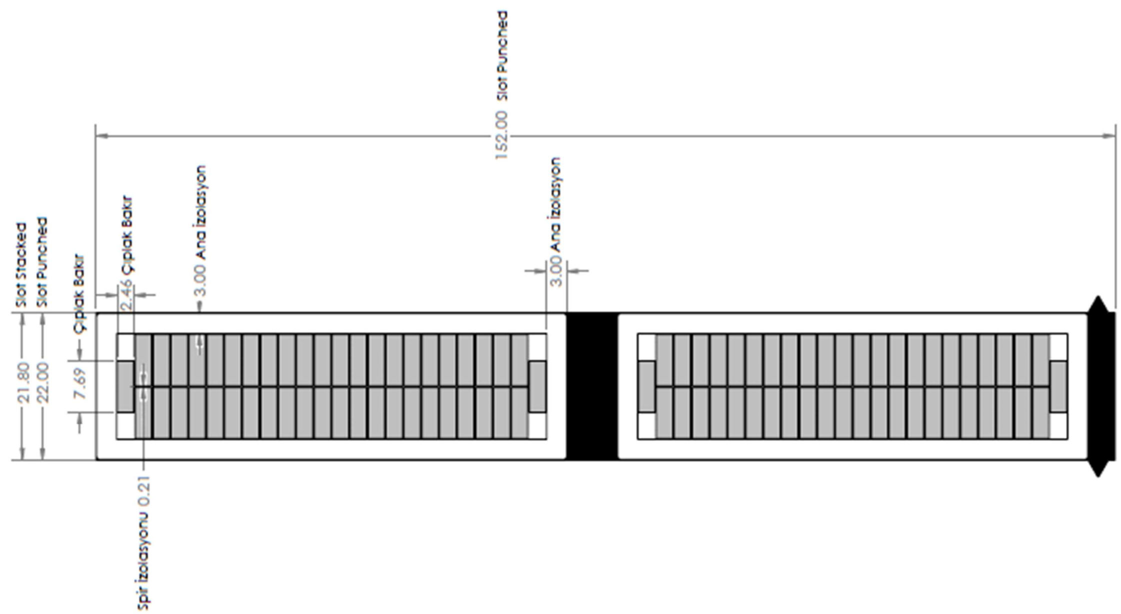
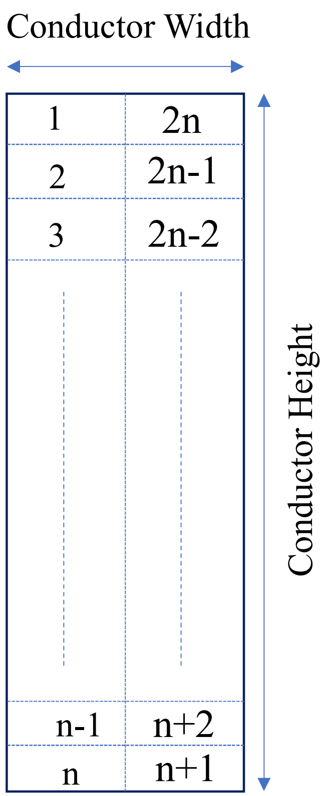
Selection of the Number of Strands





The number of vertical strands= n
The number of horizontal strands= 2
The number of strands=2n

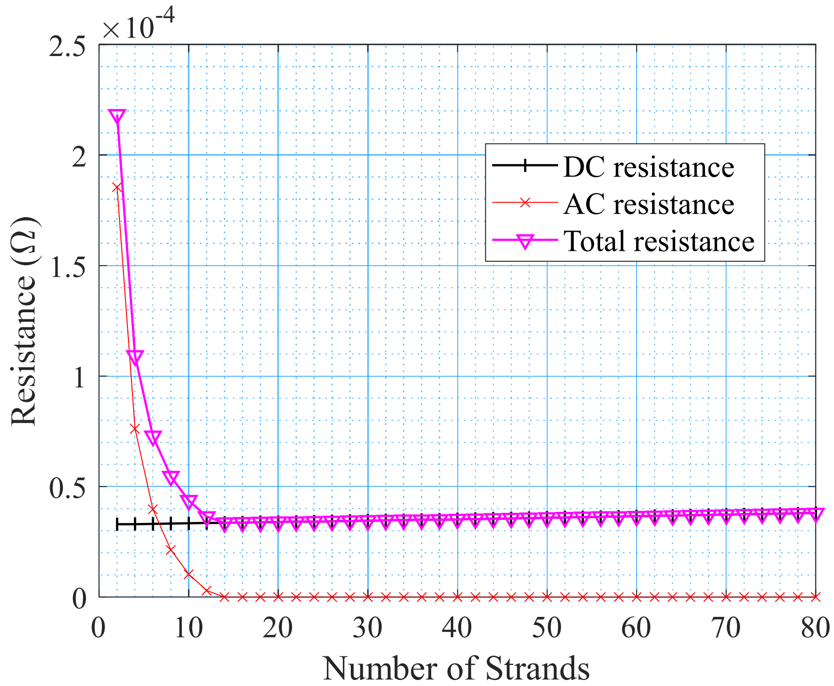
Losses of Copper :

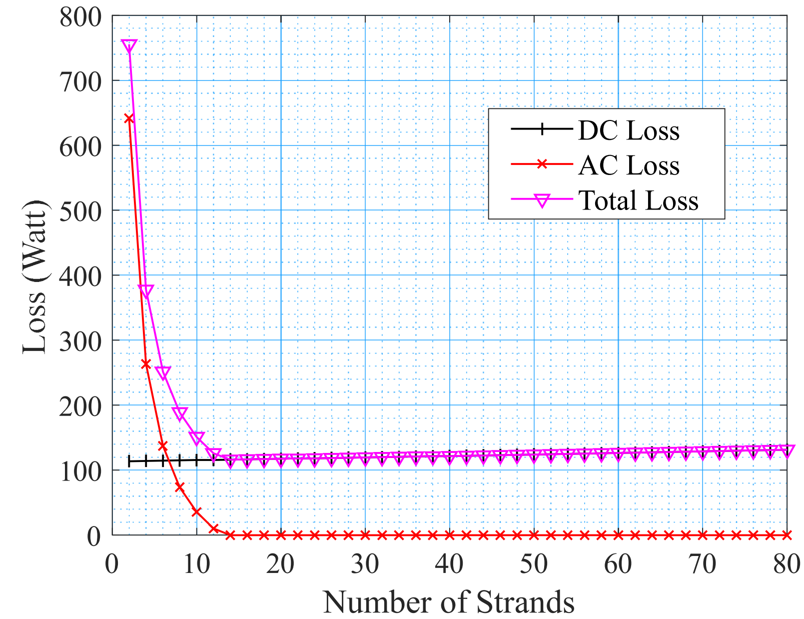
1. DC loss
2. Eddy (AC) loss
3. Circulation loss

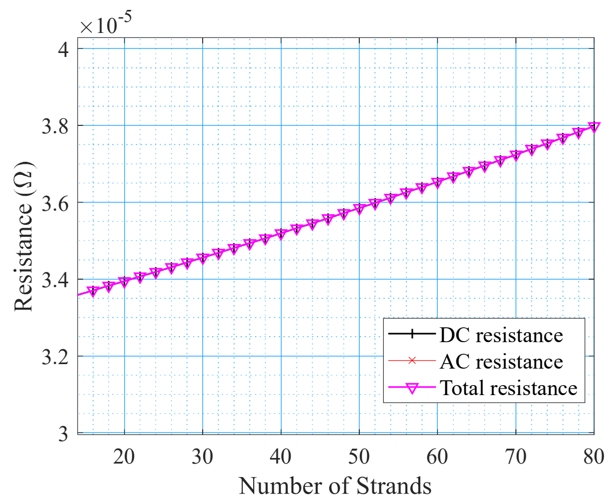
Increasing strand number

- decreases the effective copper area due to insulation,
- increases the DC resistance (loss)
- decreases AC resistance (loss) due to the strand height being smaller than skin depth

- Conductor Height = 61.4 mm
- Conductor Width = 16 mm
- Insulation between strands =0.21 mm
- Skin depth = 9.22 mm







DC resistance increases 11%
if #strands raise from 20 to 80

Circulation Current
The Impact of the Radial and Tangential Flux Components

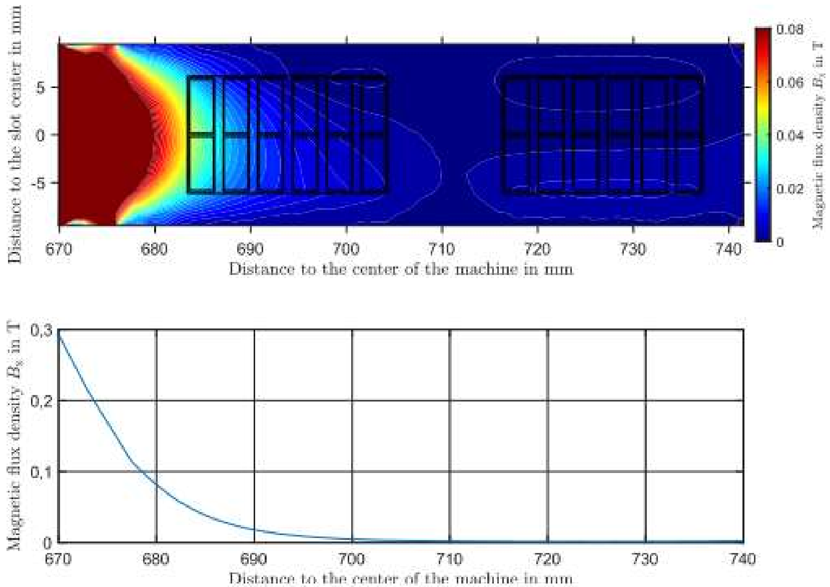


FIGURE 4. Radial component of the flux density along the slot length.

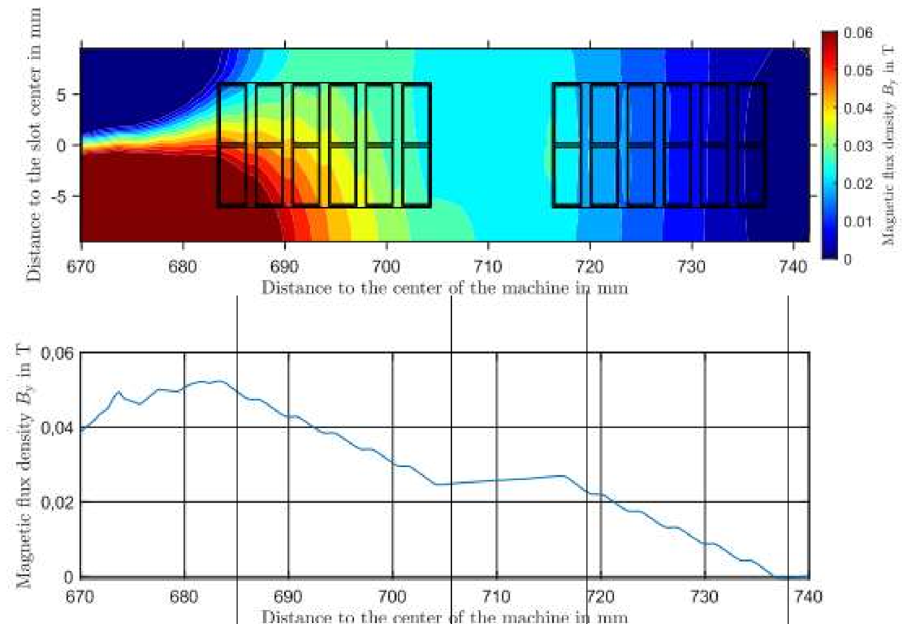


FIGURE 5. Tangential component of the flux density in the slot.

Starting first winding

Ending first winding

Starting first winding

Ending first winding

M. W. Meiswinkel, A. Ebrahimi, C. Wohlers and T. Neschitsch, "Transient Roebel Bar Force Calculation in Large Salient-Pole Synchronous Machines," in IEEE Access, vol. 9, pp. 2266-2273, 2021, doi: 10.1109/ACCESS.2020.3046789.

The Radial Flux Component

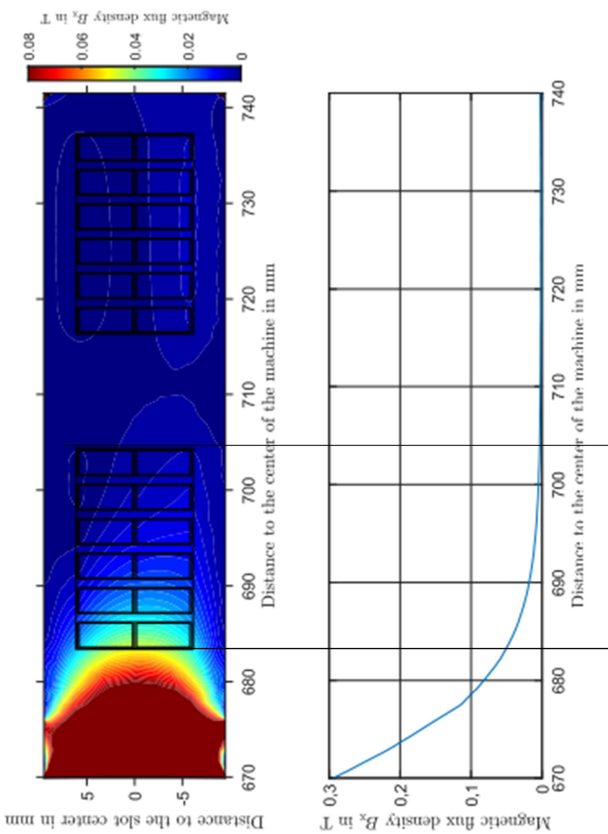


FIGURE 4. **Radial component of the flux density along the slot length.**

Ending first winding

Starting first winding

- Radial flux is stemmed from the field (rotor).
- It diminishes while moving away the airgap. (B α $\frac{1}{r^2}$)
- In double layer windings, only the close one to the airgap is affected.
- The effect of the flux can be ignored in the winding far away from the airgap.

The Tangential Flux

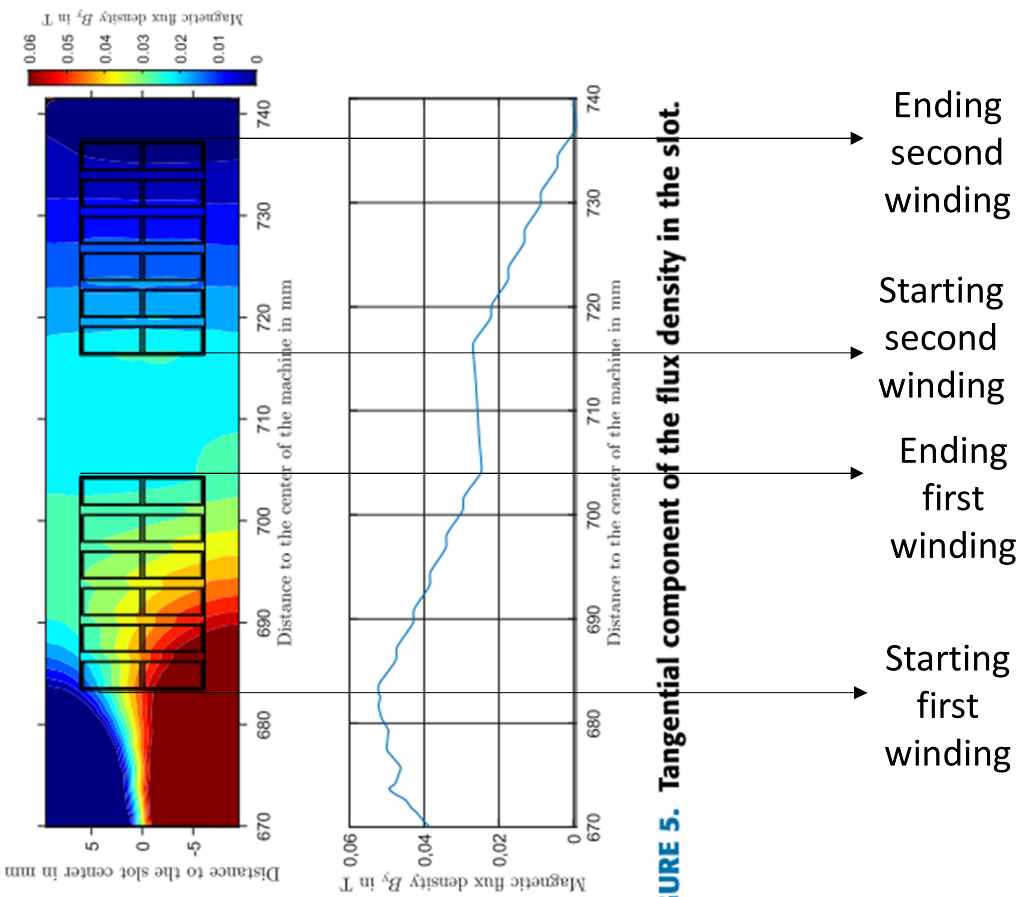
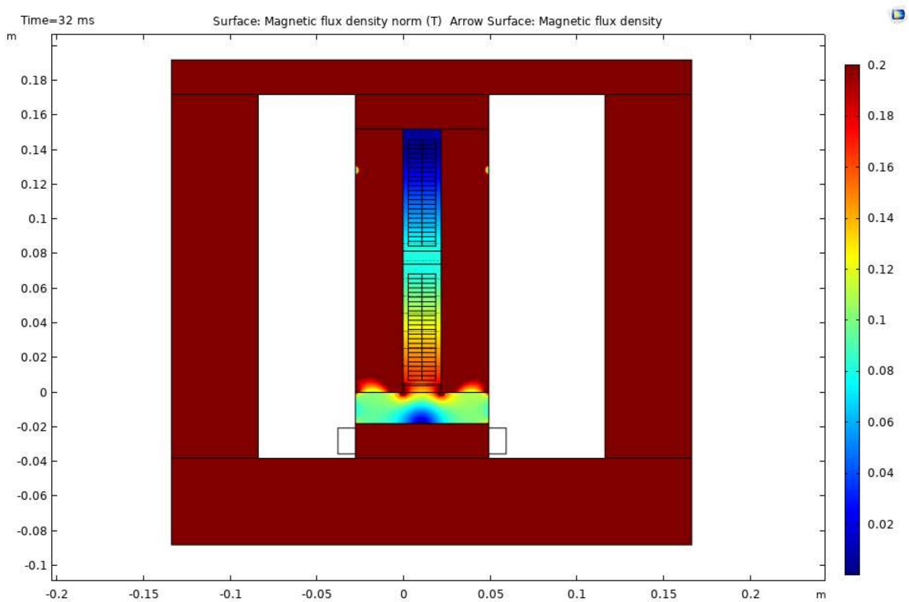
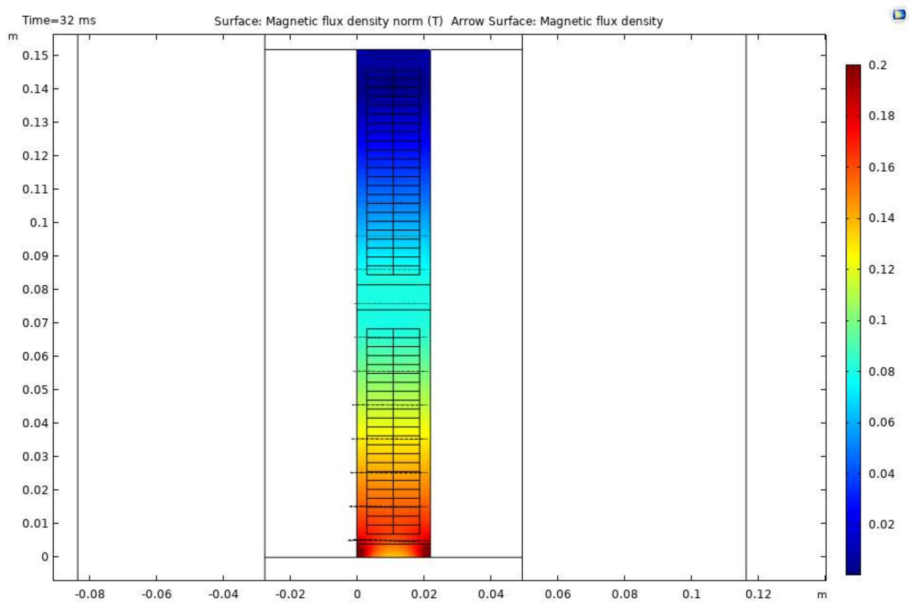


FIGURE 5. **Tangential component of the flux density in the slot.**

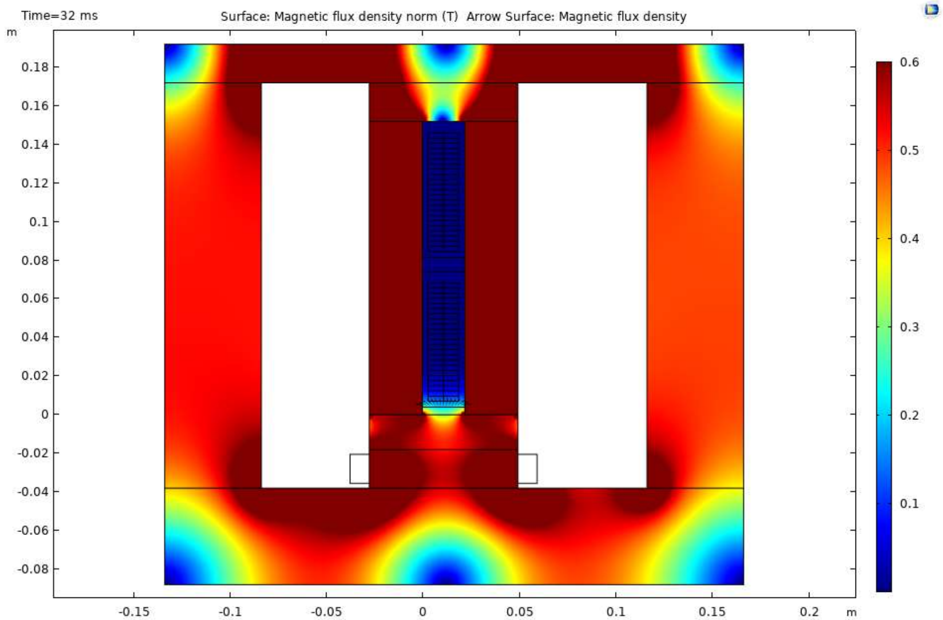
- Tangential flux is stemmed from the strands themselves.
- It diminishes while moving away the airgap. (Triangle shape B field, obeying $Hdl = NI$)

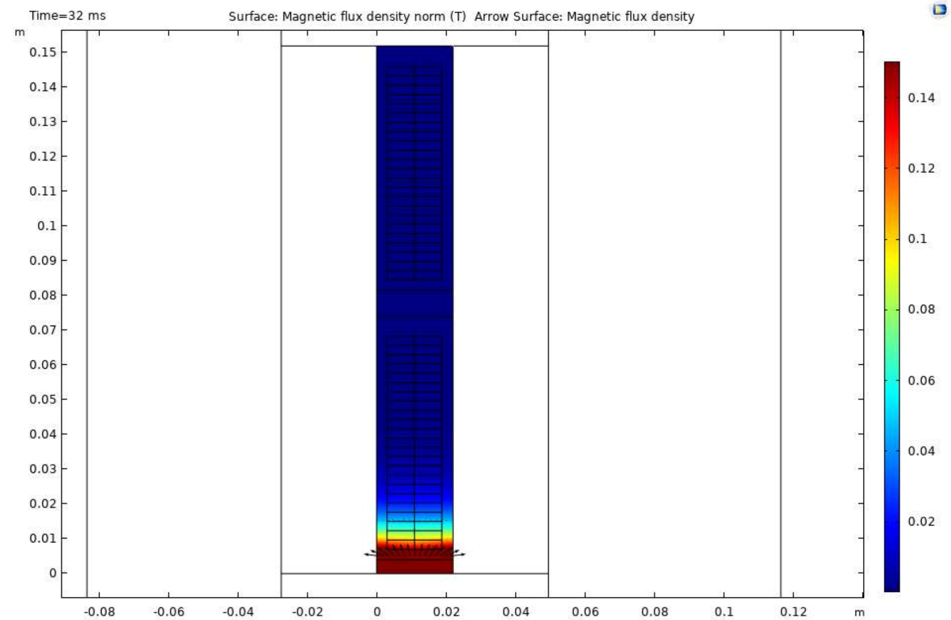
Tangential Flux on the Strands for Equal Current Distribution

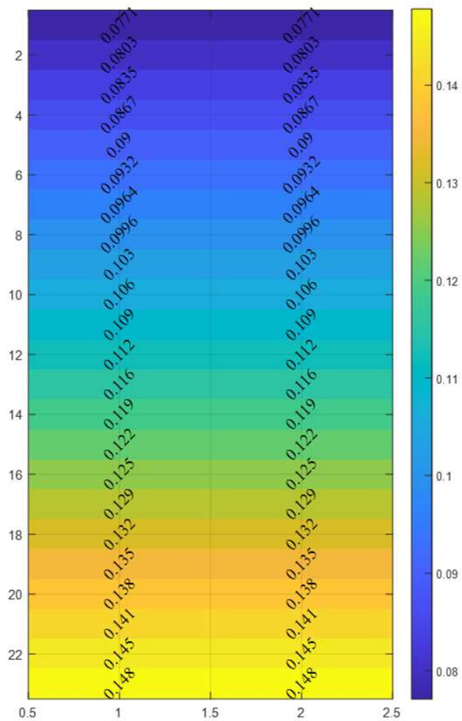




Radial Flux on the Strands







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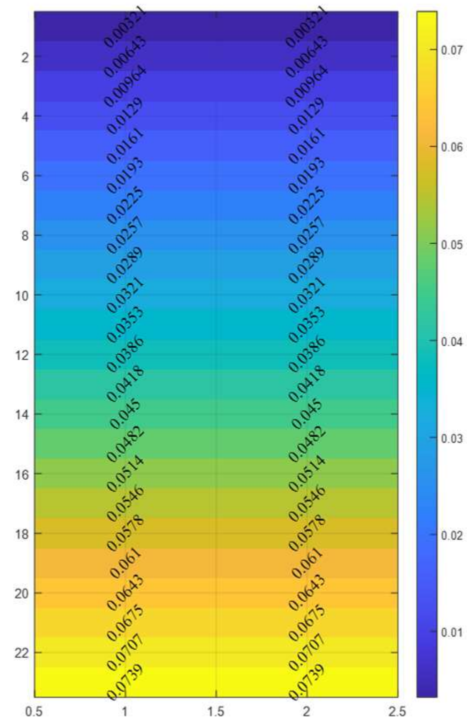
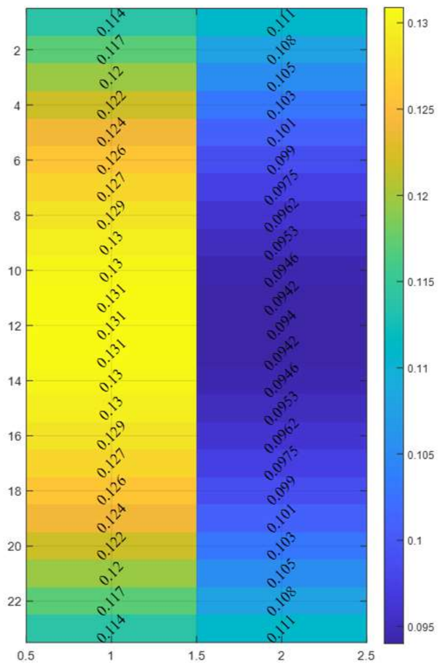


Bottom

Induced voltage from tangential fluxes without Roebel



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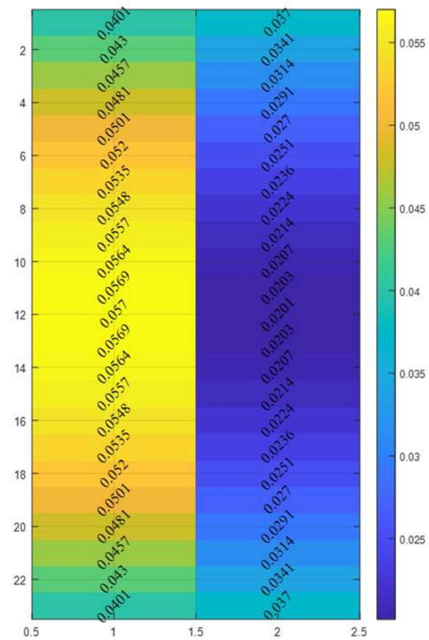
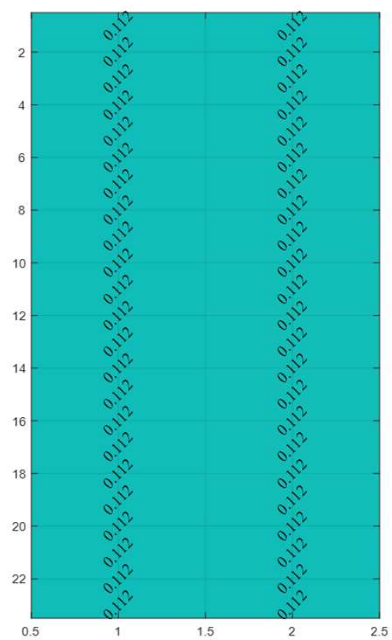


Bottom

Induced voltage from tangential fluxes with 180^o roebel



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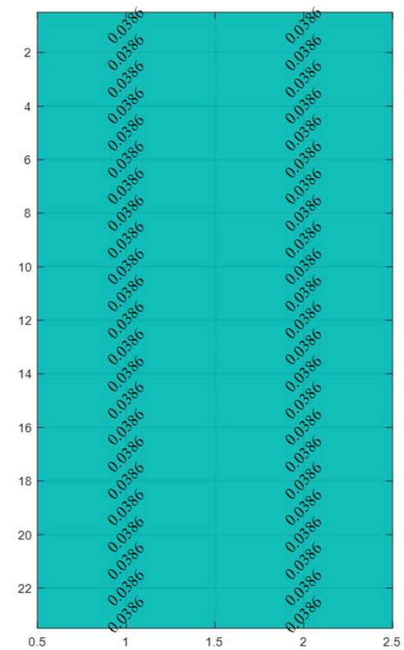
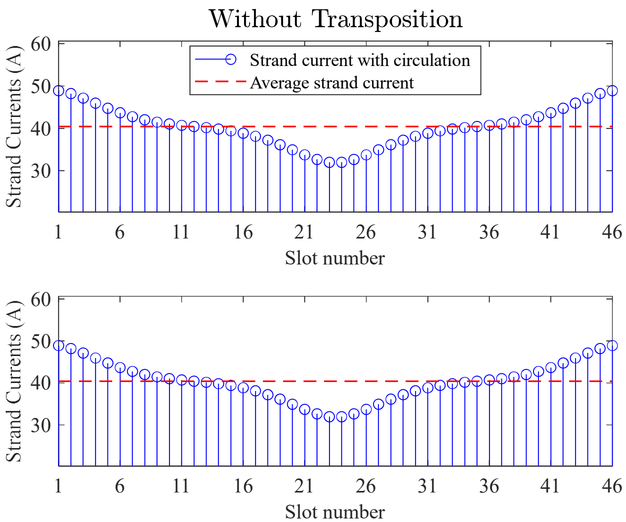


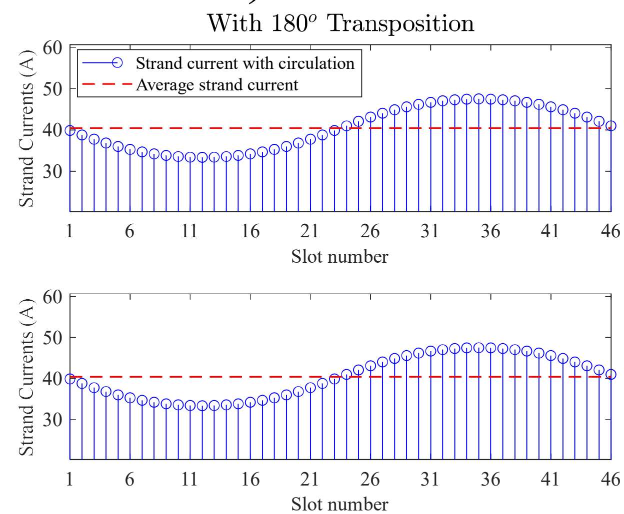
Bottom

Induced voltage from tangential fluxes with 360^{o} roebel

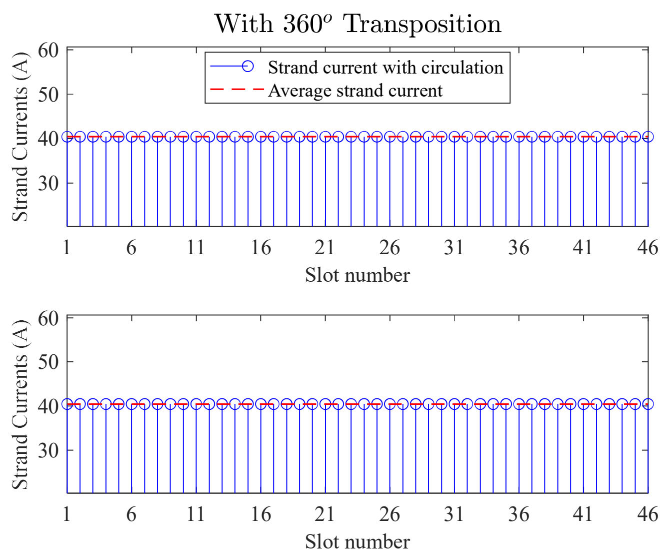
Circulating Currents (Tangential Flux)



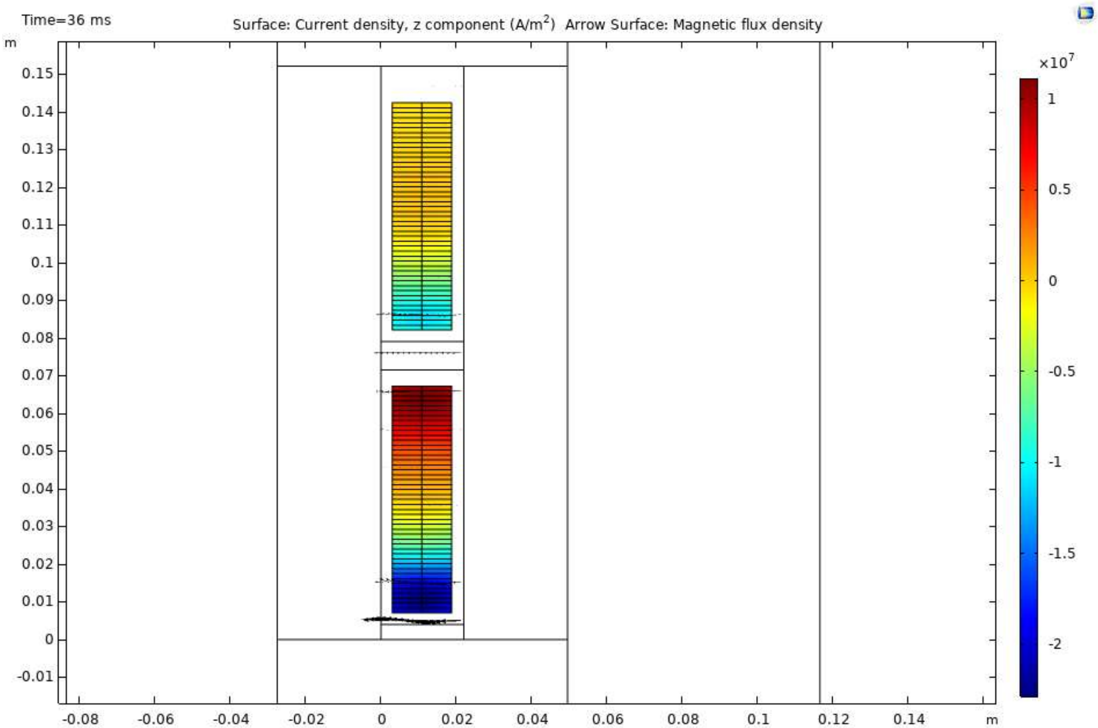
$$100\frac{r_{ac}}{r_{dc}} = 101.6782$$

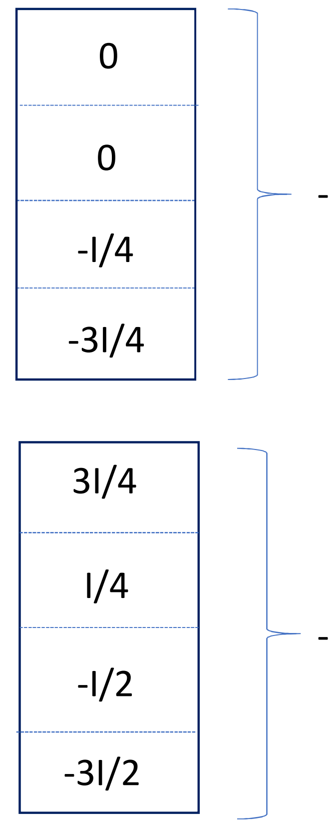


$$100\frac{r_{ac}}{r_{dc}} = 101.8565$$



Straight wire Current Density Distribution

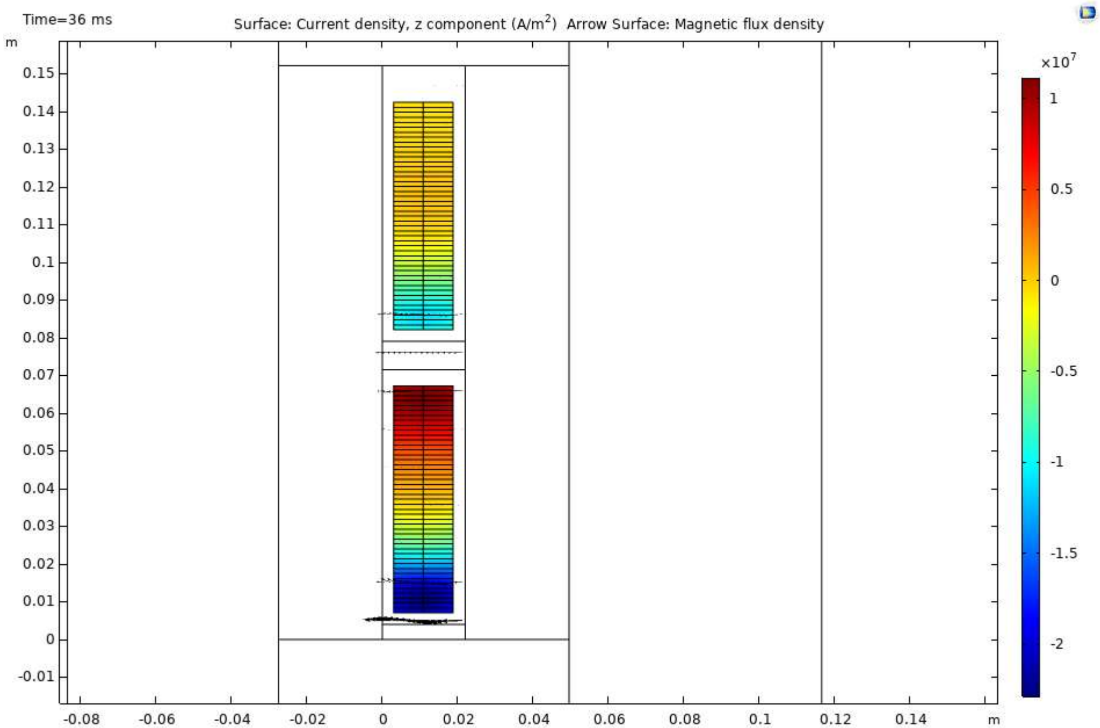


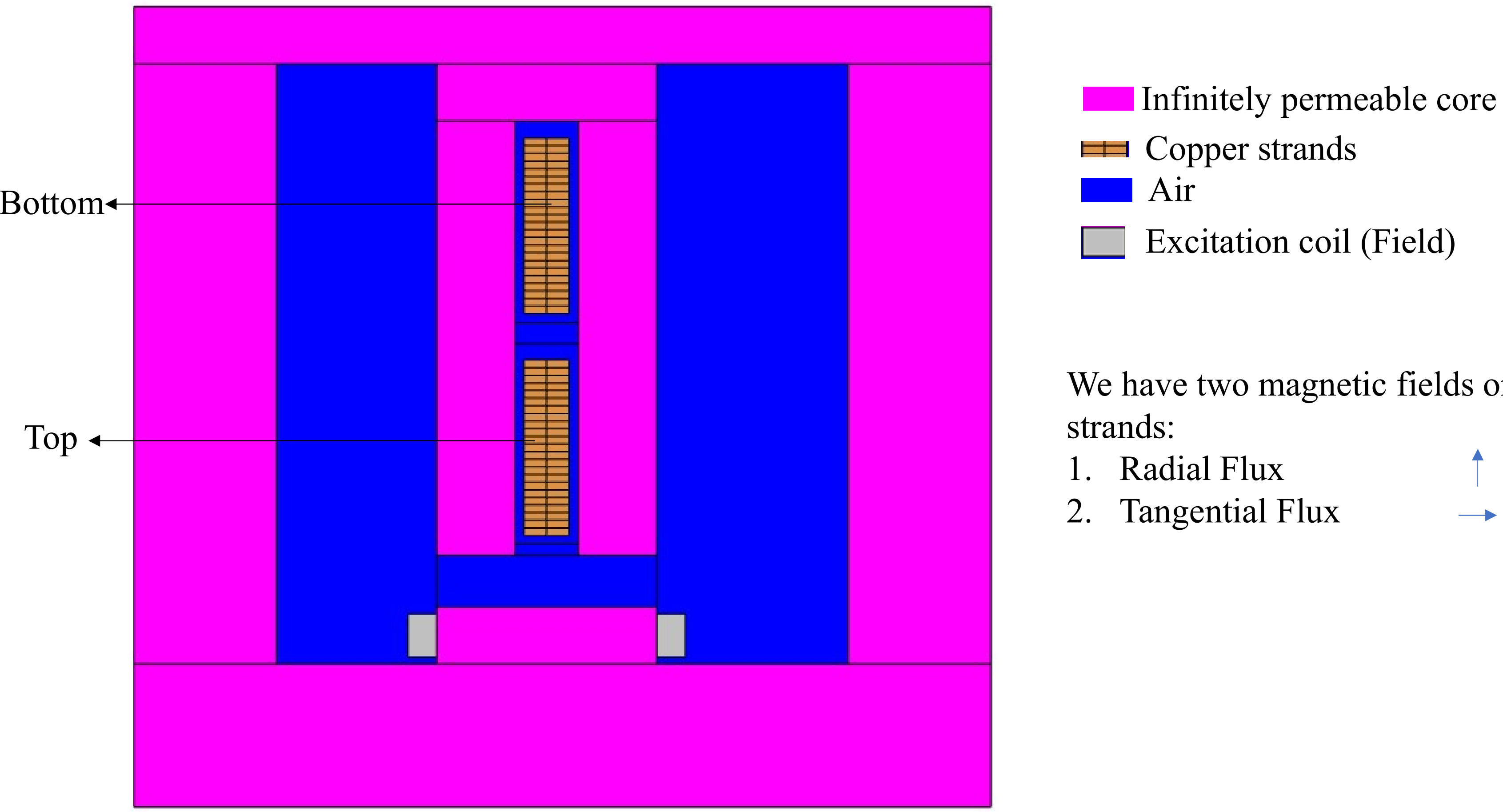


DC Loss	Circulation (Airgap)	Circulation (Back Core)
$123\ W$	$830\ W$	$215\ W$

Straight wire Current Density Distribution

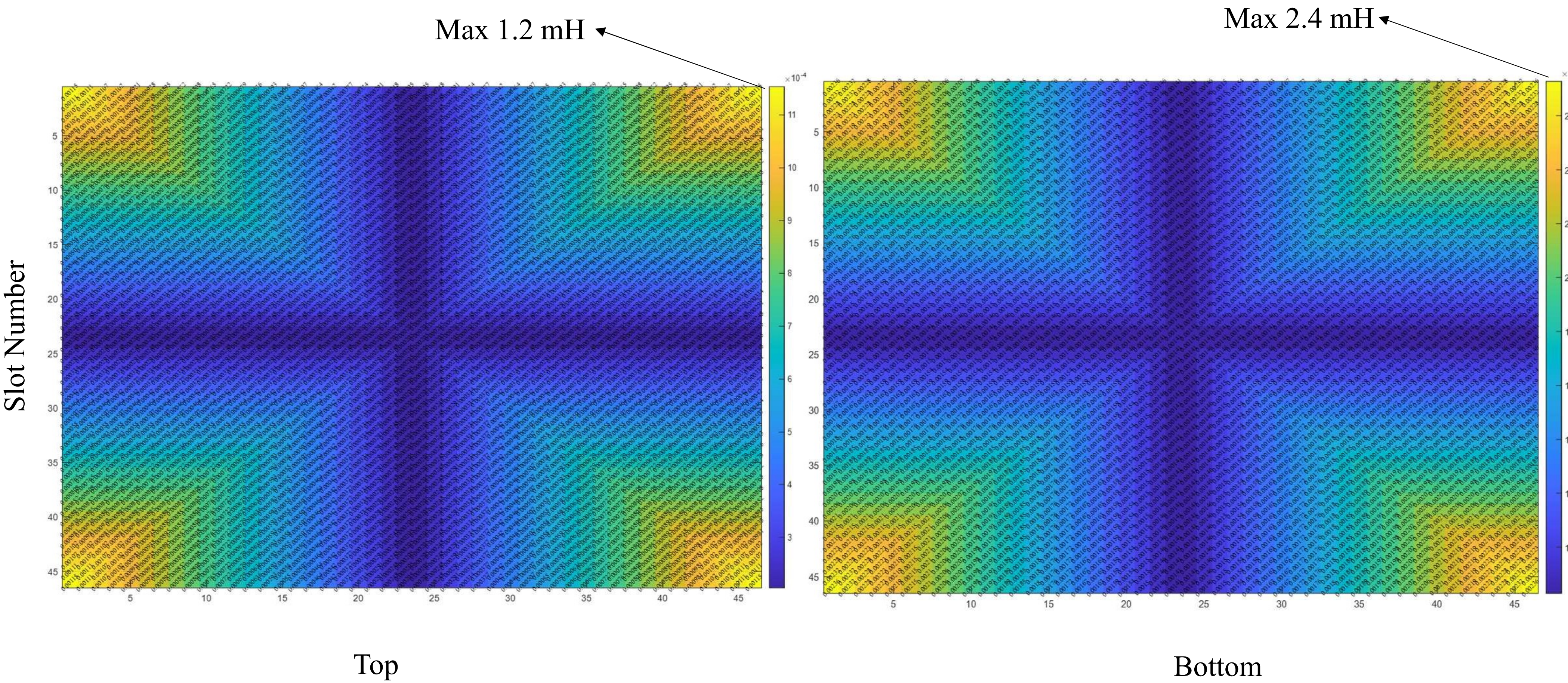
Straight wire Current and Flux Density Distribution



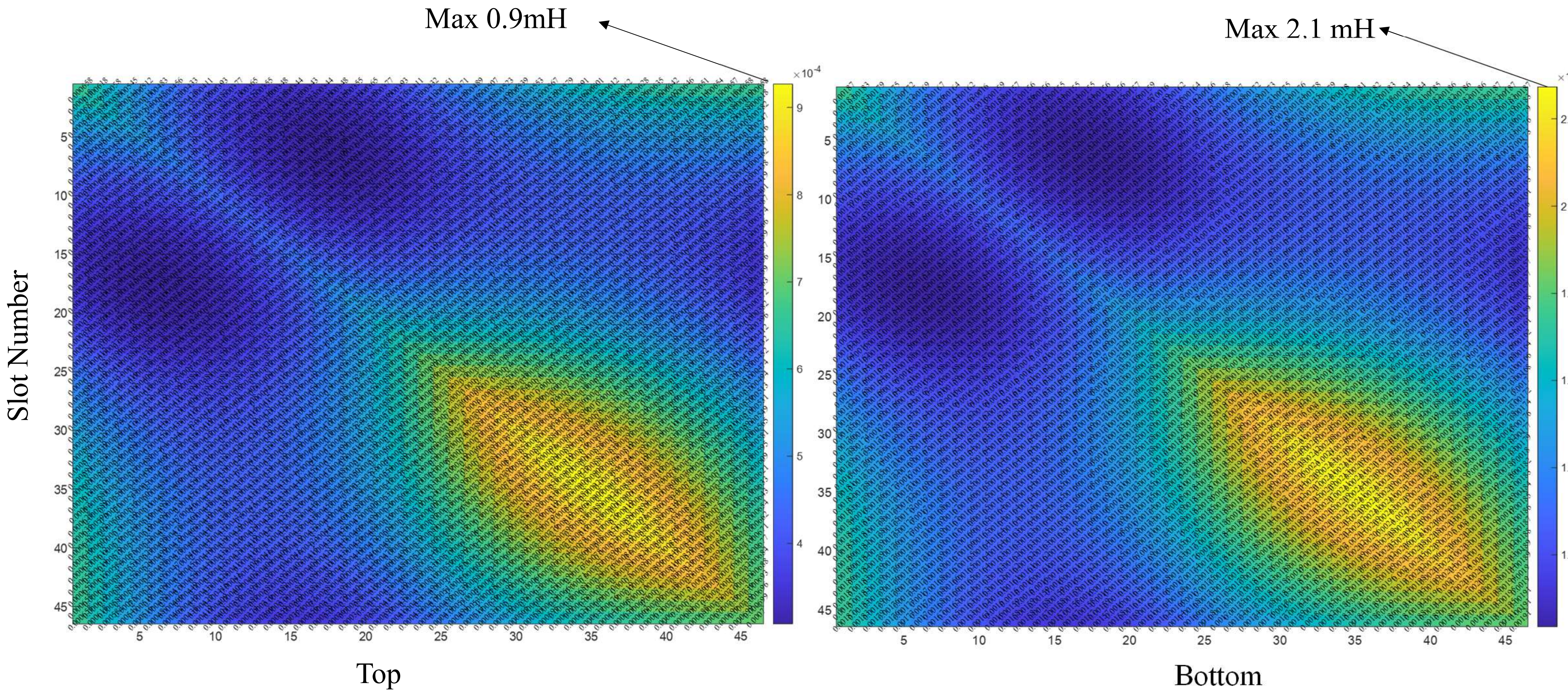


We have two magnetic fields on the strands:

1. Radial Flux
2. Tangential Flux

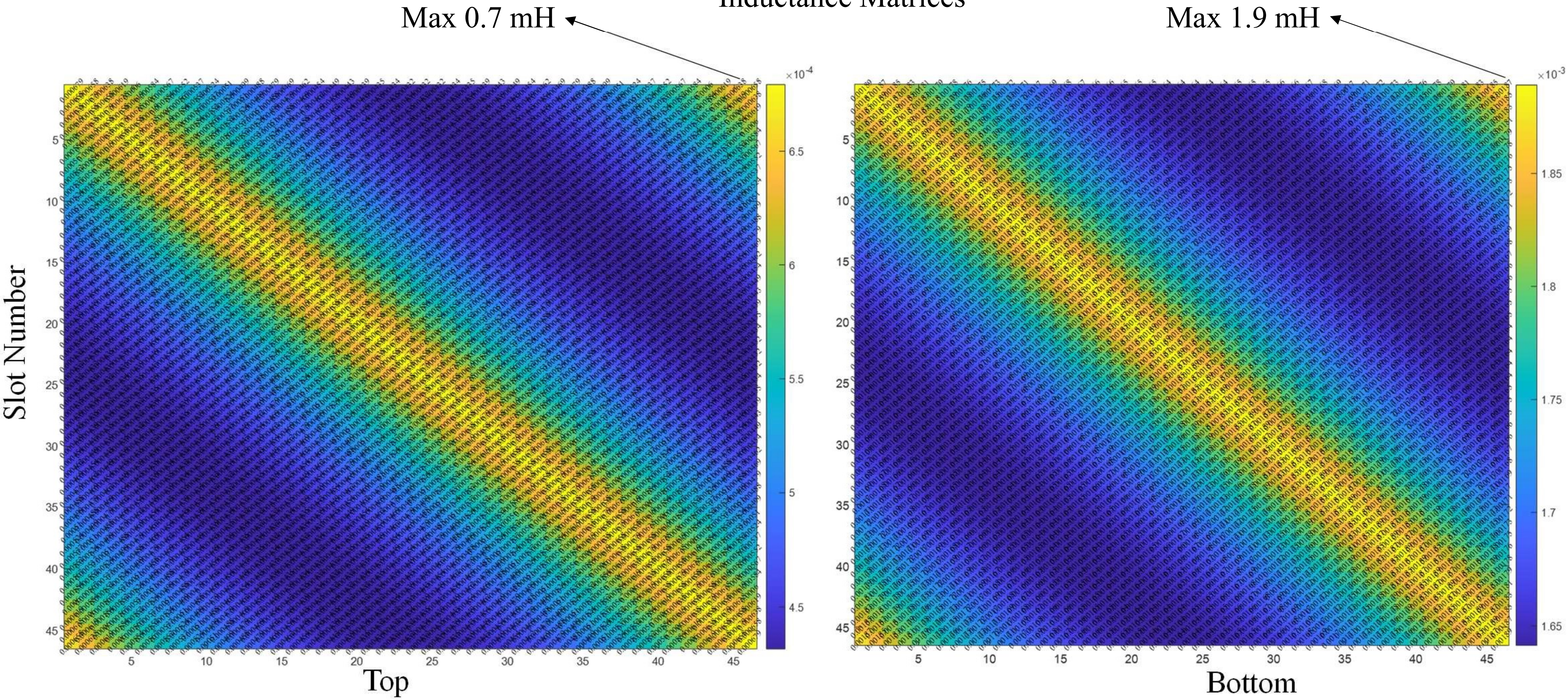


Inductance matrices without roebel

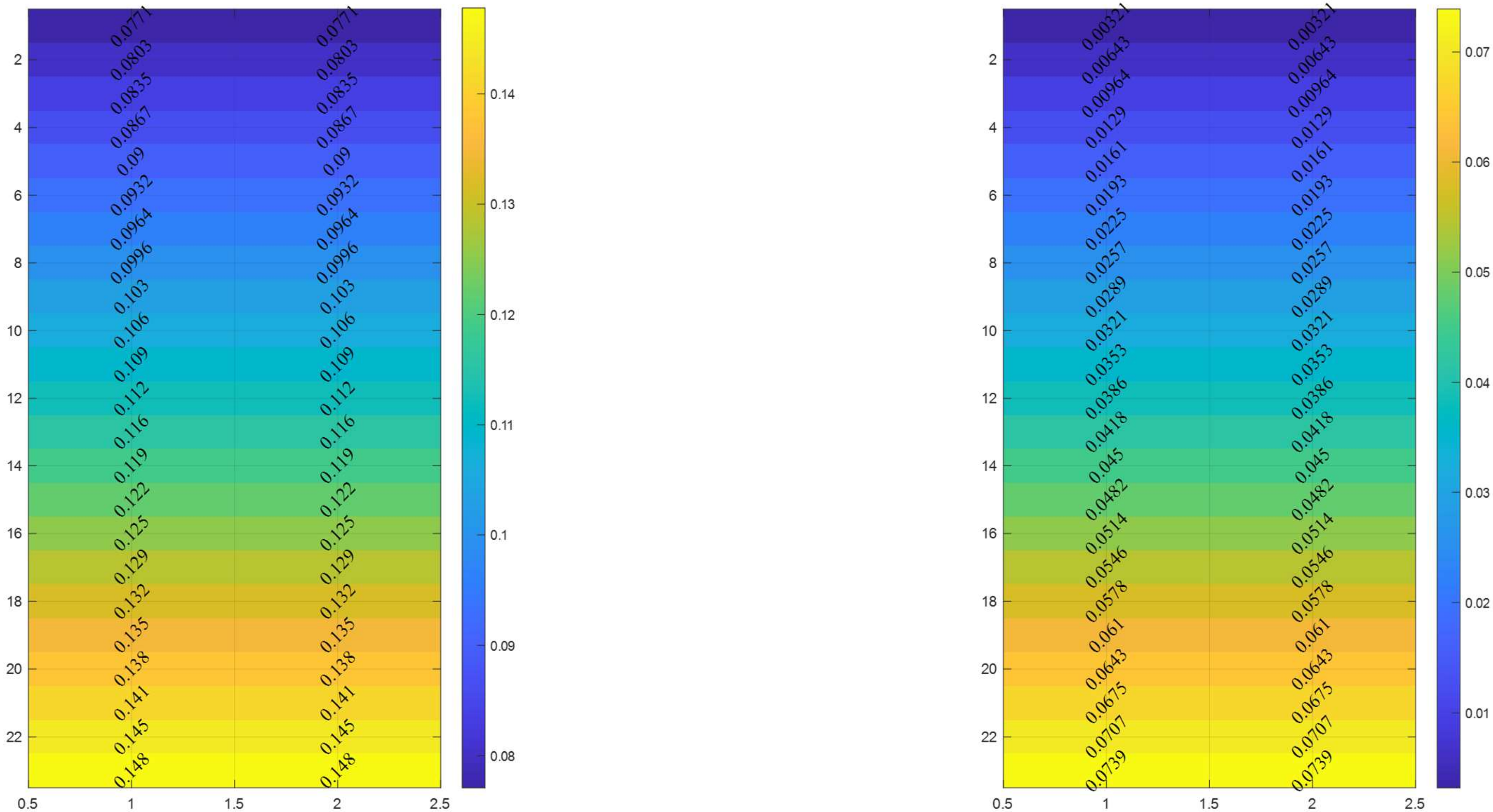


Inductance matrices with 180^o roebel

Inductance Matrices

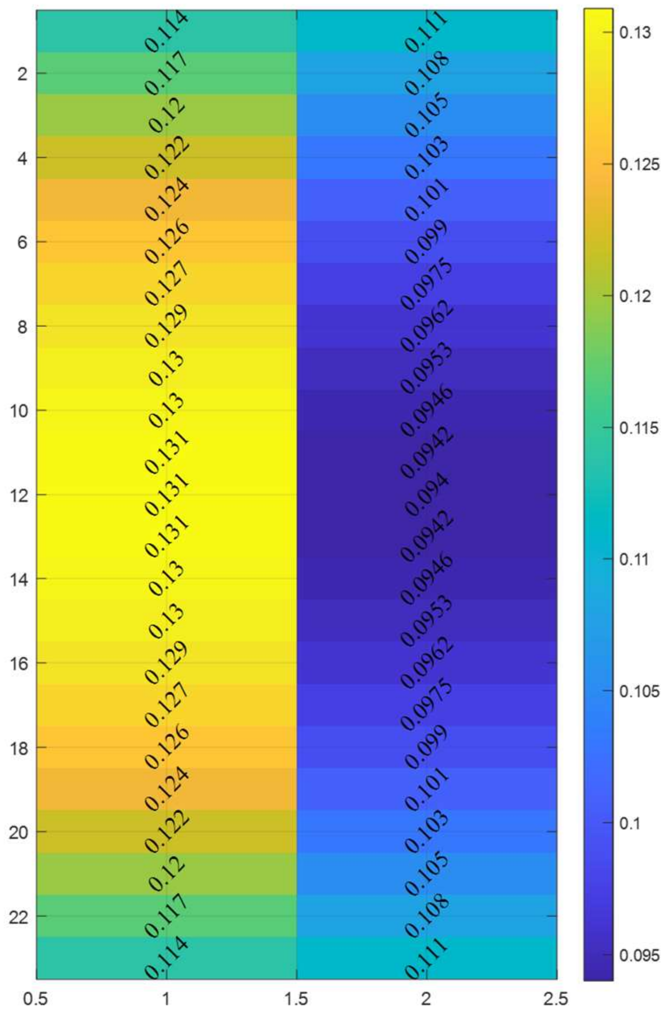


Inductance matrices with 360^{o} roebel



Top Bottom

Induced voltage from tangential fluxes without roebel



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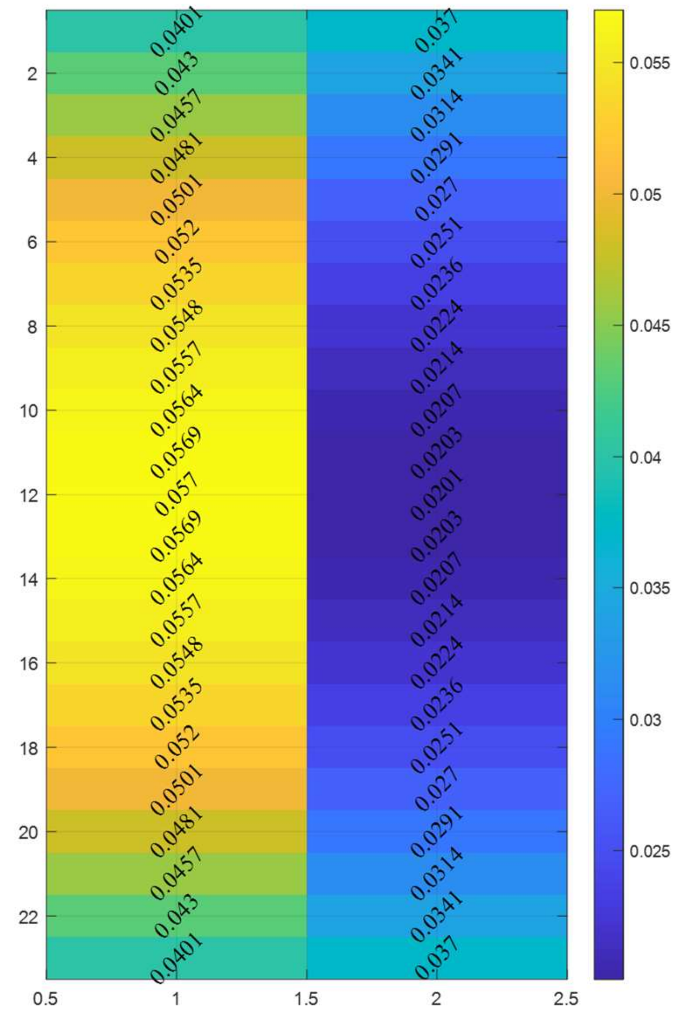
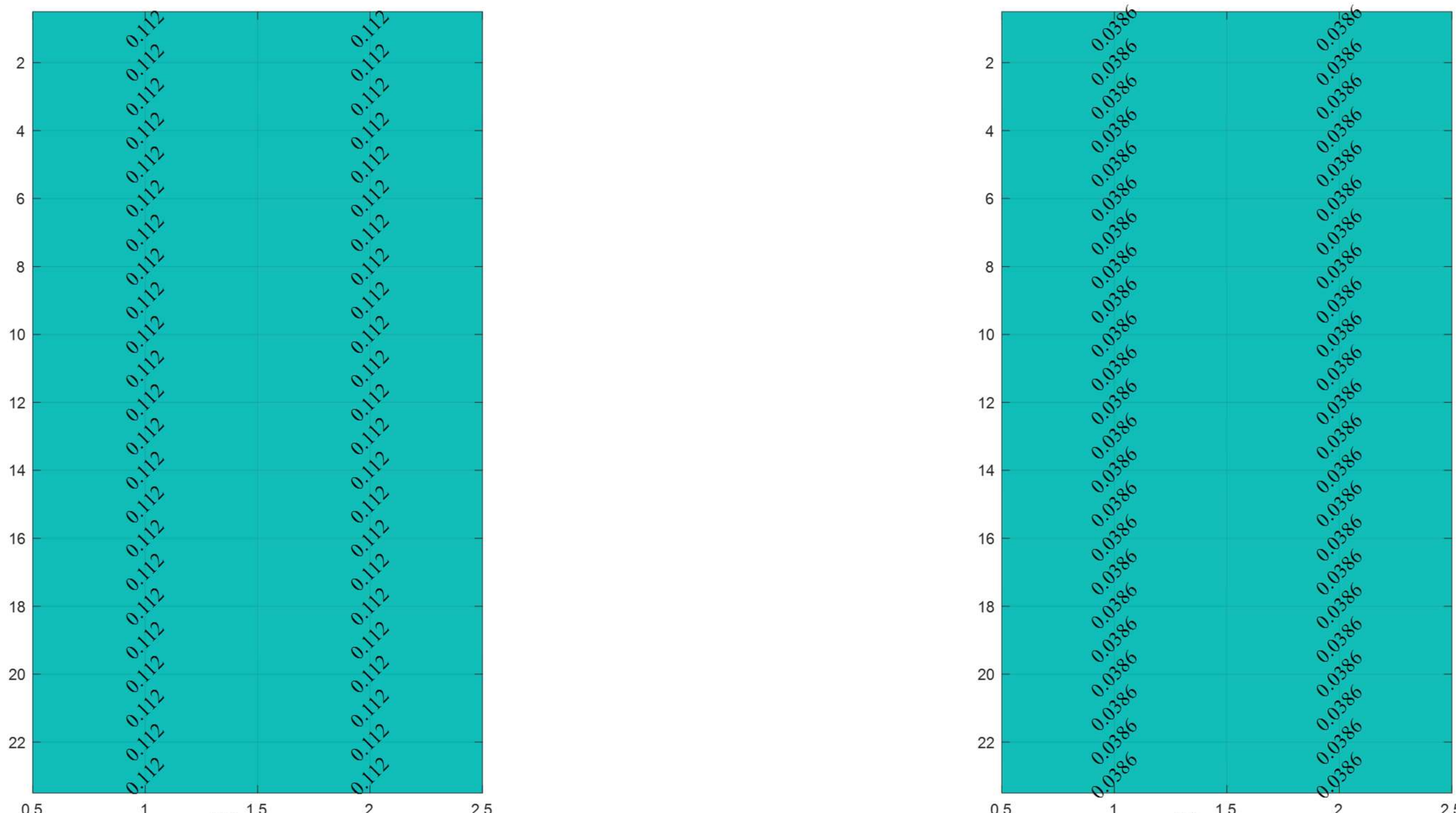


Bottom

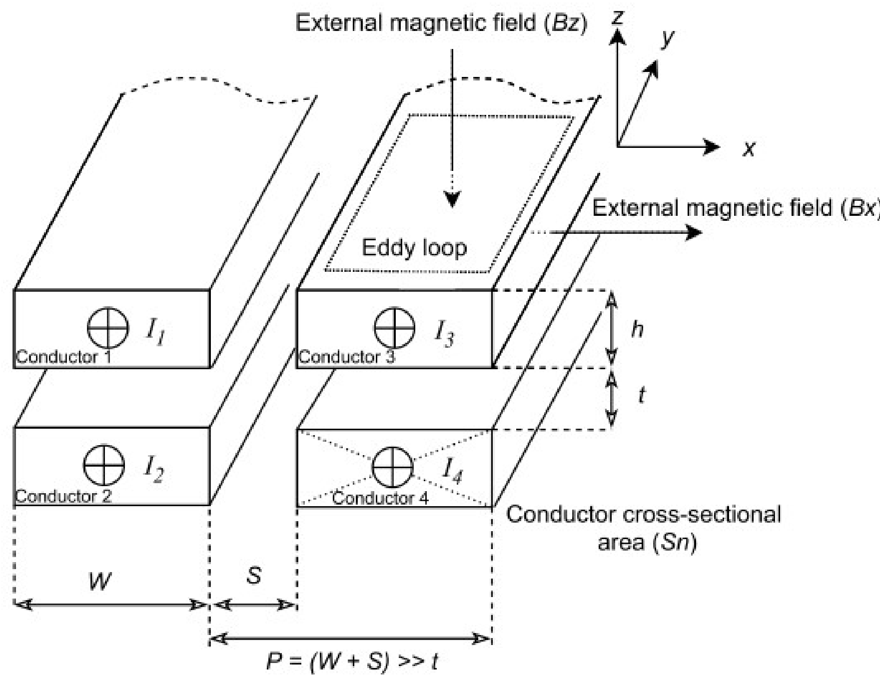
Induced voltage from tangential fluxes with 180^o roebel



Top

Bottom

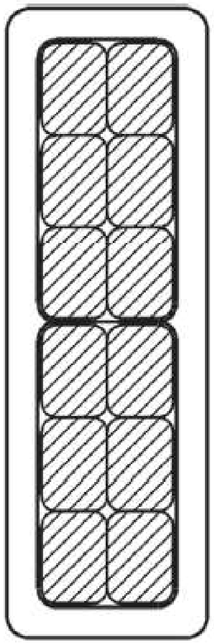
Induced voltage from tangential fluxes with 360^o roebel



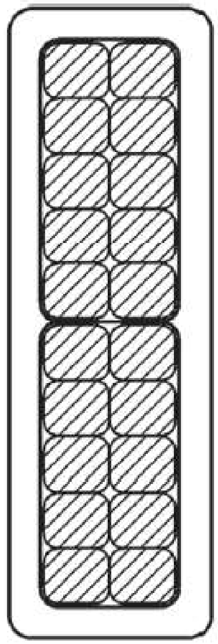
$$R_{AC} = R_{skin} + R_{proximity\_z} + R_{proximity\_x} = F_{skin} \cdot \frac{1}{\sigma W h} + \frac{1}{12} h \omega^2 \sigma B_z^2 W^3 + \frac{1}{12} W \omega^2 \sigma B_x^2 h^3$$

$$F_{skin} = \frac{h}{\delta}$$

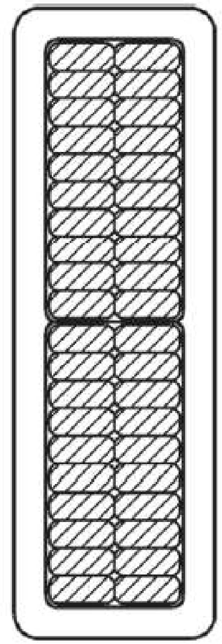
Loss designation	Case 1	Case 2	Case 3
DC I^2R loss	183.749 kW	191.520 kW	204.492 kW
Loss in top strand	5.0658 pu	1.6415 pu	0.3114 pu
Average strand eddy current loss	0.8592 pu 157.877 kW	0.2784 pu 53.319 kW	0.0528 pu 10.797 kW
Circulating current loss (without transposition)	0.8590 pu 157.840 kW	0.8801 pu 168.557 kW	0.7907 pu 161.692 kW
Circulating current loss (with transposition)	0.0537 pu 9.867 kW	0.0550 pu 10.534 kW	0.0494 pu 10.102 kW
Total loss (without transposition)	2.7182 pu 499.467 kW	2.159 pu 413.492	1.8435 pu 376.981
Total loss (with transposition)	1.9129 pu 351.493 kW	1.3334 pu 255.373 kW	1.1022 pu 225.391 kW



2 TURNS/COIL
6 STRANDS/TURN
5.40 mm X 7.70 mm



2 TURNS/COIL
10 STRANDS/TURN
5.40 mm X 4.50 mm



2 TURNS/COIL
20 STRANDS/TURN
5.40 mm X 2.10 mm