

## TRM Case Study No. 4

### Faster Electrical and Thermal Simulation using the Example of a Heating Loop

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#### INTRODUCTION

Long twisted or spiral-shaped conductors have always been a challenge for iterative voltage drop calculation in TRM. Either the standard method had diverged after many iterations or the alternative start-restart method had calculated for a very long time, but then at least produced the correct result.

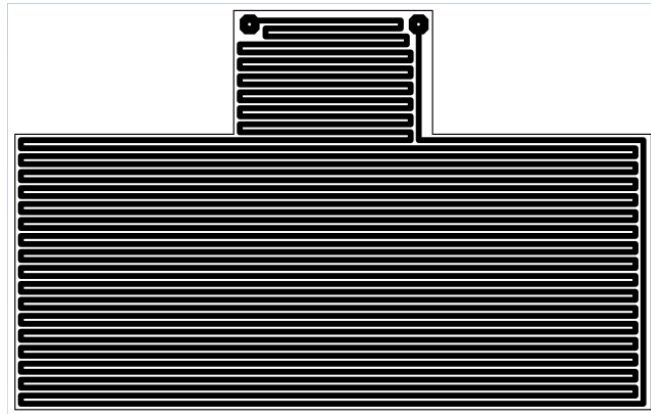
In TRM 2.3.12 (July 2019) an alternative non-iterative ("direct") method is enabled. This method requires a little more memory, but returns the result in a short time.

In this application study, we use both methods to calculate electric current heating and temperature for a meandering conductive path on different substrate structures.

Such trace shapes are used to generate a surface heating or in spiral form for electromagnetic transformers.

#### DATA

In the Internet [1] we find the .png picture of Fig 1. Construction details are not known.



**Figure 1:** Image of the heating loop [1]. Image size is 640 x 404 pixels.

Because the quality of this template is satisfactory at best due to the anti-aliasing in the png, we make a B/W monochrome bitmap with 1280 x 808 pixels twice as large for the calculation.

If we then assume a resolution of 0.1 mm per pixel, this layout is 128.0 mm x 80.8 mm. Some of the 49 horizontal lines are unfortunately somewhat narrower than the others after the .png .bmp conversion, which is well seen in the current density plot. But this does not influence the comparison of the methods.

**MODEL AND RESULTS**

The TRM model is three-layer: top layer, copper loop and substrate carrier. In the basic model the substrate is a FR-4 plate with thermal conductivity  $k=0.3$  W/Km.

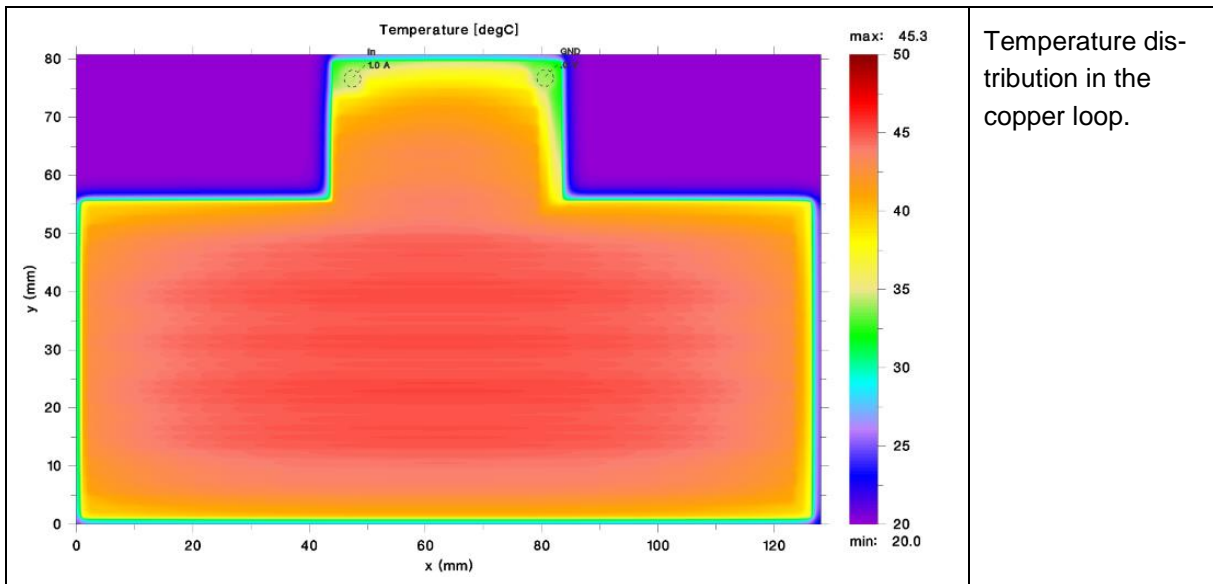
Name	Type	File	View	FR4 white?	Thick (mu)	Conductor	Dielectric
Cover	pre		View	<input checked="" type="checkbox"/>	500		k=0.2
Loop	bmp	Loop.bmp	View	<input checked="" type="checkbox"/>	20	Cu\$TRM	k=0.2
Substrate	pre		View	<input checked="" type="checkbox"/>	1000		FR4\$TRM

Figure 2: Layer structure of the basic model: foil on carrier.

At the upper end a pad with  $I=1$  A feeds, the other pad is GND. Cooling is done via free convection at 20°C ambient temperature.

**RESULT: TEMPERATURE, VOLTAGE, CURRENT**

Dissipated Power: 3.97 W  
 Voltage Drop : 3.97 V  
 $T_{max}$  45.8 °C inside the loop



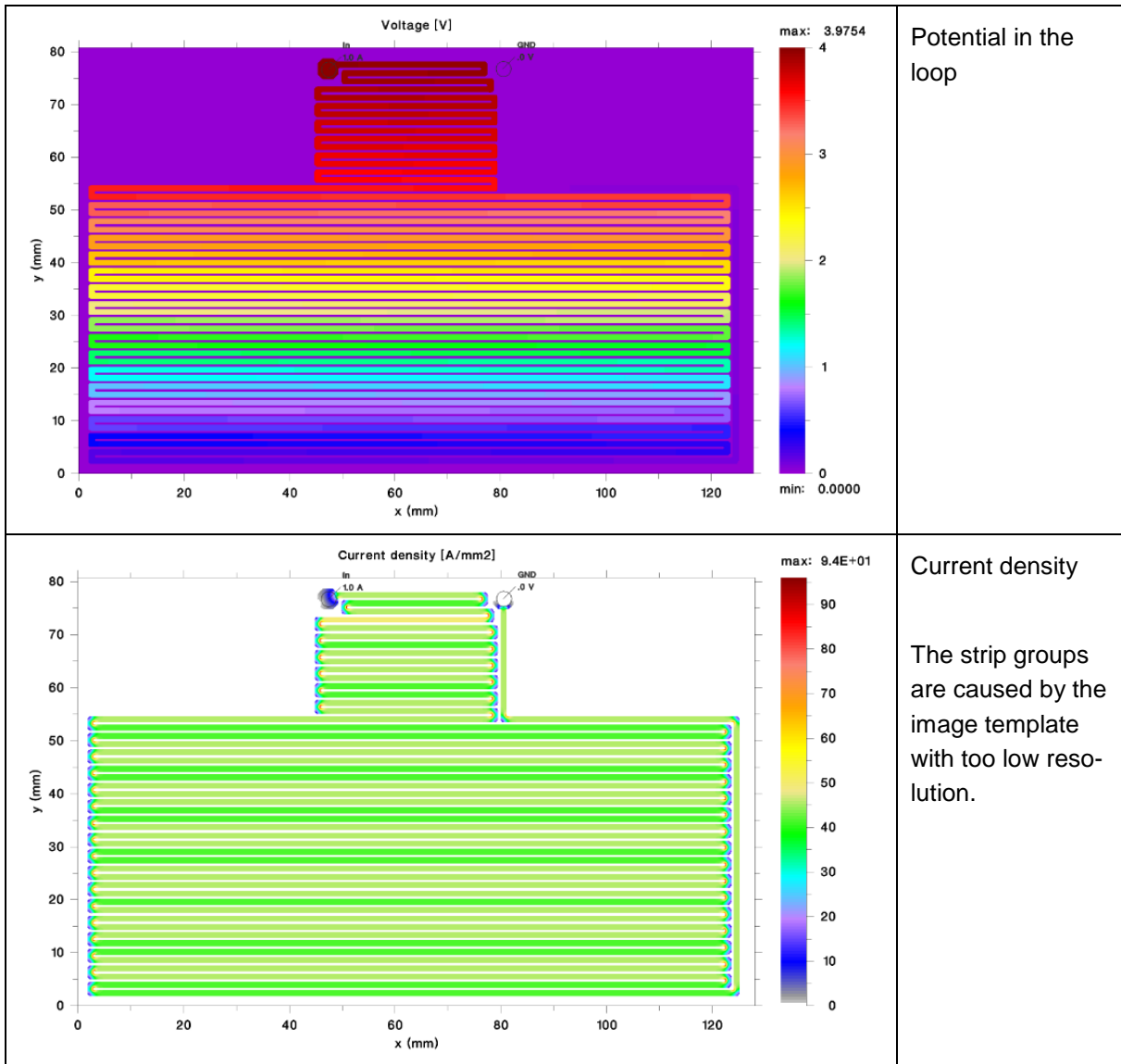


Figure 3: Basic model on FR4 substrate. x-y resolution: 0.1 mm.

Control calculation: The length of the current loop is approximately  $L \approx 39 \times 120 \text{ mm} \approx 4.7 \text{ m}$ . The cross-section of the conductor is  $11 \text{ pixel} \times 20 \text{ } \mu\text{m} = 0.022 \text{ mm}^2$ . This results in an estimated resistance of

$$R \approx \frac{4.7 \text{ m}}{0.022 \text{ mm}^2} * 0.0175 \frac{\Omega \text{ mm}^2}{\text{m}} \approx 3.7 \Omega$$

For  $I=1 \text{ A}$  this results in  $\Delta U = R * I \approx 3.7 \text{ V}$  und  $P = R * I^2 \approx 3.7 \text{ W}$ .

### COMPARISON OF CALCULATION METHODS

The results of the *iterative* and the *direct* method are comparable, if one considers that an iterative method always needs a termination criterion. A 99.9% accuracy level must be used here. Only then there is agreement. The direct method is almost always on machine accuracy. Interestingly, the iterative method is no longer able to master the 0.1 mm resolution.

**Table 1:** Comparison of calculation resources and results.

	Direct (0.2 mm)	Iterative (0.2 mm) 99%	Iterative (0.2 mm) 99.9%	Direct (0.1 mm)
<b>CPU/RAM Voltage</b>	1 sec / 1 GB	300 sec / 0.5 GB	473 sec / 0.5 GB	5 sec / 2GB
<b>CPU/RAM Temperature</b>	10 sec / 1.8 GB	13 sec / 0.5 GB	20 sec / 0.5 GB	60 sec / 8 GB
<b>Power loss</b>	4.2 W	4.0 W	4.2 W	4.0 W
<b>Voltage drop</b>	4.2 V	4.1 V	4.2 V	4.0 V
<b>Temperature (max.)</b>	47.4 °C	46.0 °C	47.3 °C	45.8 °C

At 0.2 mm resolution the direct method and the 99.9% iteration match. However, the voltage calculation of the direct method is 500 times faster. The iteration of the temperature is faster than that of the voltage, because the heat flow is not forced along a long snake but has the whole PCB volume to propagate. In addition, it has a short vertical path to the sink = ambient air.

The iterative method does not really please a parameter study. Therefore we will use the faster direct method in the following.

## VARIATION OF SUBSTRATE PARAMETERS

The heating loop is now applied to different substrates. The parameters and the results are listed in Table 2.

**Table 2:** Variation of the substrate material

	1 mm FR-4 ( $k=0.3$ )	1 mm Glass ( $k=1$ )	1 mm Ceramics ( $k=20$ )	500 mm Flex ( $k=0.2$ )
$T_{max}$	45.8 °C	44.9 °C	43.5 °C	45.8 °C

Why is the better thermal conductivity of ceramics not more noticeable?

Because the heat conduction has "nothing to do" here. Because of the geometric shape of the heat source, the heat is already spread in the best possible way. More heat spreading by the material is not possible. One would see an effect only with singular or far apart power lines.

## REFERENCE

[1] Michael B.: „Platine als Flächenheizung“. <https://www.mikrocontroller.net/topic/180630> (Abruf am 4.7.2019)