Boost Inductors:

Design for Cost and Loss Minimization

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EDN INNOVATION
Honoring Excellence in Electronics
FINALIST 2009

ISO9001:2008 Registered

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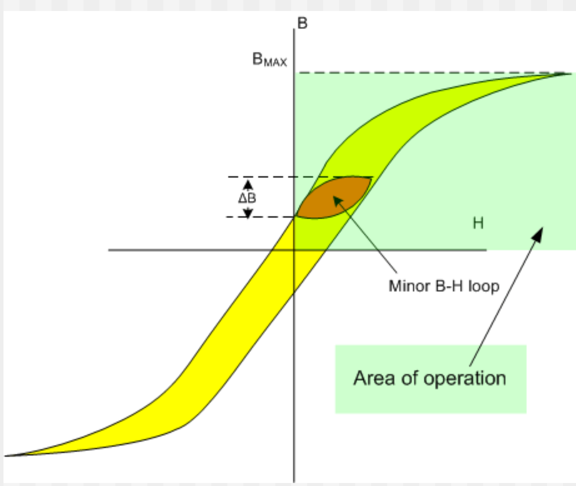
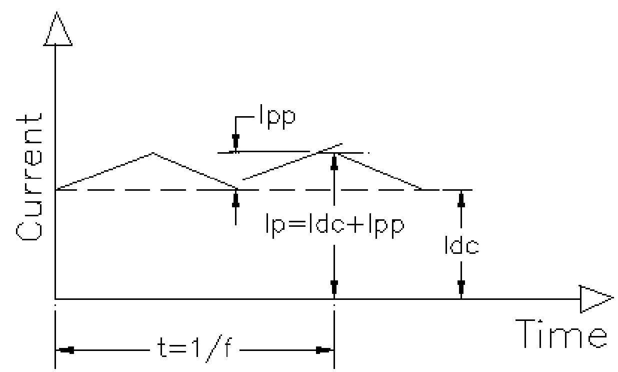
Loss and Saturation both Effect the Boost Inductor

- DC bias: saturation at peak current.
- AC ripple: losses in core and copper.
- Inductance: effects ripple.





Topics

Will discuss:

- Core material comparison, loss/cost/turns*Idc
- Gapped E core windings: cost and loss comparison

Will not discuss:

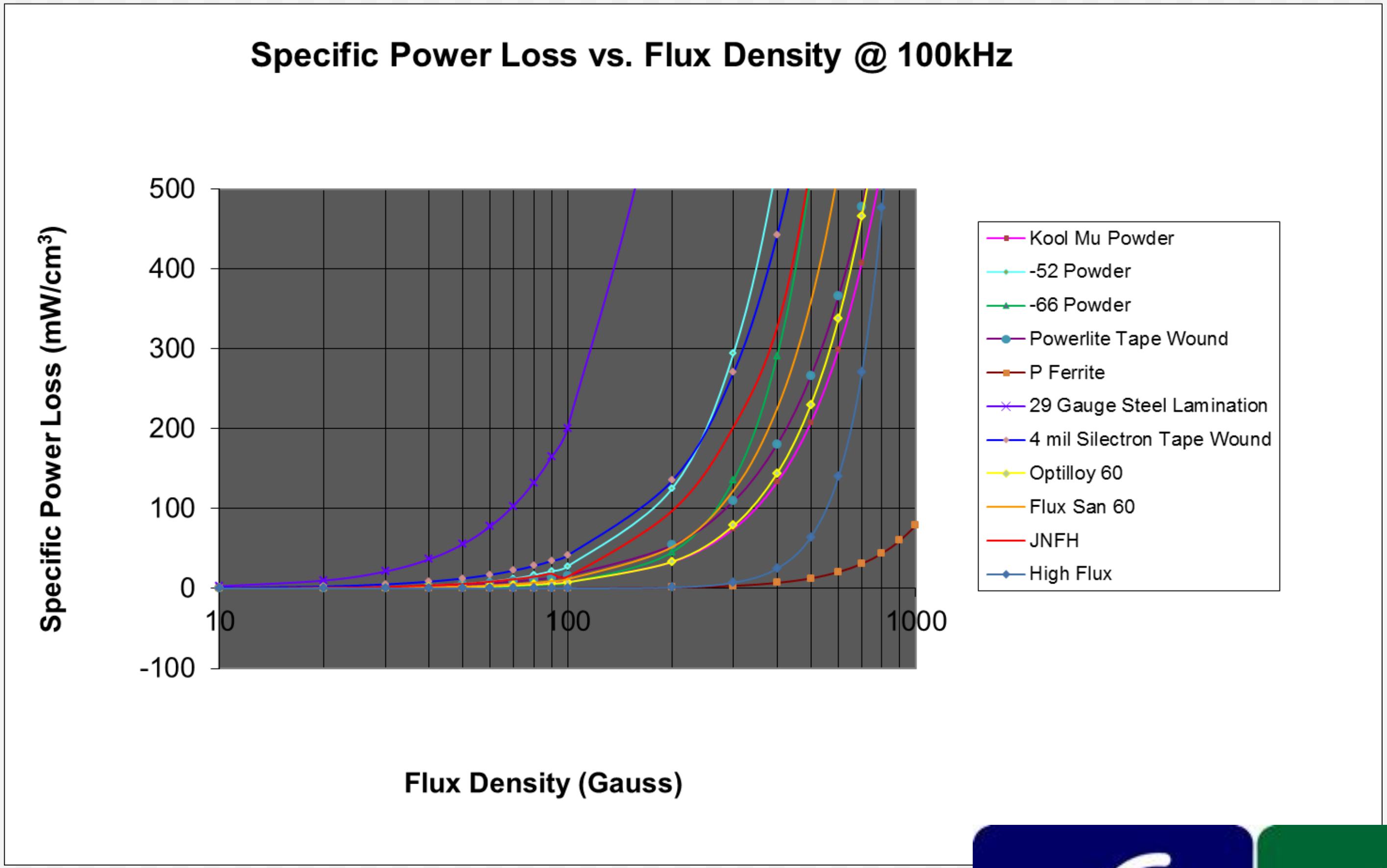
- Toroidal windings
- Sizing of inductor, choice of inductance value
- Reduction of size from thermal management

Scope: 1 kW to 100 kW
1 kHz to 500 kHz

Material Properties

			POWDERED CORES (distributed gap)				STRIP WOUND CORES (discrete gap)			SOFT FERRITES (discrete gap)	LAMINATIONS
	Fe	Fe	Fe Al Si	Fe Ni	Fe Si	Fe Al Ni Al	Fe Si	Fe Si	Amorphous	Mn Zn Fe	Fe Si
		200C rated		50-50			0.004"	0.004"	Alloy 2605 SA1		29 gauge
Trade Name	Iron Powder	Iron Powder	Kool mu	Hi Flux	Flux San	Optilloy	Microsil	JFNH	Metglas	3C90	Magnesil
	Material 52	Material 66	Sendust	High Flux	X Flux						
Manufacturer	Micrometals	Micrometals	Micrometals Mag Inc	Micrometals Mag Inc	Micrometals Mag Inc	Micrometals Mag Inc	Magnetic Metals	JFE Steel Co.	Hitachi	Magnetics Inc.	Tempel Steel
Cost ($/cm3)	.066	.138	.141	.35	.15	.26	.81	.9	.73	.1	low
Density (gm/cm3)	7	6.2	5.5	6.87	6.8	6.64	7.7	7.7	7.8	5.1	7.5
Bsat (gauss)	18000	15000	10500	7500	16500	14000	18000	18000	15600	5000	18000
Initial Permeability	75	66	26-125	14-160	26-60	14-125	200-2000	200-2000	45-600	50-2500	200-2000
Cont. Operating Temp (deg. C)	100	200	200	200	200	200	500	500	150	200	500
Curie Temp. (degrees C)	770	750	460	400	700	400	750	750	399	200	750
Available Geometries	E-core, Toroid	E-core, Toroid	E-core, Toroid	Toroid	Toroid	Toroid	C-core	C-core	C-core, toroid	All	EI, UI

Core Loss at 100 kHz



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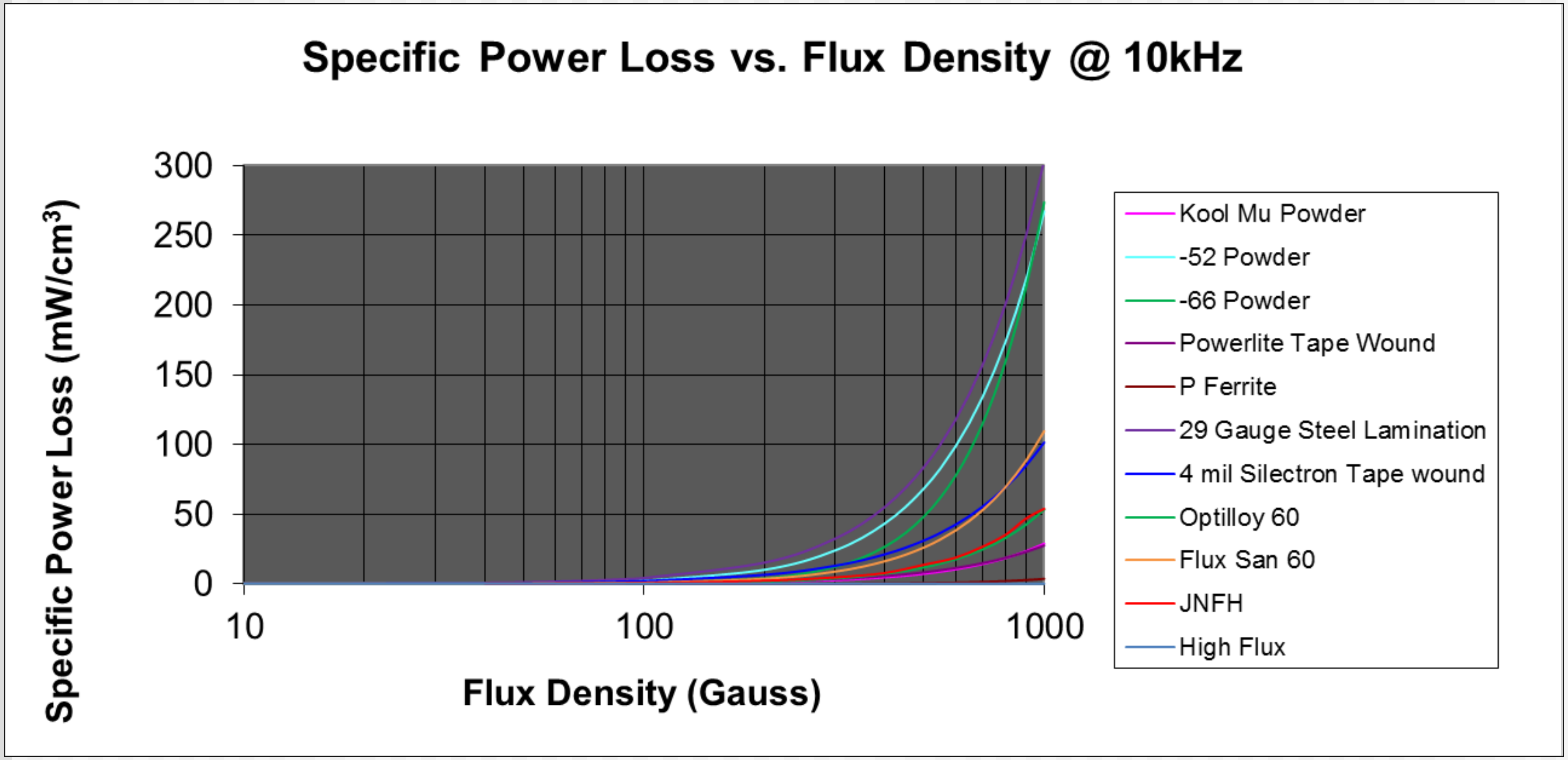
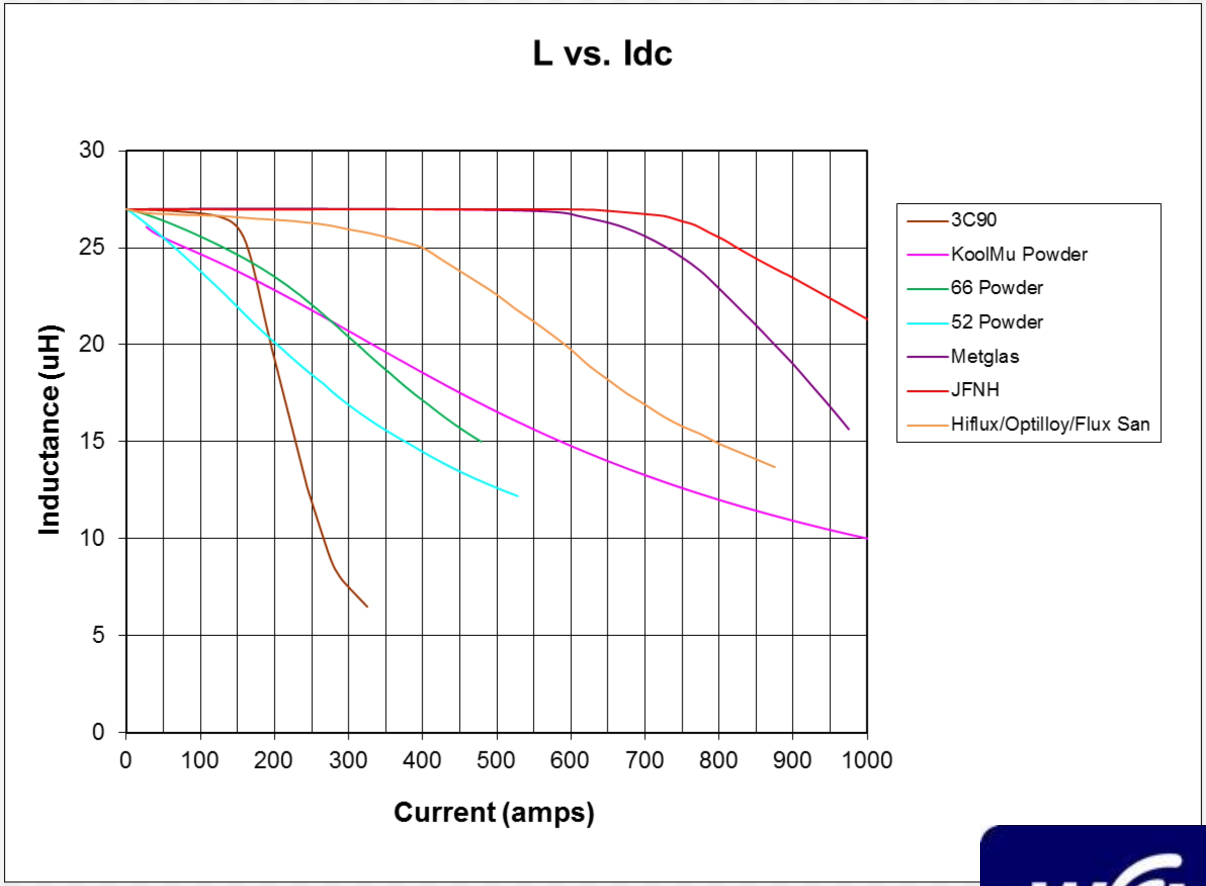
Core Loss at 10 kHz



Saturation of Core Materials



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Design Comparison

- 65 uH, 30 Adc inductor
- Wind with 10 awg on toroidal core
- Design steps

Ignore losses, choose the smallest toroidal core that will support 65 uH minimum at 30 Amps.

Calculate loss and core T rise as a function of ripple and frequency.
Determine size and estimate cost.

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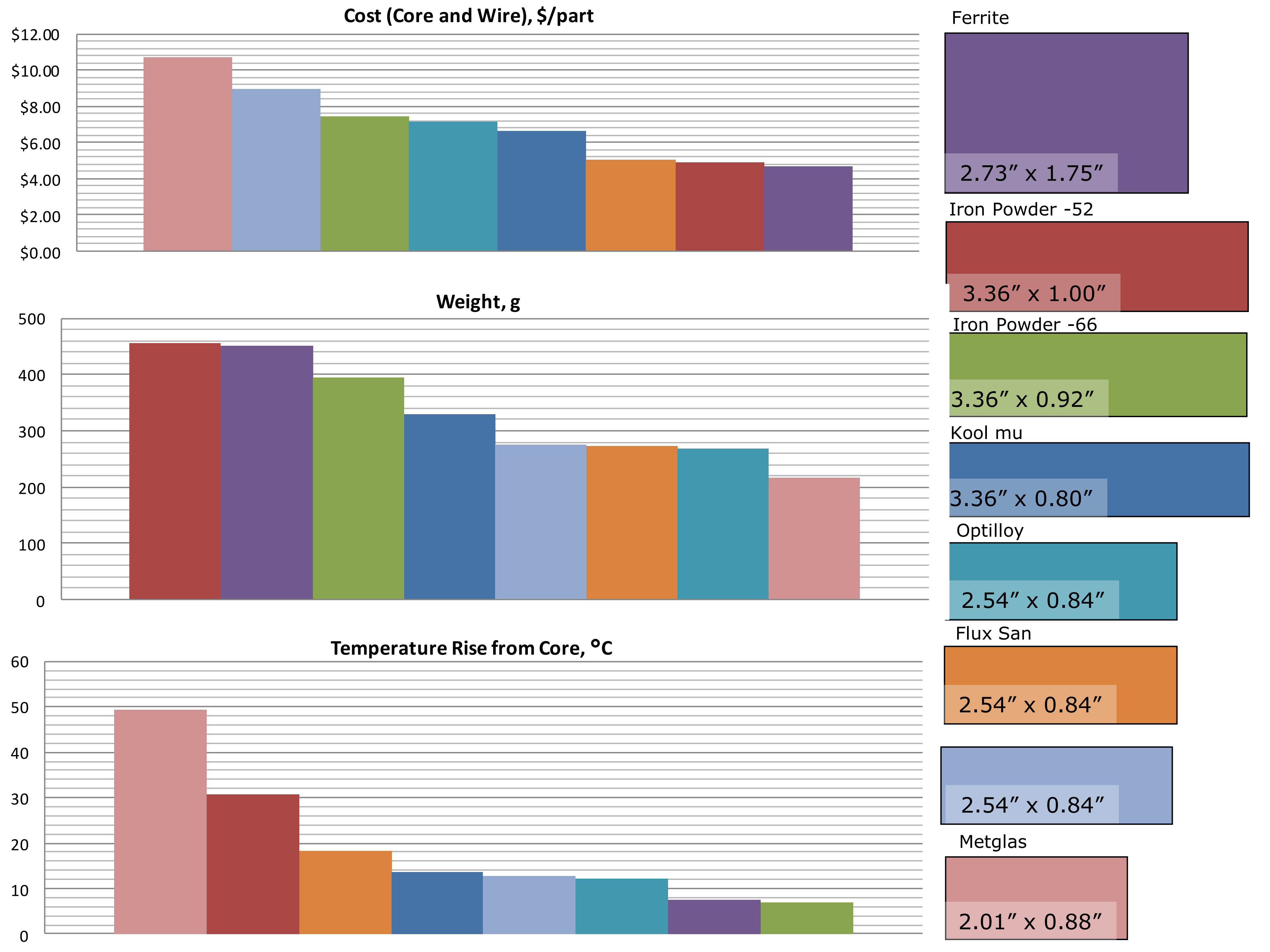

Cost (Core and Wire), $/part
$12.00
$10.00
$8.00
$6.00
$4.00
$2.00
$0.00
Weight, g
500
400
300
200
100
0
Temperature Rise from Core, °C
60
50
40
30
20
10
0
Ferrite
2.73″ x 1.75″
Iron Powder -52
3.36″ x 1.00″
Iron Powder -66
3.36″ x 0.92″
Kool mu
3.36″ x 0.80″
Optilloy
2.54″ x 0.84″
Flux San
2.54″ x 0.84″
2.54″ x 0.84″
Metglas
2.01″ x 0.88″

Components of Inductor Loss

dc loss

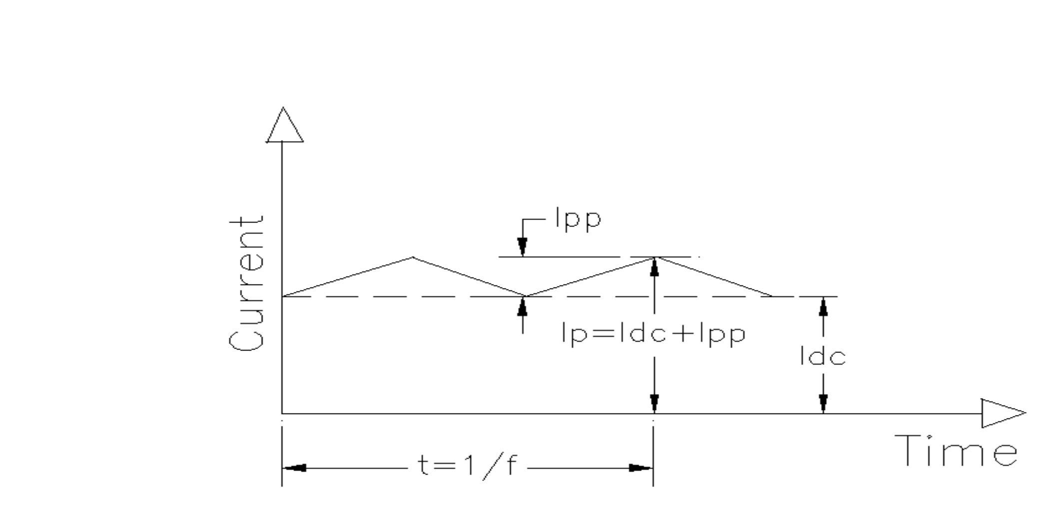
$$P_{dc} = I_{dc}^2 R_{dc}$$

Winding only

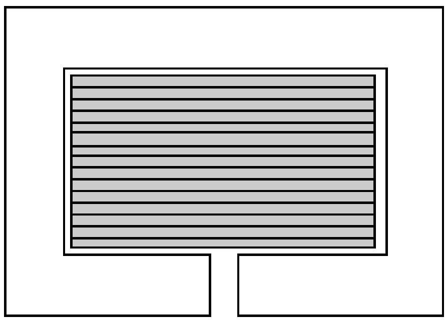
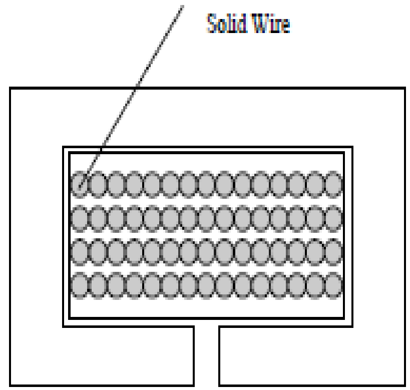
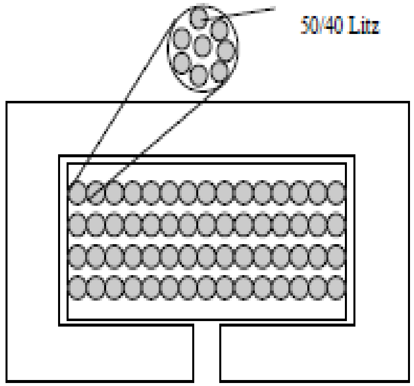
ac loss

$$P_{ac} = I_{ac,rms}^2 R_{ac}$$

Core and winding



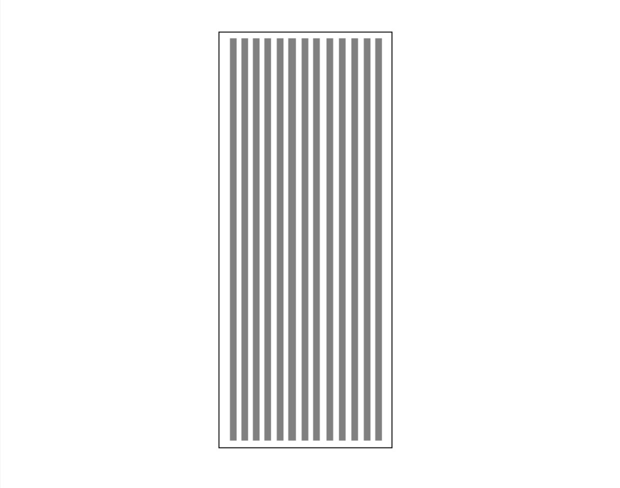
Comparison of DC Resistance: Foil, Solid Wire & Litz Wire

FOIL	SOLID WIRE	50/40 awg LITZ WIRE
		
DCR = very low	DCR = low	DCR = medium/high

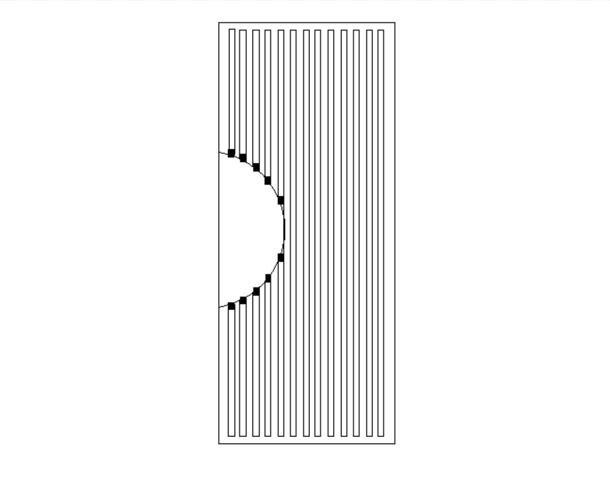
- Foil windings:
  - Fast and easy to wind
  - Do not require bobbins or other supports

Current Distribution: Ungapped E-Core and Gapped E-Core

Full Foil:
Ungapped Core



Shaped Foil:
Gapped Core



AC current evenly distributed on surface of foil across full width of foil.

AC current pulled to small copper cross section in the vicinity of the gap.

Shaped Foil is a patented technology developed by Professor Charles Sullivan and Dr. Jennifer Pollock at Dartmouth College.

Experiment: What is the Loss/Cost Tradeoff for the Different Windings?

- Step 1: Define the Inductor
  - Inductance: 70 uH
  - Current: 40 Adc
  - Core: E70/33/32 Ferroxcube 3C90 material
  - Gap: 2.64 mm (1.32 mm each center leg)
  - Turns: 16
- Step 2: Wind inductors with conventional windings using best practices
  - Full window
  - Single layer
- Step 3: Determine winding losses for each inductor as a function of ripple magnitude

shaped foil™

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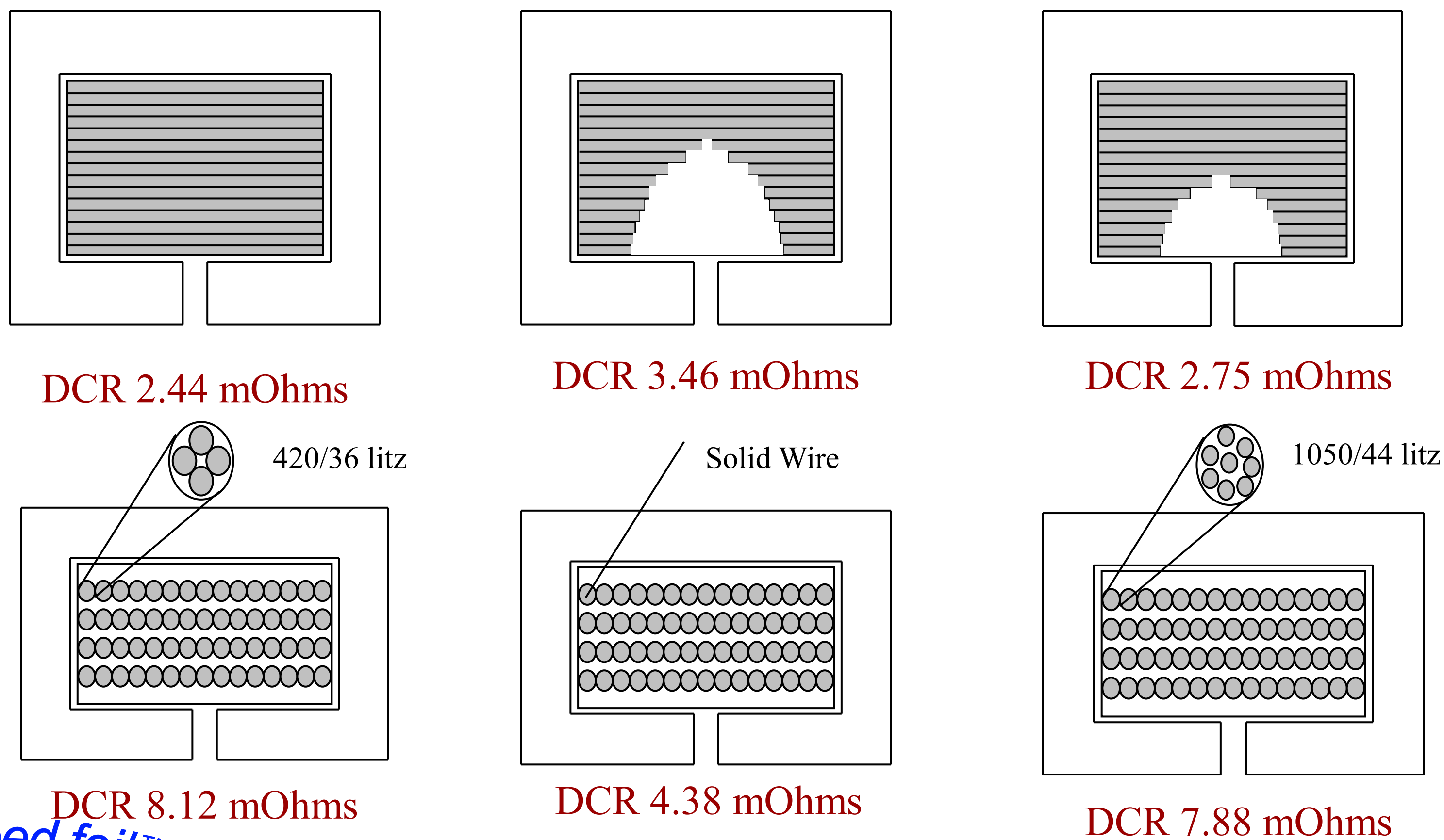
Winding Cross Sections



Winding Cost Comparison

	12 awg	1050/44	210/36	full foil	0.4 cut out	0.3 cut out
$/LB	$5.061	$49.74	$16.97	$4.91	$4.91	$4.91
$/LB regained	-	-	-	-	$4.00	$4.00
Tape 3M56	$100.00	$100.00	$100.00			
Cost 3M Tufquin for 1000 parts	-	-	-	$331.98	$331.98	$331.98
weight with bobbin	0.50766	0.35805	0.26974	-	-	-
without bobbin	0.48802	0.33841	0.2501	0.87325	0.87325	0.87325
LBs for 1000 parts	488.02	338.41	250.1	873.25	873.25	873.25
Cost for 1000 parts	$2,469.87	$16,832.51	$4,244.20	$4,287.66	$4,287.66	$4,287.66
Recovered cost for 1000 parts	-	-	-	-	$820.00	$356.00
Total Cost for 1000 parts	**$2,569.87**	**$16,932.51**	**$4,344.20**	**$4,619.63**	**$3,799.63**	**$4,263.63**

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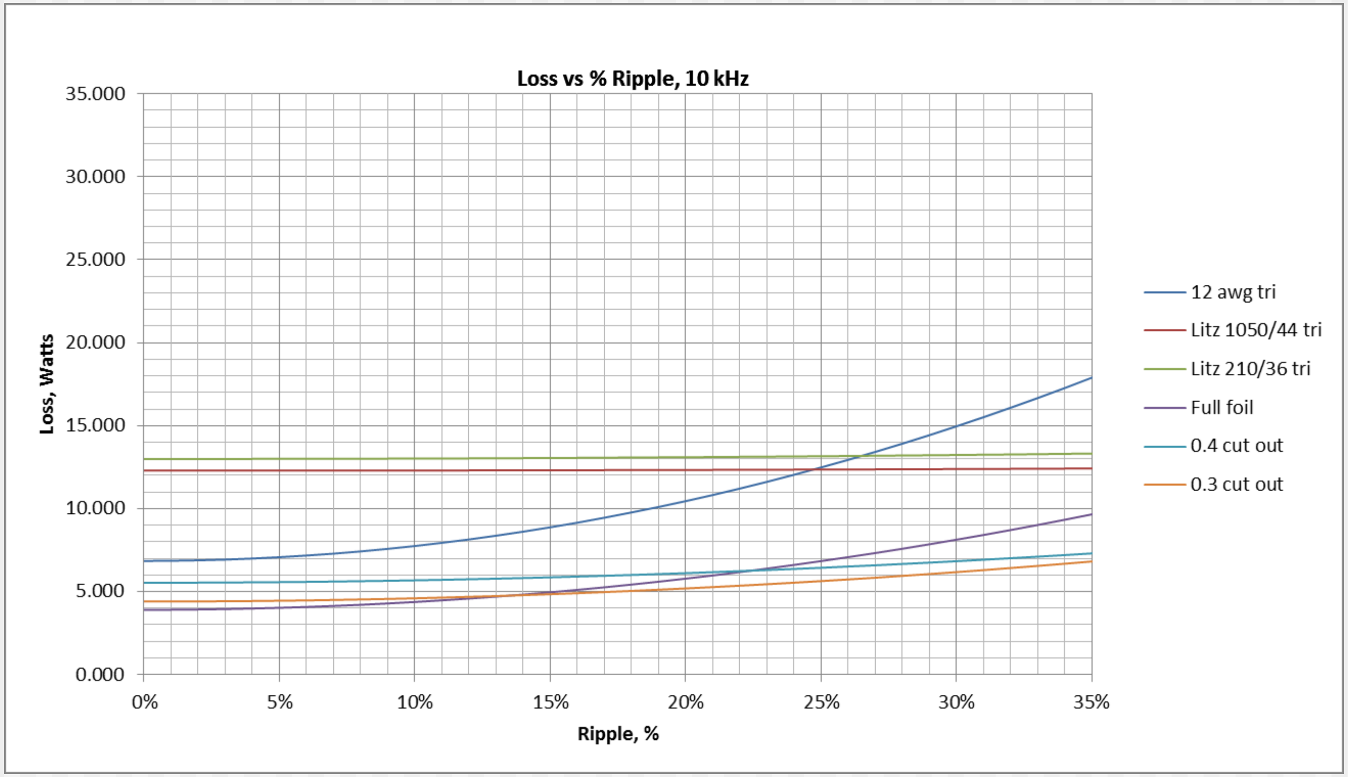
Total Winding Loss vs. Ripple Current 10 kHz



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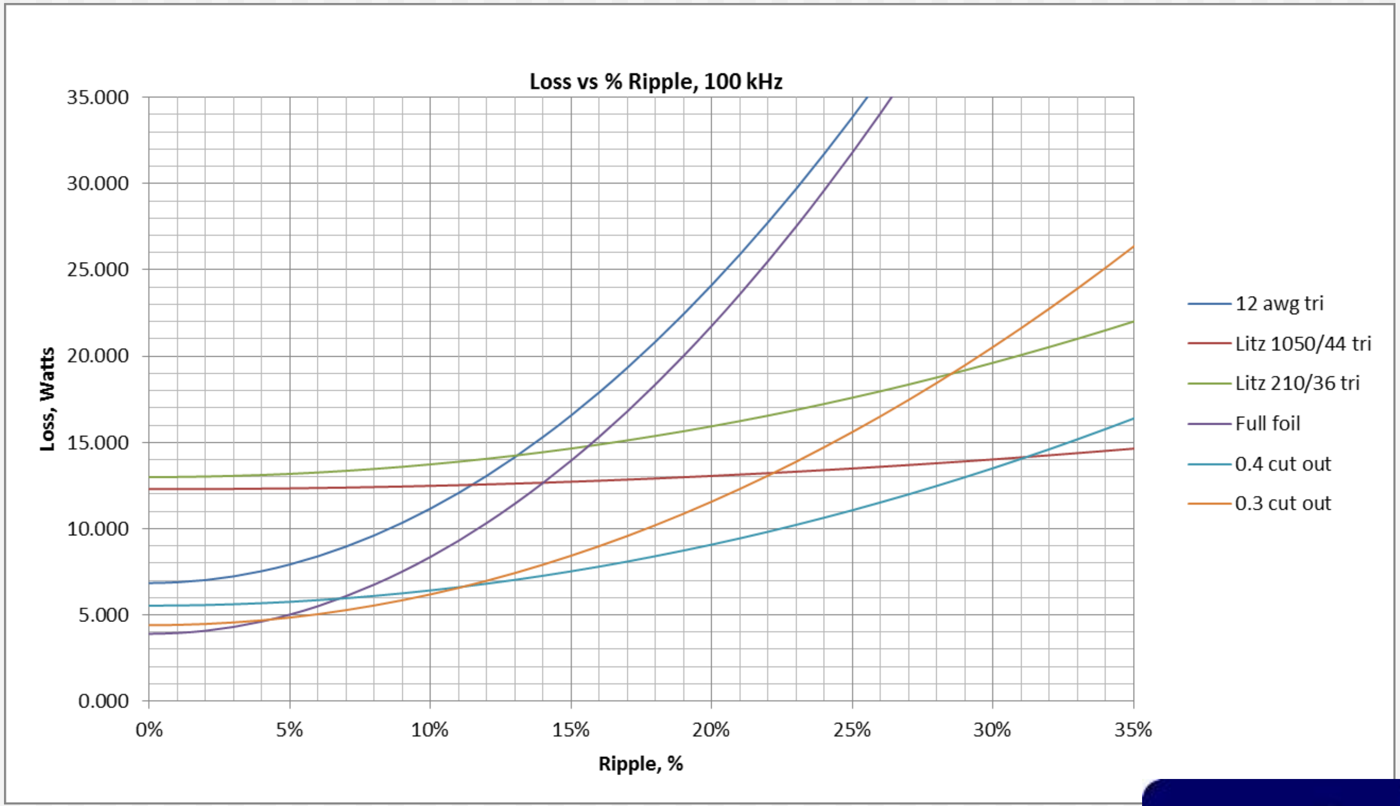
Total Winding Loss vs. Ripple Current 100 kHz



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Thank you for your time

Weyman Lundquist, President

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