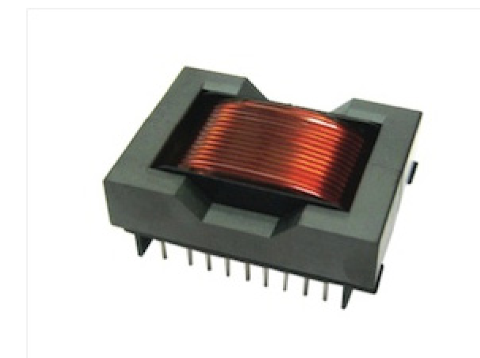
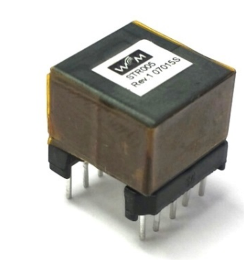
Smaller, lighter, less expensive and more efficient:

Magnetics Design for System Objectives





System objectives:

- Efficiency
- Size
- Weight
- Cost
- Reliability
- Time to market

Three paths to improvement:

- Model losses accurately
- Reduce losses (with similar cost)
- Reduce cost (with similar efficiency)

Fungible benefits: either improvement can be used for either objective.

System optimization:

- Interactive choice of switching frequency, inductance, turns ratio, etc., considering:
  - Impact on magnetics size, loss, and cost.
  - Impact on circuit performance, loss, and cost.
  - Prioritize specific objectives for each application.

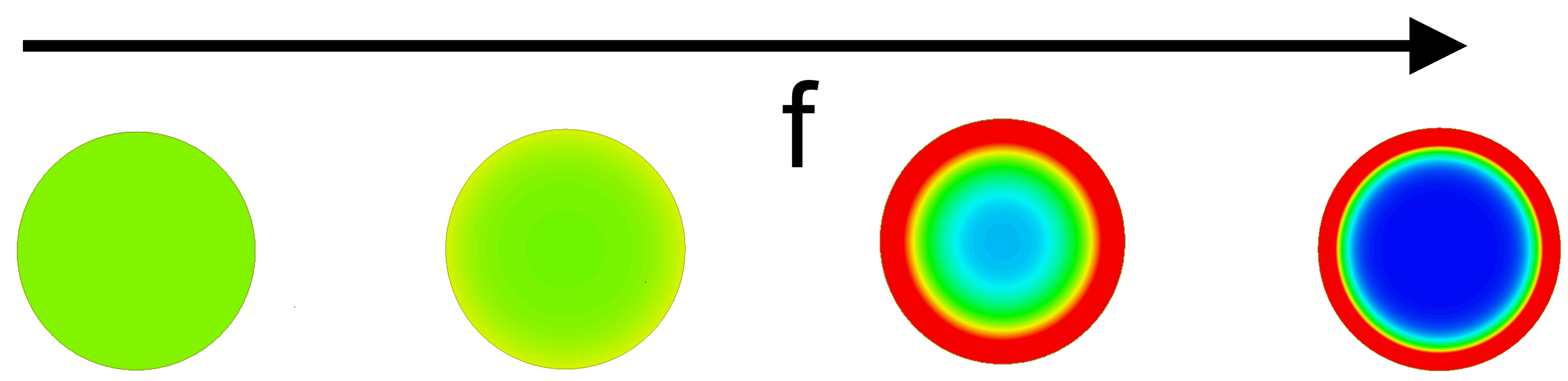
Magnetics design:

- Component design: size, shape, cooling strategy, winding/core loss tradeoff.
- Winding design: dc resistance, high frequency loss, and capacitance.
- Core selection: loss and saturation.

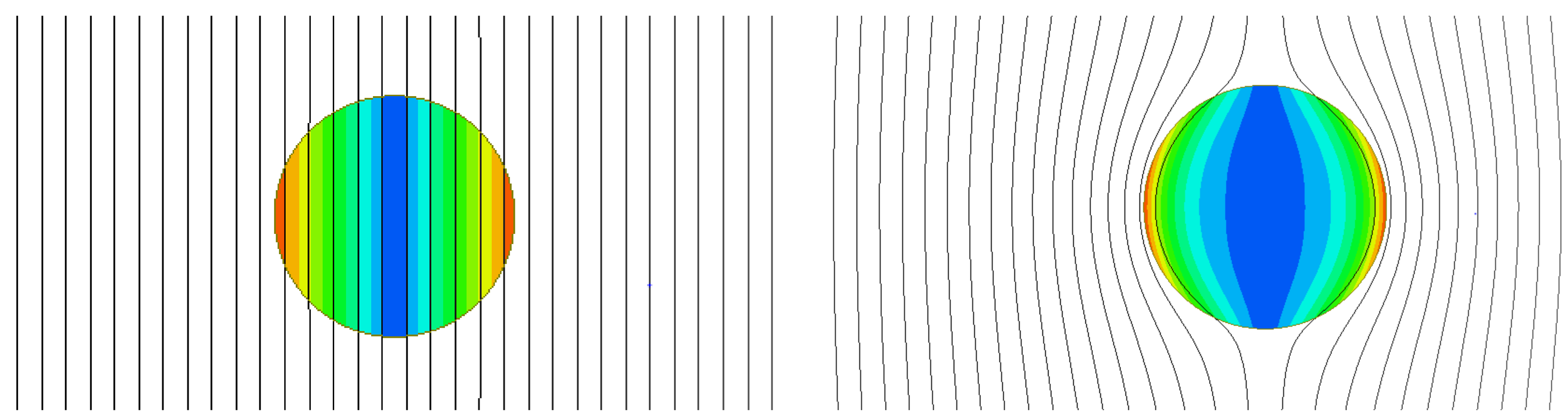
High frequency winding loss and proximity effect

Two high-frequency loss effects:

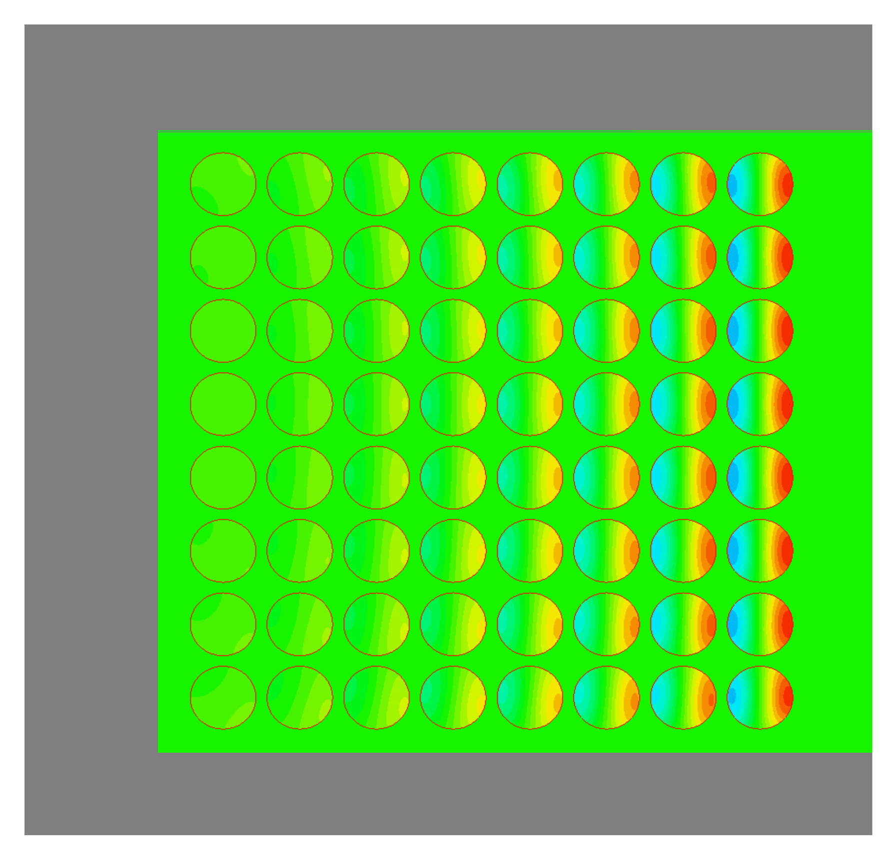
- Skin effect: Current near the surface in a skin depth $\delta = \sqrt{\dfrac{\rho}{\pi \mu f}}$



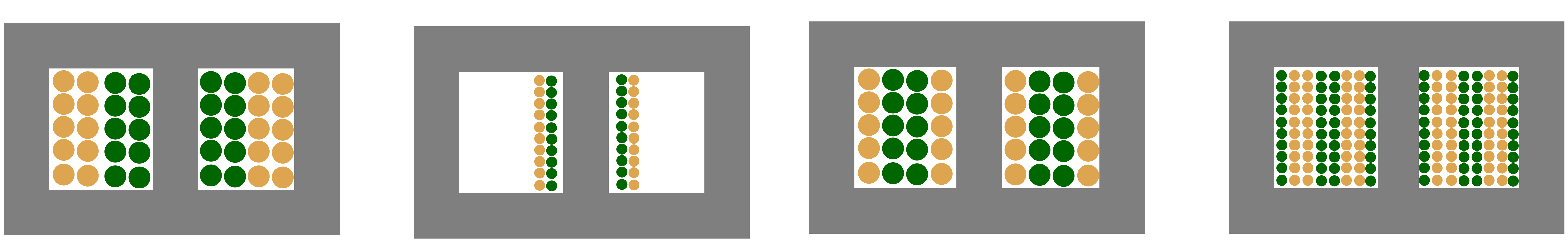
- Proximity effect:
  Fields from the winding and core induce losses in the winding.



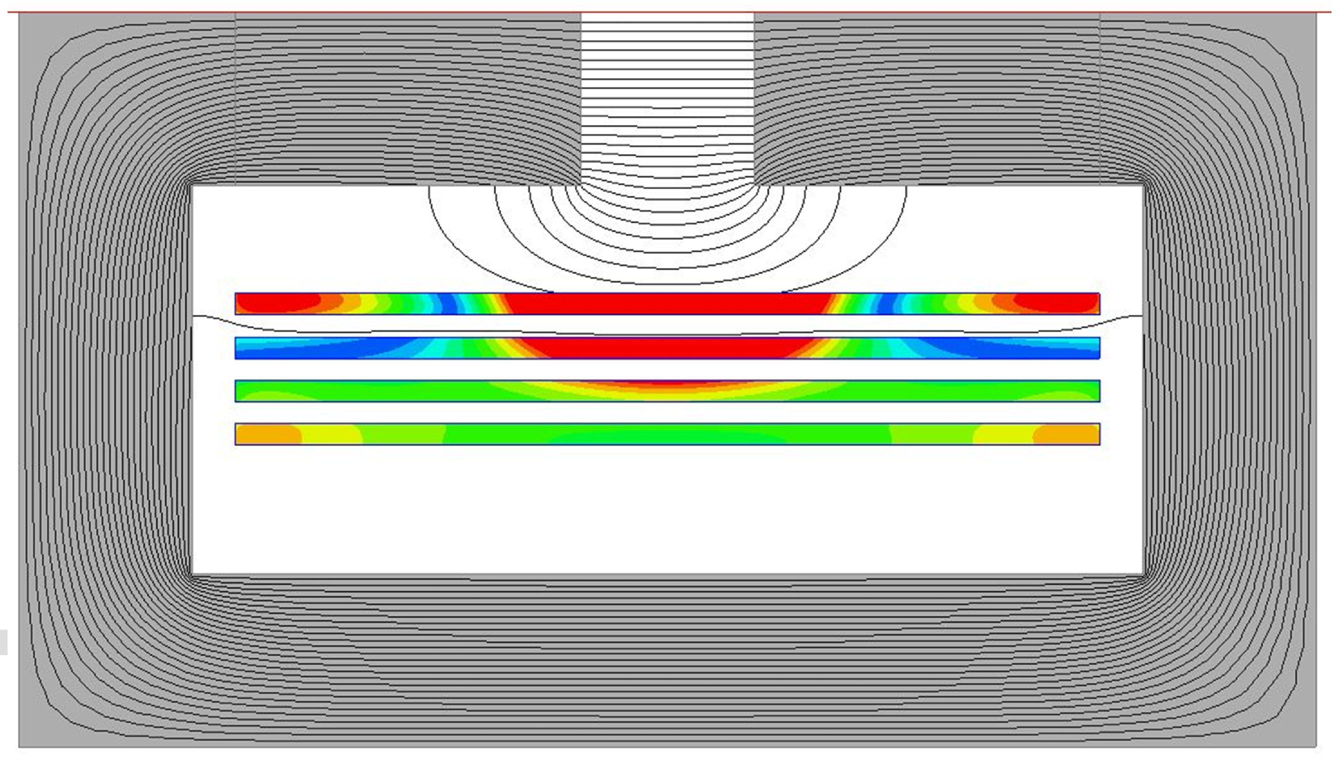
- In a multi-layer winding, proximity effect is worse. $R_{ac} = 28 \cdot R_{dc}$ in this example, while d = 2δ means skin effect only increases R_{ac} by 2%.

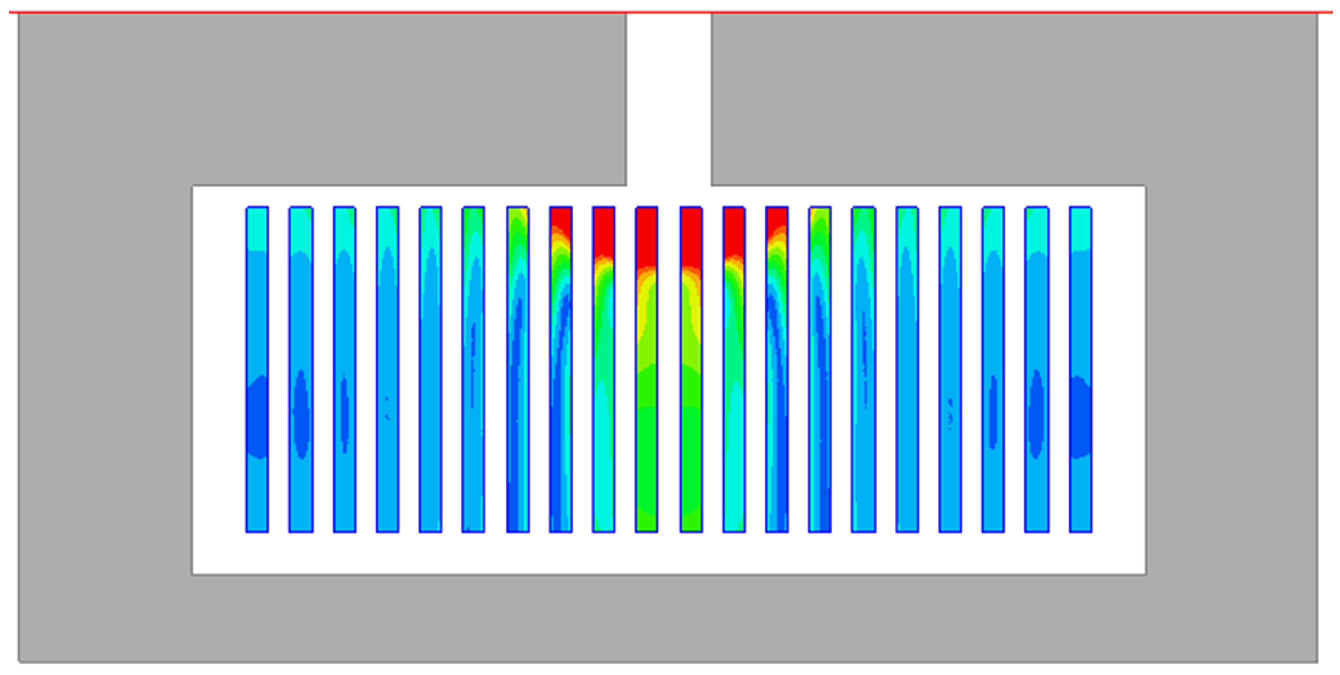


- It's all about ways to reduce proximity effect.
  - Two general options:
    - Very thin layers not just < δ but << δ
    - Reduce the number of layers—ideally a single-layer .
    - With a number of layers, p, can improve by $1/\sqrt{p}$ vs. single-layer, if you use the optimal thickness.
  - Litz wire: needs proper design to avoid making the loss worse instead of better. See http://bit.do/simplitz for details.
  - For transformers, interleaving solves proximity effect, limited only by capacitance and complexity



Inductor Windings and Proximity Effect

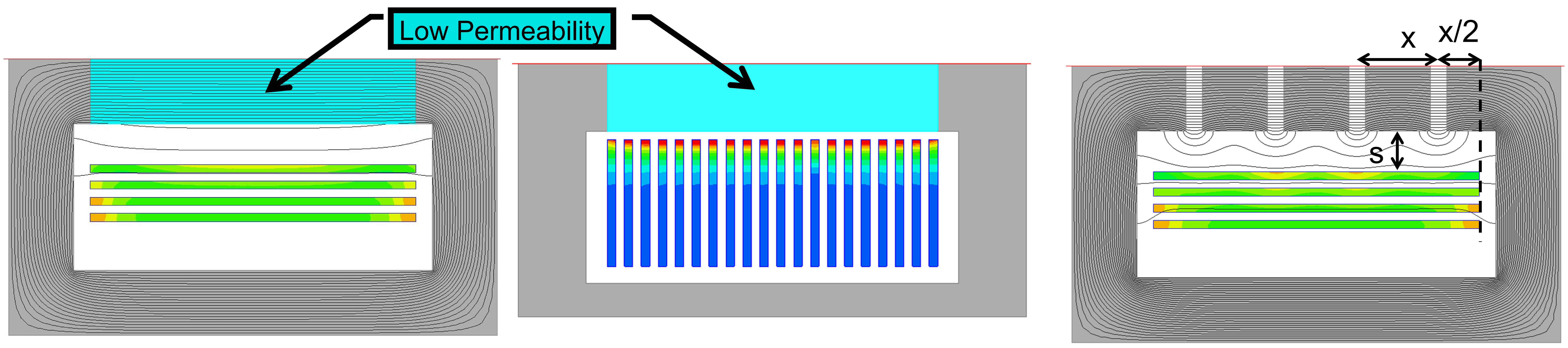




- Bigger challenge than in transformers, because
  - Interleaving doesn't apply.
  - Gaps concentrate and distort the magnetic field.

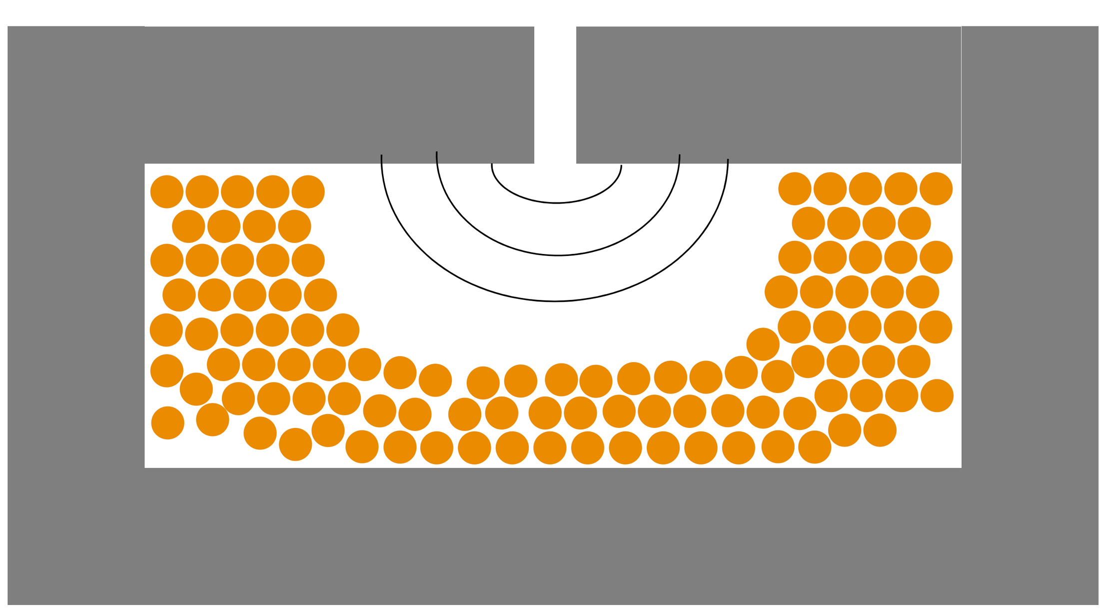
Solution 1: Shape the field to be 1D:

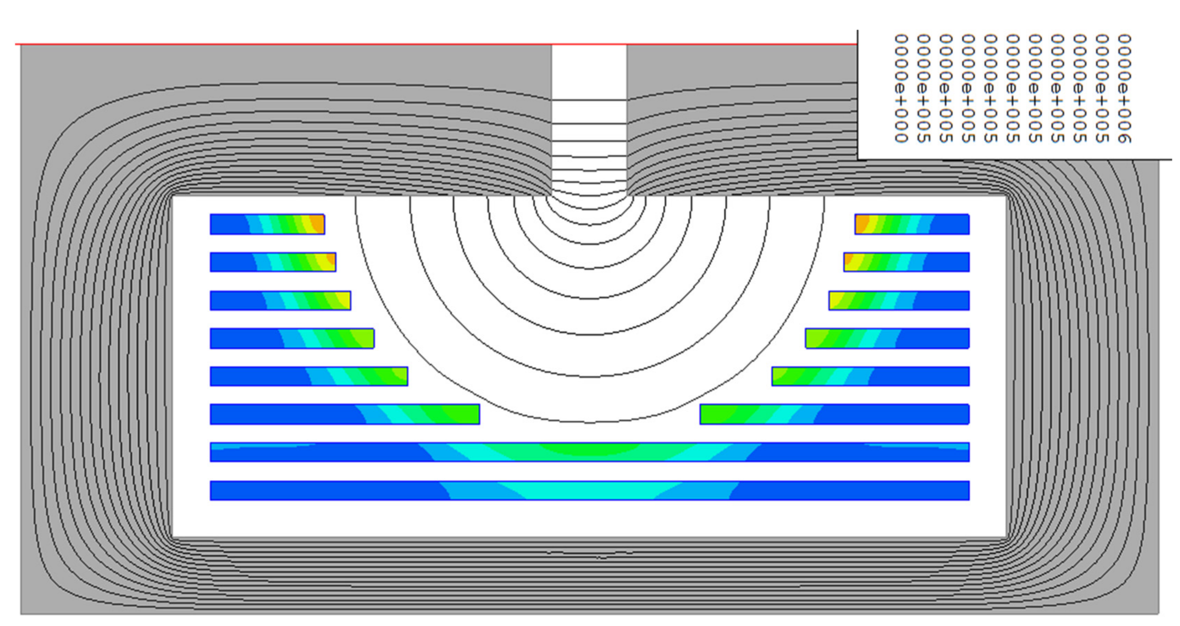
- Distributed gap or quasi-distributed gap; single-layer or multi-layer winding.



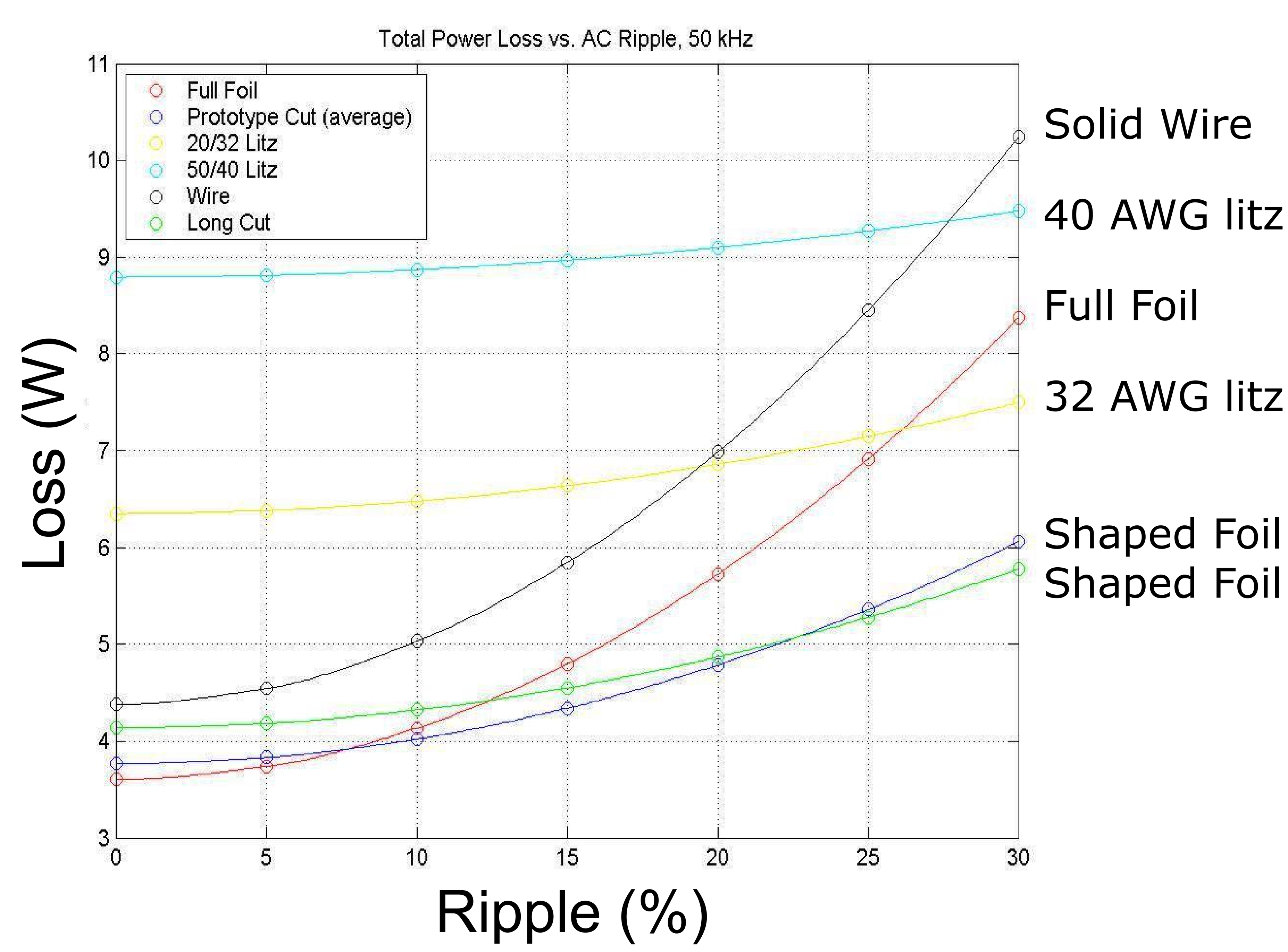
Solution 2: Shape the winding to work with 2D field:

- Shape optimization with round wire or foil





- Use with litz wire for resonant inductors.
- Shaped foil has "single-layer" behavior—almost no proximity effect—and low dc resistance.
- Optimize size of cutout for ac/dc resistance tradeoff.
- Looks expensive to make, but WCM's proprietary alternative shape is much easier to make.



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