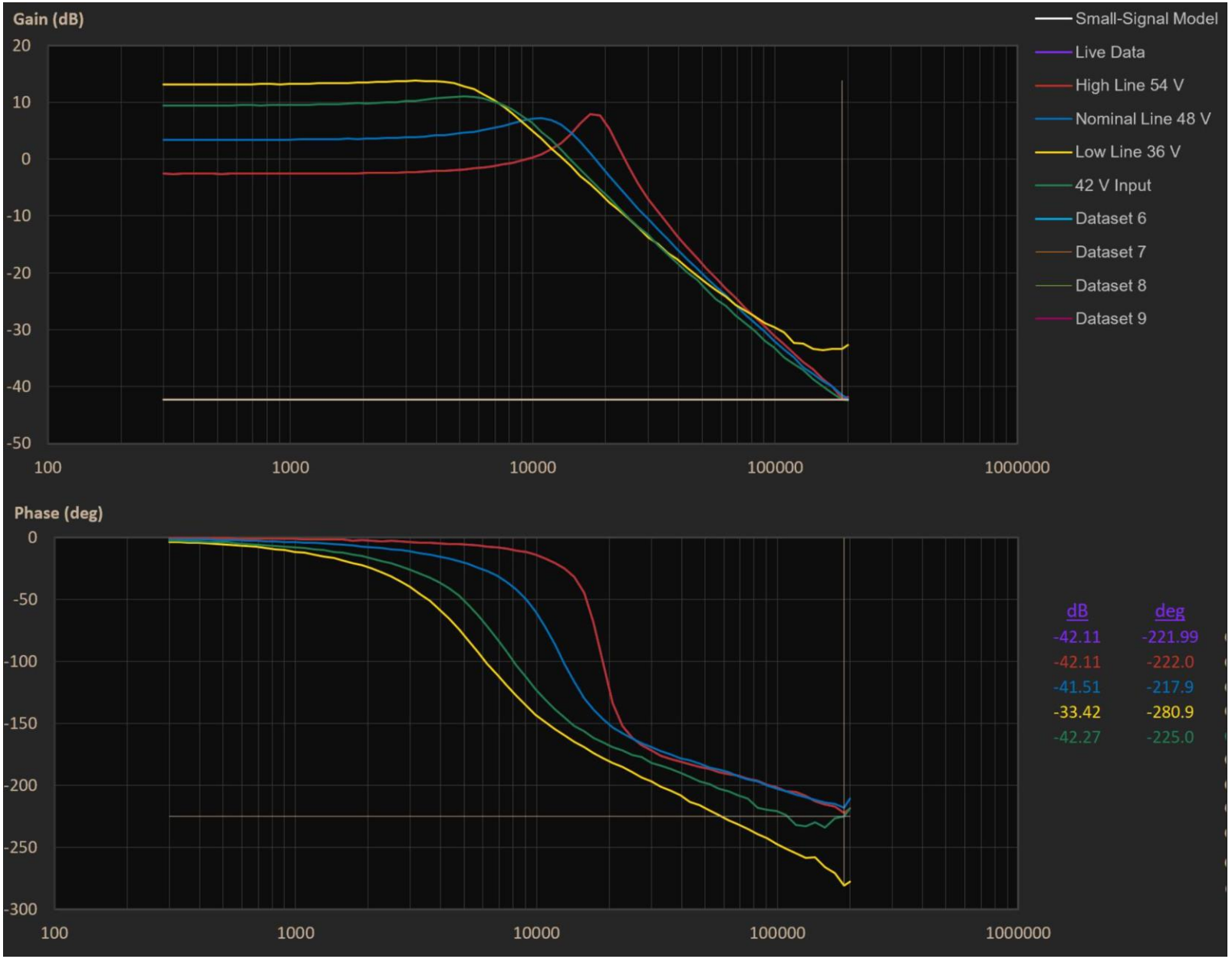
Note – 34 extra inductors in simulation circuit.
LTspice doesn't have any problem with this

LTspice Simulation of Control Transfer Function



3 LLC POWER STAGE.asc

LTspice Simulation of Control Transfer Function

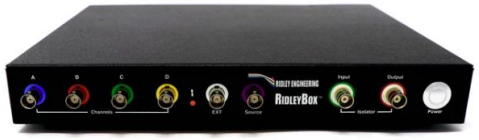


Next Webinar Topic?

Magnetics?
Control?
Modeling?
Measurement?
Topologies?
Simulation?
Other?

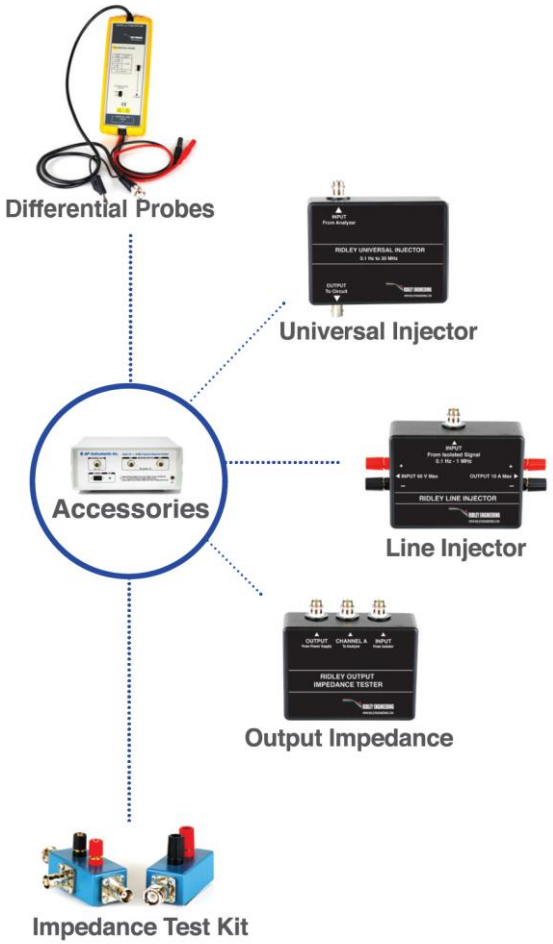
Ridley Engineering Products

Frequency Response Analysis Tools



RidleyBox

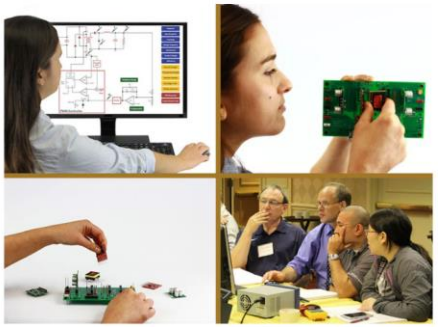
AP Model 310



Hands-On Design Workshops

5-Day Workshop: DEC 5-9, 2022 in Camarillo, CA

Sold out



5-Day Workshop: MAR 6-10, 2023 in Camarillo, CA

$3,500.00

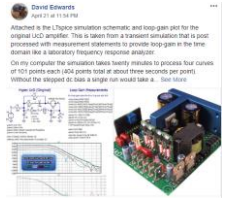
5-Day Workshop: JUN 12-16, 2023 in Camarillo, CA

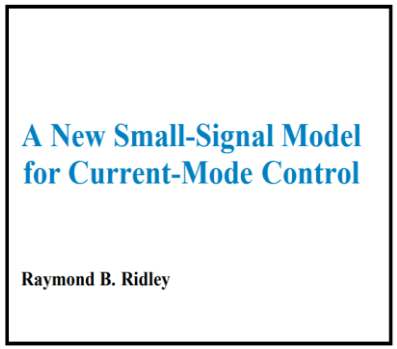
$3,500.00

RIDLEY WORKS®

Email info@ridleyengineering.com
For full demo

Power Supply Design Center Facebook Group





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