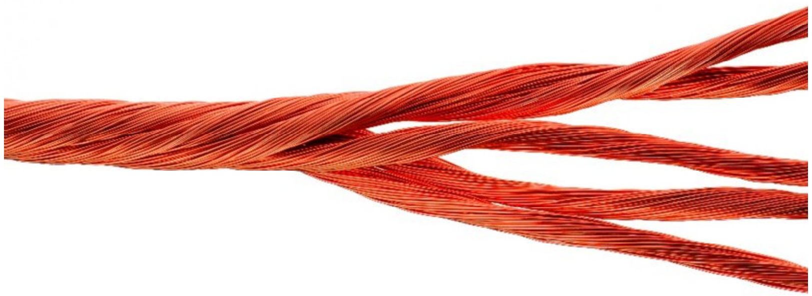
LITZ WIRE

A Practical Discussion of Its Uses and Limitations
in High Frequency Transformers



Kyle D. Jensen
Field Application Engineer

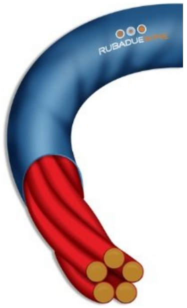
What is Litz Wire?

- *Litzendraht* – German word for “Stranded”

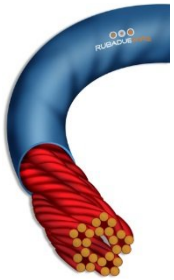
- While any stranded conductor can be referred to as Litz, we use the term to describe a conductor manufactured by twisting together individually insulated wires in specific patterns to produce a desired electrical effect.

What is Litz Wire?

- Typically Referred to by Type
- Type 1 – Simple construction where individual wires are twisted together in one operation.



- Type 2 – Simple construction where individual wires are twisted together in two operations, usually in opposing directions.

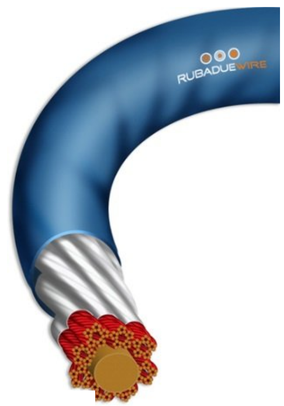


What is Litz Wire?

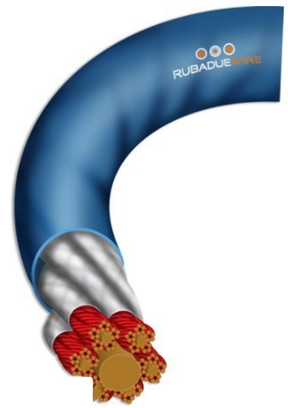
- Type 3

Type 4

Type 5



Type 6



- Very specialized constructions to help further reduce eddy currents in higher power applications. Also found in Power Transfer and RF applications.

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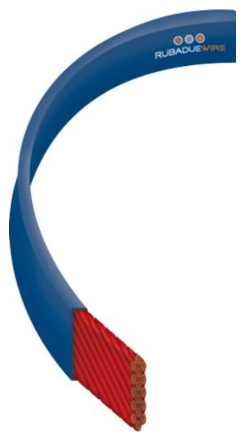
What is Litz Wire?

- Type 7

Type 8



- Useful in applications where high aspect ratios are beneficial.

Type 9 (Coaxial)

- Very specialized design for high power transfer applications.
- Usually matched copper area for inner & outer conductors

Why Use Litz Wire?

- When changing from a DC based design to one that employs AC, designers must take into consideration several key concerns that will affect the ultimate performance of the end product.

- Skin Effect
- Proximity Effect
- Increased Resistance in the winding

Why Use Litz Wire?

- **Skin Effect** – the tendency for current in an AC circuit to flow on the outer edges of the conductor resulting in increased resistance.
- **Proximity Effect** - the tendency for current to flow in other undesirable patterns (loops or concentrated distributions) due to the presence of magnetic fields generated by nearby conductors.
- In transformers and inductors, proximity-effect losses typically dominate over skin-effect losses.

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Why Use Litz Wire?

- To overcome Skin Effect a Rule of Thumb is to select a conductor with a diameter no larger than 2 skin depths.

f	60 Hz	20 kHz	200 kHZ	1 MHz	10 MHz
δ	8.5 mm	.467 mm	.148 mm	66 µm	21 µm
	1/0 AWG	24 AWG	35 AWG	42 AWG	51 AWG
2δ	17 mm	.93 mm	.30 mm	132 µm	42 µm
	7/0 AWG	18 AWG	29 AWG	36 AWG	45 AWG

Source: C. R. Sullivan, High Frequency Windings, APEC 2014 Industry Session Presentation

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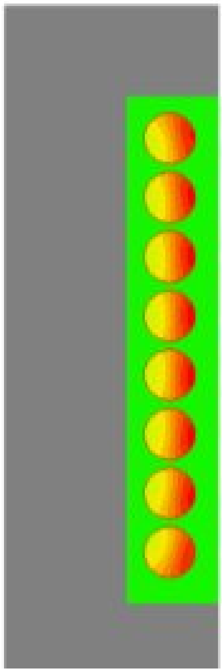
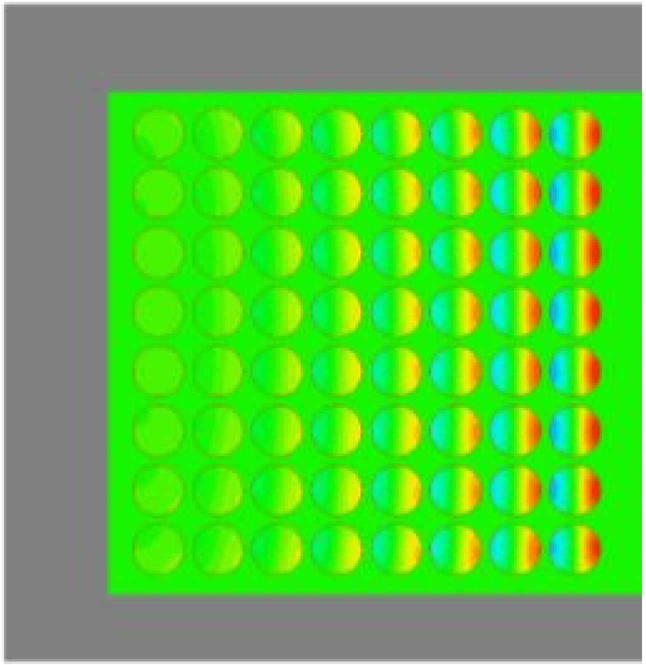
Why Use Litz Wire?

Example: Frequency = 200 kHz | Wire Diameter = 0.3 mm (approx. 29 AWG)



Rac/Rdc = 1.36



Rac/Rdc = 27.7

Source: C. R. Sullivan, High Frequency Windings,
APEC 2014 Industry Session Presentation

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Why Use Litz Wire?

- Designing with Proximity Effect in Mind

The effect of using many layers (Simplified 1-D analysis):

For p layers, the layer thickness (t) for minimum R_{ac} can be expressed as: $t = 1.3\delta/\sqrt{p}$

Achievable R_{ac} is proportional to: $1/\sqrt{p}$

A wire diameter of δ/10 is a target.

However, @ 1 MHz, δ/10 = 6.6 µm (.0002598” nom)

For reference: 58 AWG = .00039” OD

Source: C. R. Sullivan, High Frequency Windings, APEC 2014 Industry Session Presentation

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Why Use Litz Wire?

- Using Litz wire has the potential for improvement over single-layer solid wire.

$$\frac{P_{litz}}{P_{solid}} \approx 0.58 \frac{d}{\delta}$$

	f	300 kHz	1 MHz	3 MHz	10 MHz
	δ	.148 µm	66 µm	38 µm	21 µm
Strand Size		**Loss Reduction**			
44 AWG	51 µm	80%	55%	22%	***NONE***
46 AWG	40 µm	84%	65%	39%	***NONE***
48 AWG	32 µm	87%	72.7%	51%	11%

Source: C. R. Sullivan, High Frequency Windings, APEC 2014 Industry Session Presentation

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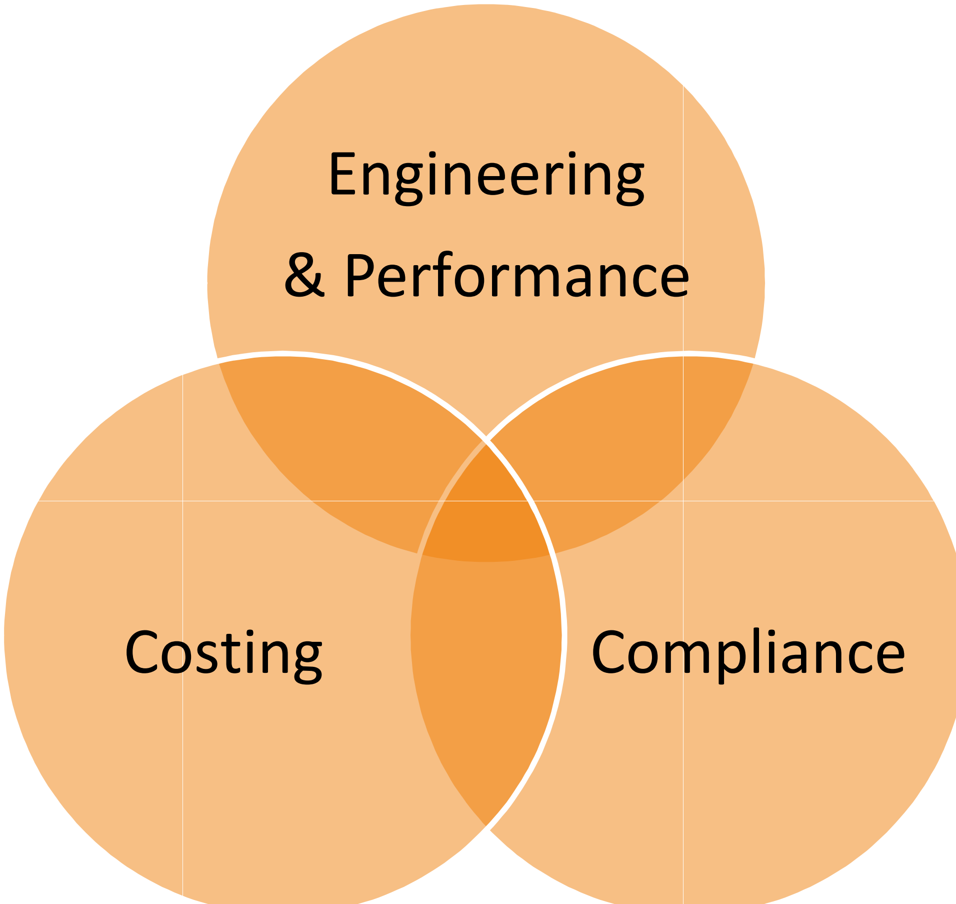
How to Design with Litz Wire



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How to Design with Litz Wire

- **Compliance**

- Needs to be included at the beginning of the conversation, not the end…
- Critical for proper material selection and design considerations – insulation requirements, thickness, temp class, simple recognized components or full Electrical Insulation System required???

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How to Design with Litz Wire

- **Design Considerations**
  - Operating Frequency or Effective Frequency for nonsinusoidal currents.
  - Total Current
  - Voltage / Electrical Insulation Requirements
  - Acceptable Heat Rise
  - Litz packing factor / increased conductor diameter

How to Design with Litz Wire

- **Design Considerations**
  - Typical Strand Size by Frequency Chart

Operating Frequency	Strand Size AWG	Bare Copper Diameter	DC Resistance (Ω/kFT nom.)
10 kHz – 20 kHz	33	.0071” | .180mm	205.7
20 kHz – 50 kHz	36	.0050” | .127mm	414.8
50 kHz – 100 kHz	38	.0040” | .102mm	648.2
100 kHz – 200 kHz	40	.0031” | .079mm	1079
200 kHz – 350 kHz	42	.0025” | .064mm	1659
350 kHz – 850 kHz	44	.0020” | .051mm	2593
850 kHz – 1.4 MHz	46	.00157” | .040mm	4207
1.4 MHz – 3.0 MHz	48	.00124” | .031mm	6745

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How to Design with Litz Wire

- **Design Considerations**
- Strand Size by Frequency Charts, while helpful for coming up with a starting point, do not take into consideration anything more than skin depth.
- This narrow focus can lead to more failures.

How to Design with Litz Wire

- **Design Considerations**
  - To determine the number of strands per conductor, the typical methodology is to use a factor such as Amps/mm^2 or circular mil area/Amp.
  - These factors were based on 50/60 Hz components and have since been applied to higher frequency applications.

How to Design with Litz Wire

- **Design Considerations**
  - Typcial current density factors such as 500 cma/A to 1,000 cma/A can result in less than optimal conductor designs as they do not consider the rest of winding design.
  - When properly evaluated, windings can have significantly higher current density.

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How to Design with Litz Wire

- **Design Considerations**
  - When designing with Litz, you must remember that a stranded conductor of a given AWG size can be significantly larger than its solid counterpart.
  - 22 AWG Solid Single MW 80-C = .0266” nom OD
  - 22 AWG 5x32/44 Single MW 80-C = .0344” nom OD
  - This affects number of turns / layer, total layers, copper density, etc…

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How to Design with Litz Wire

- **Design Considerations**
  - With the two most common "Rules of Thumb" called into question, is there a better way?
  - In their paper: *Simplified Design Method for Litz Wire,* Charles Sullivan (Dartmouth College) & Richard Zhang (MIT), present a straight forward approach that considers the winding as a whole to help select an appropriate Litz Wire design.

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How to Design with Litz Wire

- ***Simplified Design Method for Litz Wire***

Determine Skin Depth δ

↓

Find breadth *b* and number of turns/section N_s

↓

Find recommended number of strands using *k* from Table 1

↓

Select design that fits in space and meets resistance required

↓

Calculate max number of strands in 1st bunching operation $N_{1,max}$

↓

Select design with fewer than $N_{1,max}$ strands and in groups of 3, 4, or 5

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How to Design with Litz Wire

Strand AWG Size	33	36	37	38	39	40	41	42	44	46	48
Bare Wire (mm)	.180	.127	.114	.102	.089	.079	.071	.063	.051	.040	.031
k (mm^{-3})	203	771	1.2k	1.8k	2.8k	4.4k	6.7k	10k	24k	54k	115k
Economical F_r	1.07	1.13	1.15	1.18	1.22	1.25	1.30	1.35	1.47	1.60	1.68

Source: C.R. Sullivan, R. Zhang; Simplified Design Method for Litz Wire, Table 1

Skin Depth

$$\delta = \sqrt{\frac{\rho}{\pi f \mu_0}}$$

$\rho = 1.72\text{x}10^{-8}$ Ω▪m (Copper @ 20°C)
$\rho = 2\text{x}10^{-8}$ Ω▪m (Copper @ 60°C)
f = Frequency of sinusoidal current
$\mu_0 = 4\text{x}10^{-7}$ πH/m (permeability of free space)

Number of Strands

$$n_e = k\frac{\delta^2 b}{N_s}$$

k = Value in Table 1 above
δ = Skin Depth
b = Breadth of winding
N_s = Number of turns

Max Strands 1st Bunch

$$N_{1,max} = 4\frac{\delta^2}{d_s^{\ 2}}$$

δ = Skin Depth
d_s = Diameter of Strand

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How to Design with Litz Wire

- **Select Design that fits in space**
- The number strands calculation should be treated as a guideline. Strand counts can deviate up to +/- 25% without negative effect.
- Most suppliers will have a chart of various constructions with nominal diameters and resistance values.
- Evaluate various constructions for acceptable performance.

How to Design with Litz Wire

- **Costing**
  - Be aware, moving from a solid wire to Litz ***<u>WILL</u>*** impact raw material unit cost.
  - How much impact is design / supplier dependent.
  - By evaluating various Litz constructions in a given winding, you can perform simple cost-benefit analysis.

How to Design with Litz Wire

- **Limitations**
  - Effectiveness of Litz as a winding wire begins to drop off above 3 MHz.

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How to Design with Litz Wire

- **Limitations**
  - Packing Factor / Copper Density are affected due to the enamel layer and the inherent air gaps from twisting round wires together in multiple operations.
  - The manufacturing process can damage the enamel layer on individual strands. The use of protective layers such as textile serves, tapes, or extruded isolation layers may be needed.

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Resource Materials & Citations

- Dartmouth Power Electronics and Magnetic Components Group web site:
  - http://thayer.dartmouth.edu/inductor/index.shtml
- C.R. Sullivan and R. Y. Zhang, “Simplified Design Method for Litz Wire”, *IEEE Applied Power Electronics Conference,* 2014
- C. R. Sullivan, “Windings for High Frequency Applications”, *APEC Industry Session Presentation,* 2014

Thank you!