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THERMAL GRADIENTS IN LINEAR ANTENNA ARRAY

V.I. Zhuravliov, A.P. Youbko and E.N. Naumovich

Belarusian State University of Informatics and Radioelectronics
Minsk, Belarus

Outline:

1. Problem introduction
2. Thermal non-stationarity and emissivity in APAA
3. Modelling principles
4. Calculation results
5. Conclusions

Thermal gradients in linear antenna array

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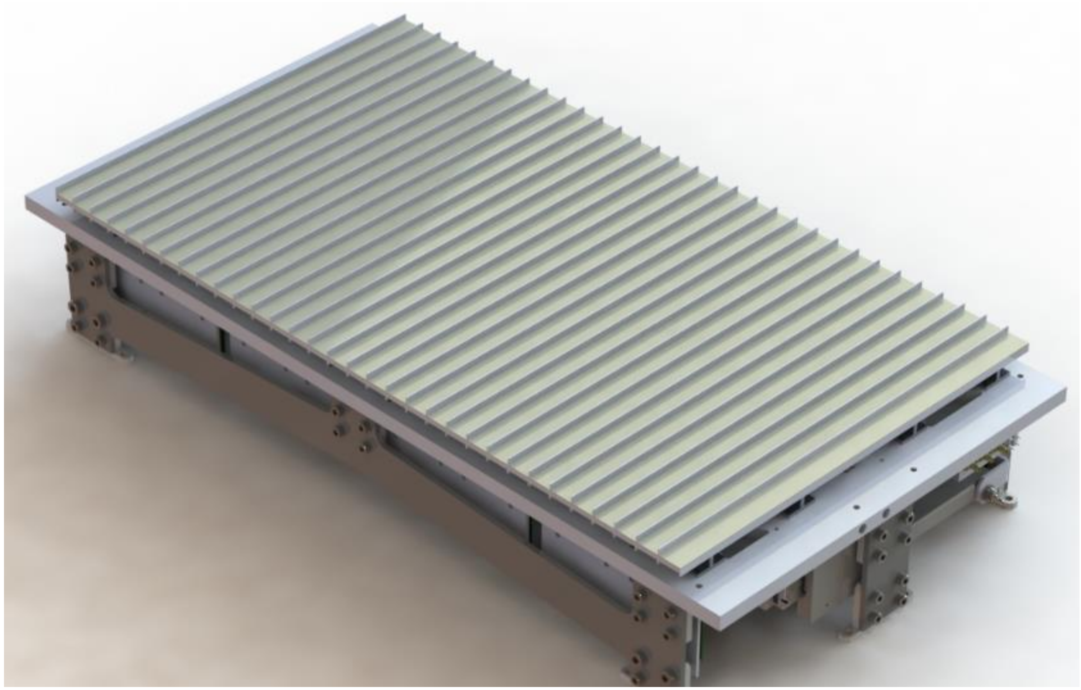
Synthetic aperture radars occupy a special place in systems for radar monitoring of the earth's surface, along with optical systems. The most modern onboard systems are based on active phased antenna arrays (APAA), which makes it possible to enhance the capacities by the use of electronic beam scanning.



N.M. Naumovich, V.I. Zhuravliov etc. "Constructive scheme of the experimental base panel of APAA fragment", VII Belarusian Space Congress, Minsk, Belarus, 2017

Thermal gradients in linear antenna array

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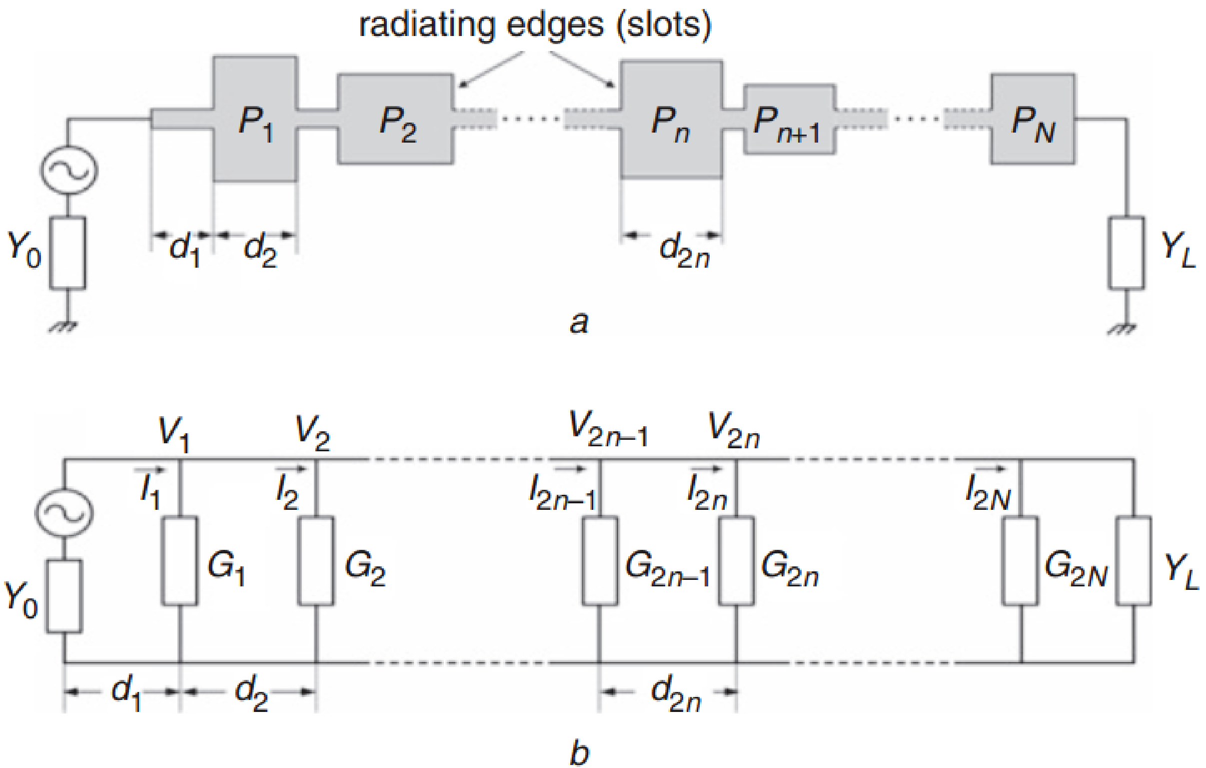
In some cases radar use planar antenna arrays consist not of separate elements, but from linear arrays to make them cheaper.



N - element microstrip antenna array and transmission line equivalent circuit of above array (2N slots)

a) N-element microstrip antenna array
b) Transmission line equivalent circuit

The linear array feed system is series-fed

D.G. Babas and J.N. Sahalos - Synthesis method of series-fed microstrip antenna arrays - Electronics Letters, 2007, vol.43. nr.2

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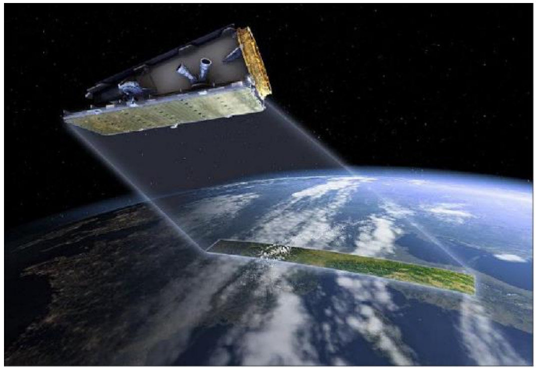
In general, it's possible to allocate two fields of antenna array application:

- Radiocommunication (e.g. MIMO systems)
- Radiolocation (e.g. AESA radars)



The approaches and design rules, used for these two fields, are quite different.

Pictures: https://en.wikipedia.org/wiki/MIMO
https://directory.eoportal.org/web/eoportal/-/novasar

The influence of temperature on antenna array parameters is more significant compared to a single transmitter:

in antenna arrays with sequential excitation phase error of each element is accumulated from element to element.

As a result, the temperature dependence on permittivity in multi-element arrays can seriously affect the characteristics, especially in the millimeter frequency range.

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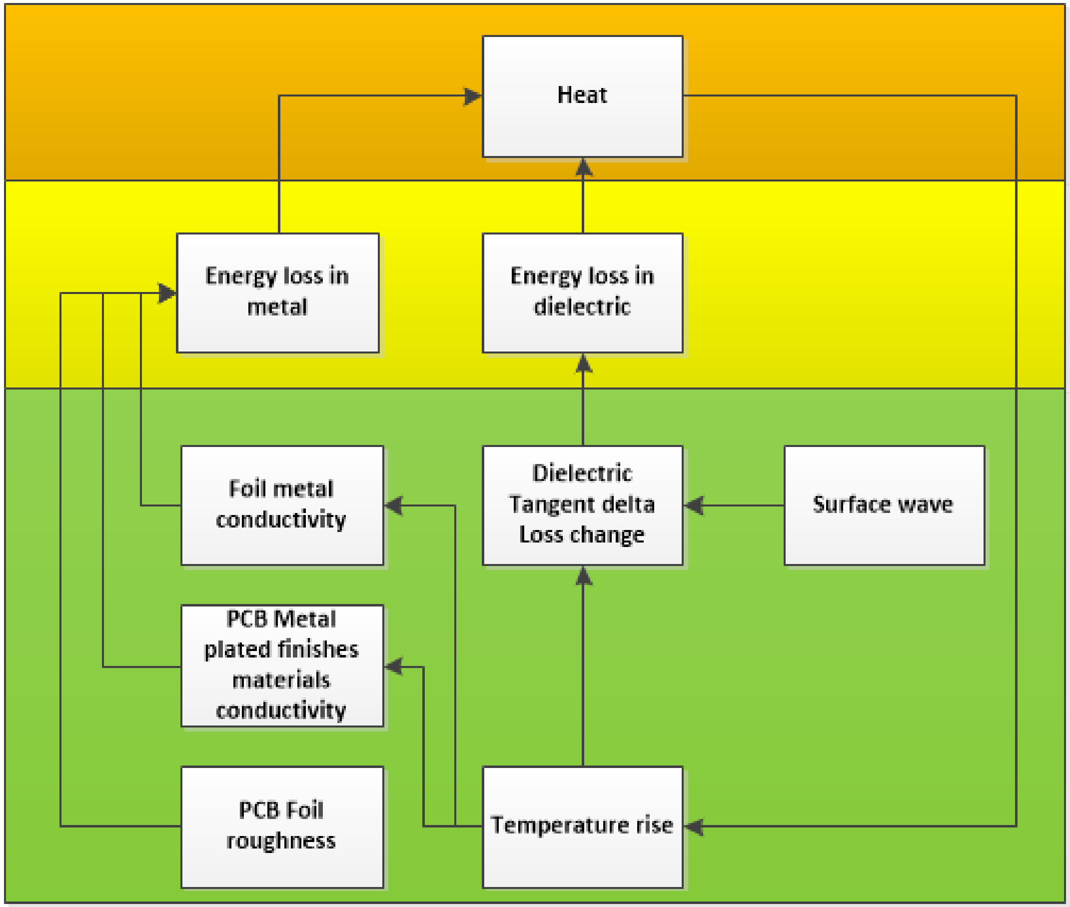
A great majority of modern antenna arrays elements are designed with the printed circuit board technology (PCB).

Heat cycle is determined mainly by:

- *metal loss* and
- *dielectric loss*.

The main reasons of heat generation are listed in green area



In case of dielectric loss, the main factor, which defines the dielectric loss during EM wave travelling through the structure is tangent delta angle.
Additional heating is occurred due to surface wave effect and bad matching, when the input power is not radiated completely and reflected several times within the structure, thus providing additional dielectric loss.

Quantitative loss can be described by equation:

$$P_D = \pi f tan(\delta) \varepsilon_0 \varepsilon_r \int \left|\vec{E}\right|^2 \delta V$$

where:
f – *frequency*;
$tan(\delta)$ – *loss tangent;*
$\varepsilon_0 \varepsilon_r$ – *vacuum and relative permittivity;*
E – *field strength.*

Metal loss factors defining the energy dissipation are as follows:

- Finite metal conductivity of main conductor (PCB copper foil);
- Finite conductor finish metal conductivity (ENIG, silver, gold etc);
- The level of conductor surface roughness.

Quantitative loss can be described by equation:

$$P_W = \frac{1}{2}\sqrt{\frac{\pi\mu f}{\sigma}} \int \left|\vec{H}_{tan}\right|^2 \delta S \ ,$$

where
f – frequency;
μ –permeability;
σ – conductivity;
H – magnetic tangential field strength.

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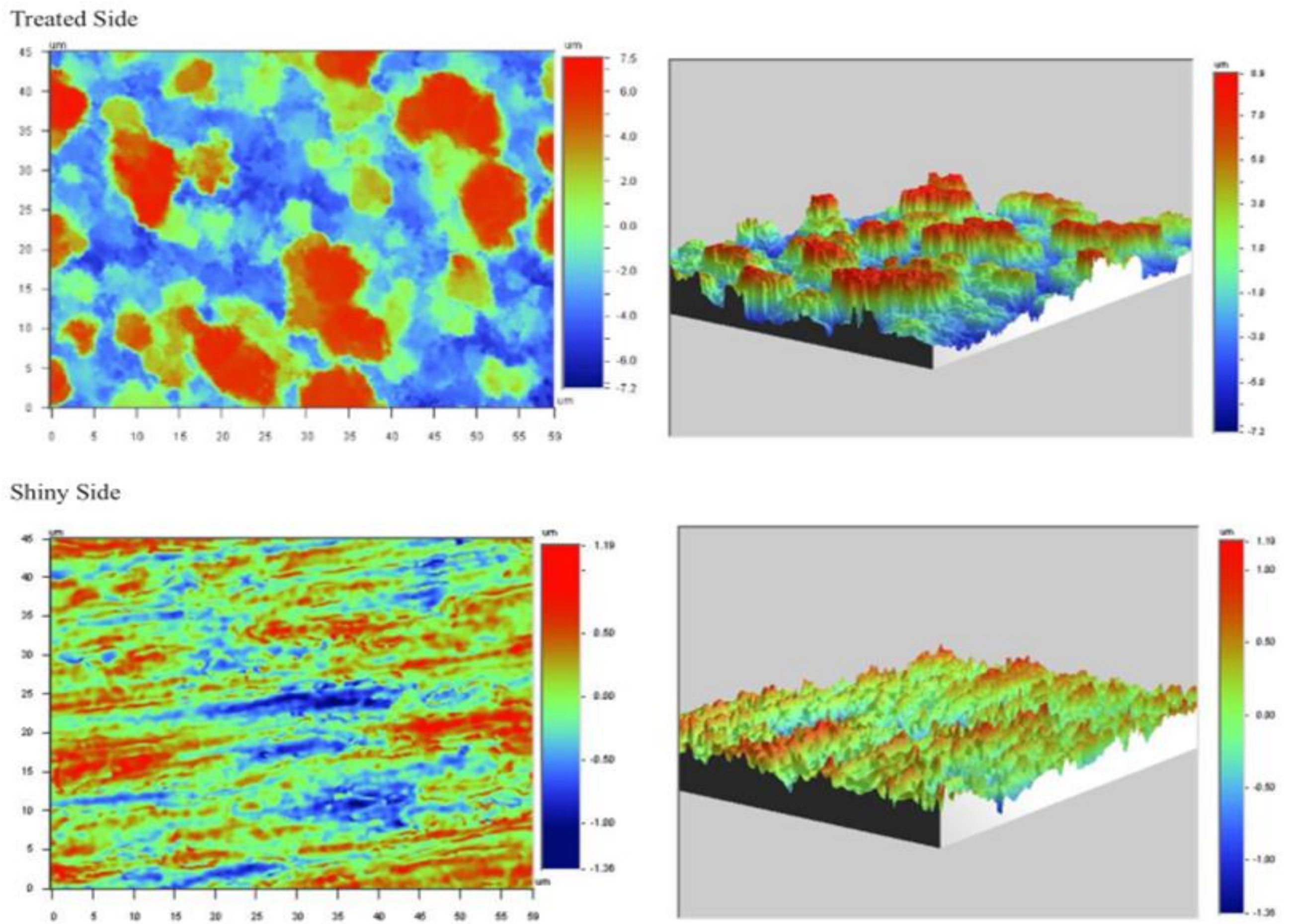
Material's surface with different roughness of PCB foil



Copper Foils for High Frequency Materials – Rogers Corp.

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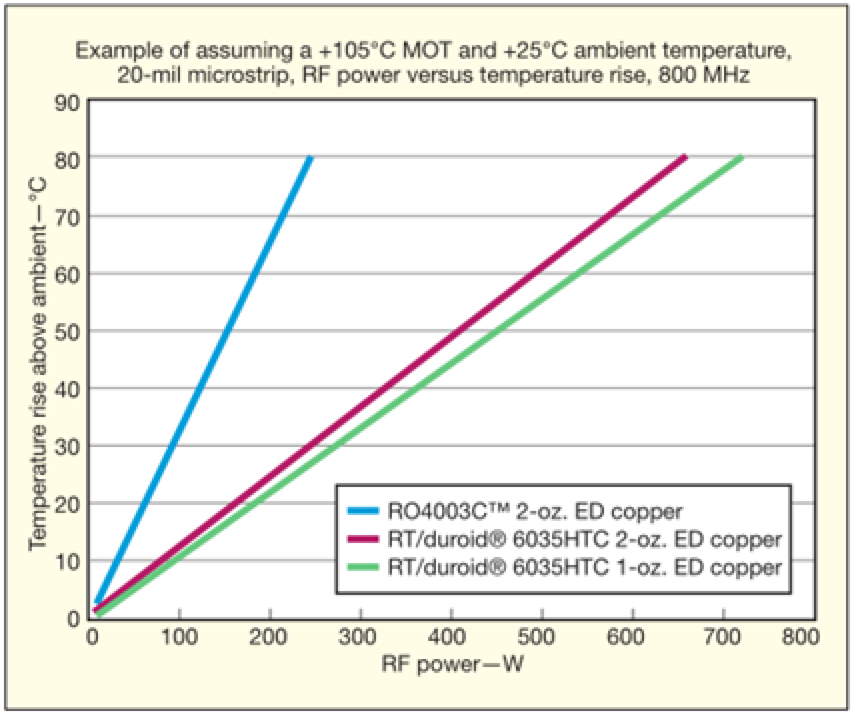

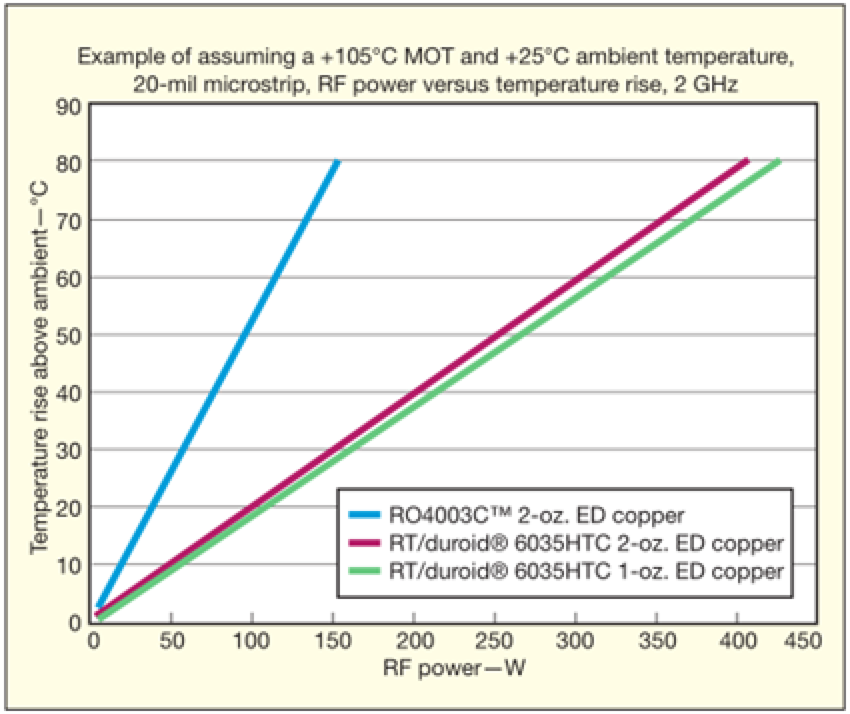

The results of compared maximum operation temperature for different dielectric materials *(by Rogers Corp.)*

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The temperature rise reasons in APAA in terms of design

- PCB temperature changes due to environmental changes
- PCB temperature changes due to inevitable electrical losses in conductors and the dielectric substrate of the PCB

Modeling initial borders:

- The series-fed linear antenna array
- Dielectric material: Taconic
- Sizes: 400 mm x 21 mm
- Electromagnetic sources with following power dissipation are centrally located
- Only dielectric losses were taken into account

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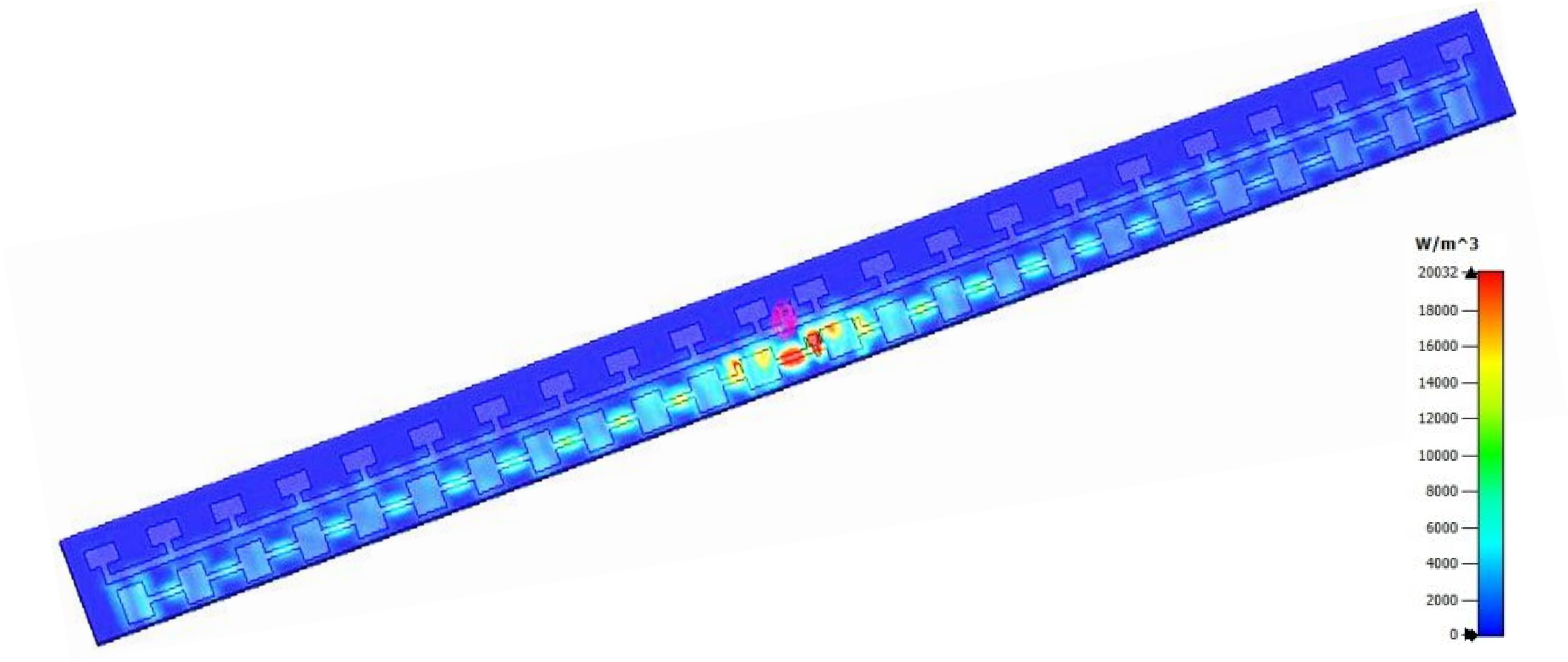

Calculated microwave power distribution (dielectric loss), f = 9,65 GHz

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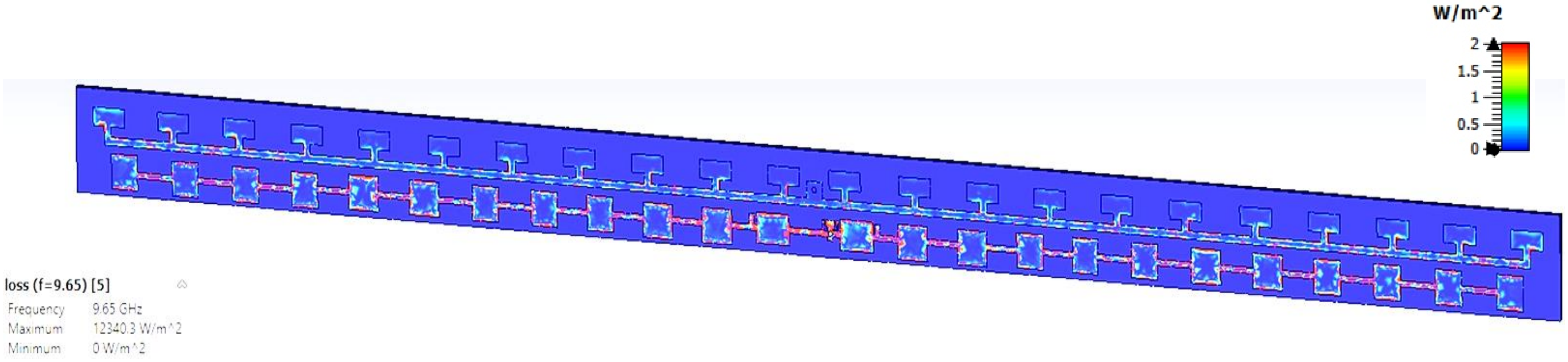

Surface loss (metal loss) simulation results (in comparison)

Thermal model:

- Distributed heat sources
- Each source is described as pulsed power
- The emitted power P_0 is irregular in time
- Each source is the rectangular parallelepiped form
- Basic heat transfers are thermal conductivity and radiation
- Convective heat transfer can be ignored (space application)

The specific thermal density of active element heat sources:

$$q_v = \frac{P}{V_0} \ ,$$

where V_0 is the element volume.

The total thermal power released in a single finite element can be determined as follows:

$$P = \frac{P_{\text{input}} - P_{\text{emit}}}{N}$$

where P_{input} is the input power;
P_{emit} is emitted microwave power;
N is the number of elements

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The heat equation particular solution by the Green's function for the temperature instantaneous value at time temperature:

$$T(t) = T_0 + \frac{P_0}{\rho C_p K} \int_0^t \operatorname{erf}\left(\frac{a}{4\sqrt{\chi\tau}}\right) \operatorname{erf}\left(\frac{b}{4\sqrt{\chi\tau}}\right) \times$$

$$\times \operatorname{erf}\left(\frac{c}{4\sqrt{\chi\tau}}\right) dt,$$

where

K – thermal conductivity coefficient,

r – material density,

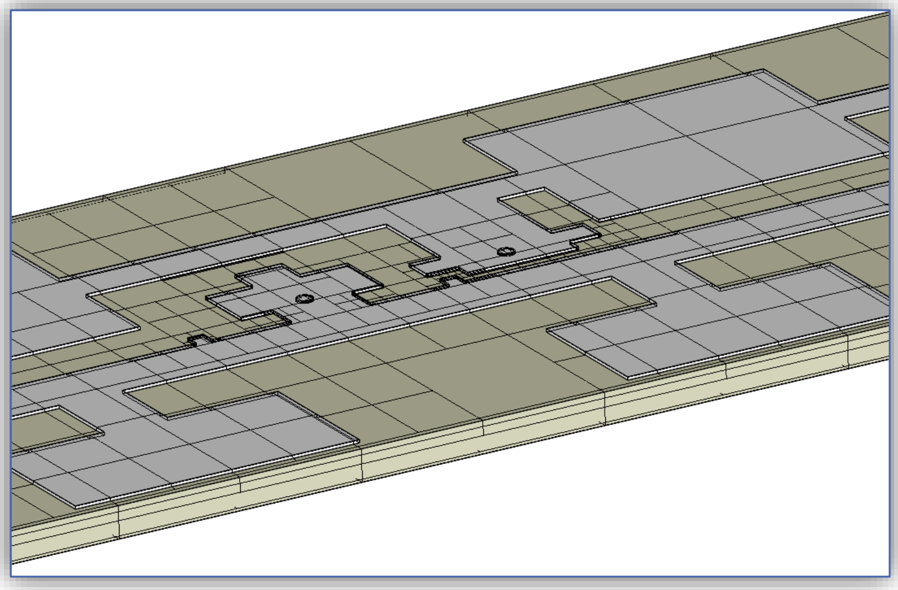
C_p – semi-finite body heat capacity

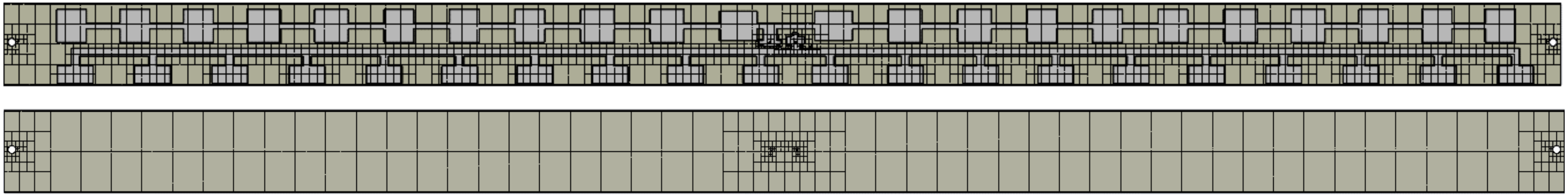
χ – heat-transfer coefficient;

T_0 – the ambient temperature.

by V.M. Dwyer, A.J. Franklin, D.S. Campbell, "Thermal failure in semiconductor devices", Solid-State Electronics. Nr 33 (1990)

Topology model for thermal modeling:





The preliminary grid for finite element method calculation

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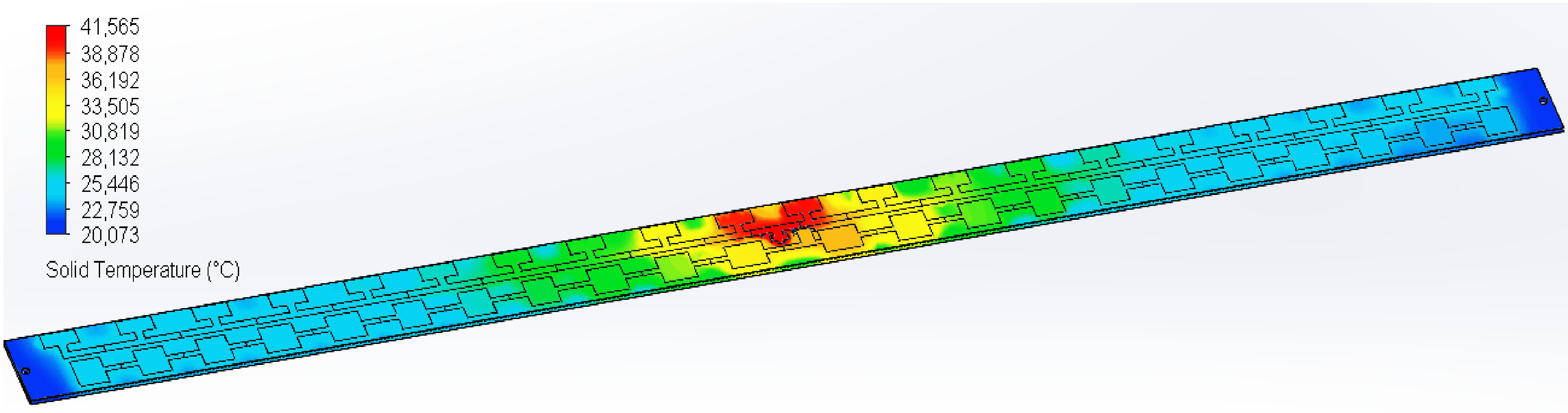
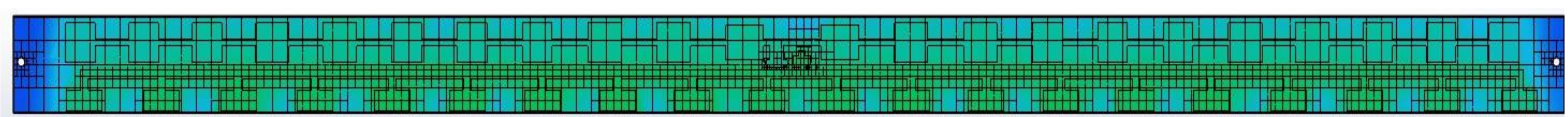
Calculation results:





The PCB temperature distribution

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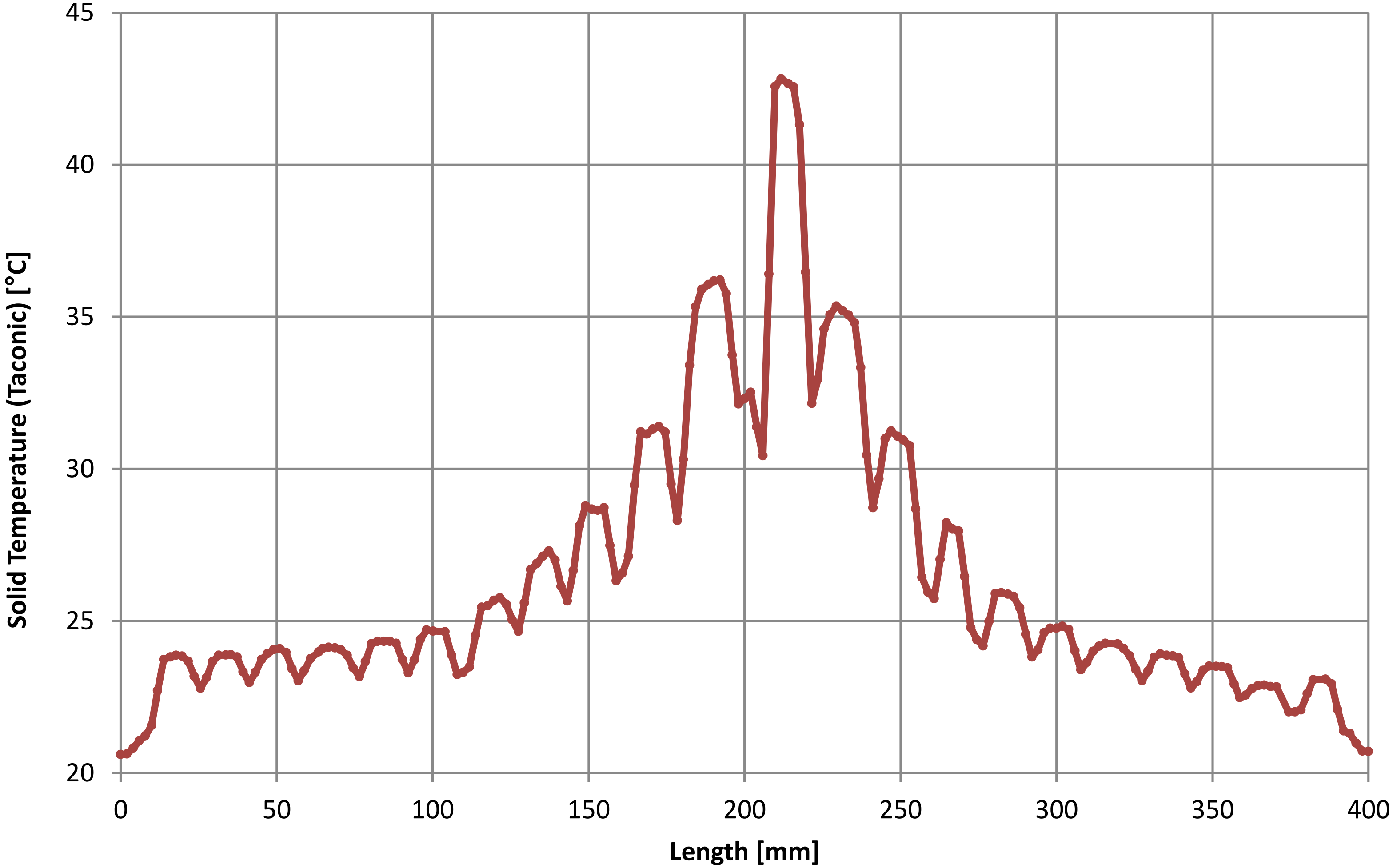

The dependence of the PCB temperature on the array length coordinate

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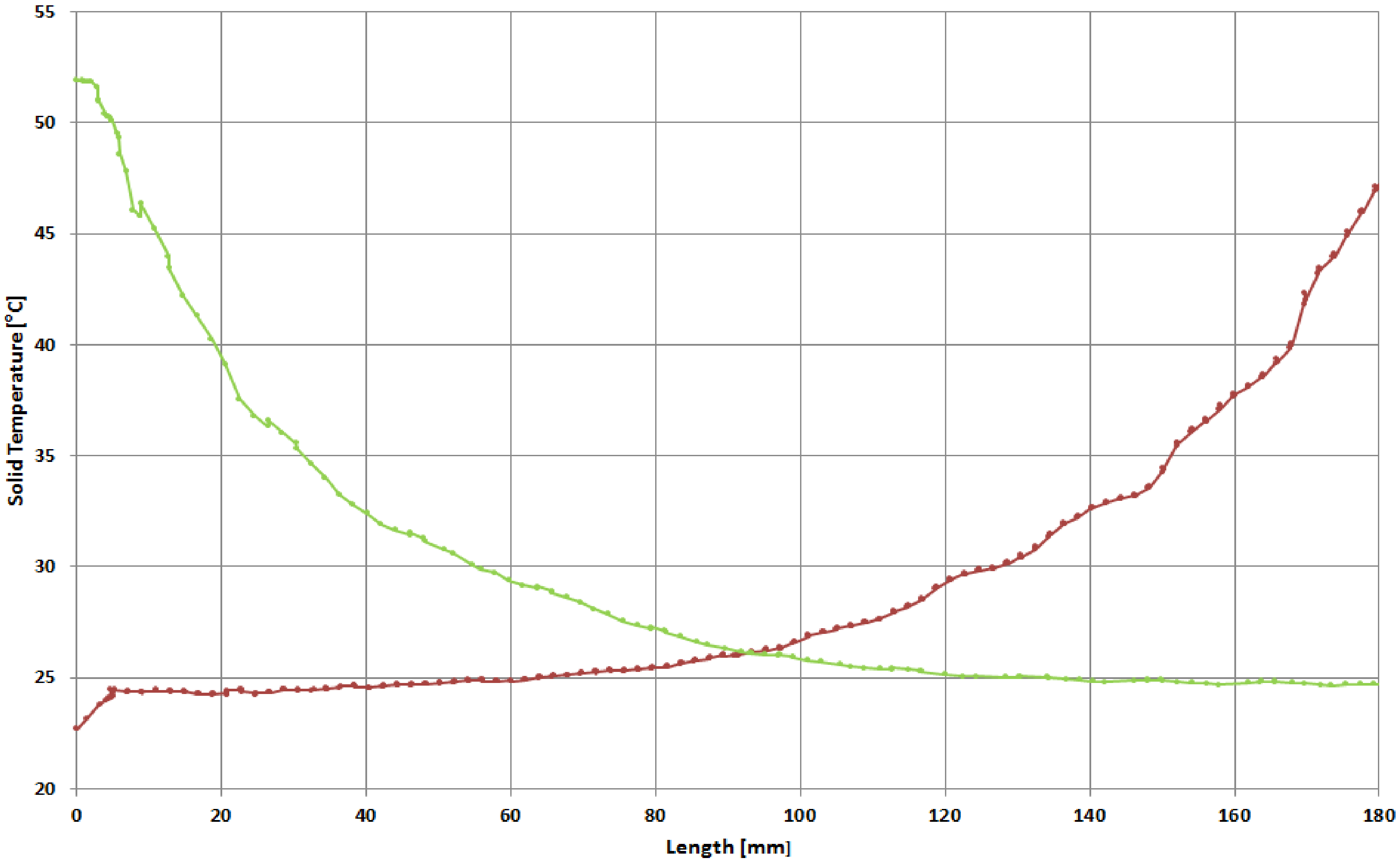

The dependence of the foil temperature on the distance from the center source

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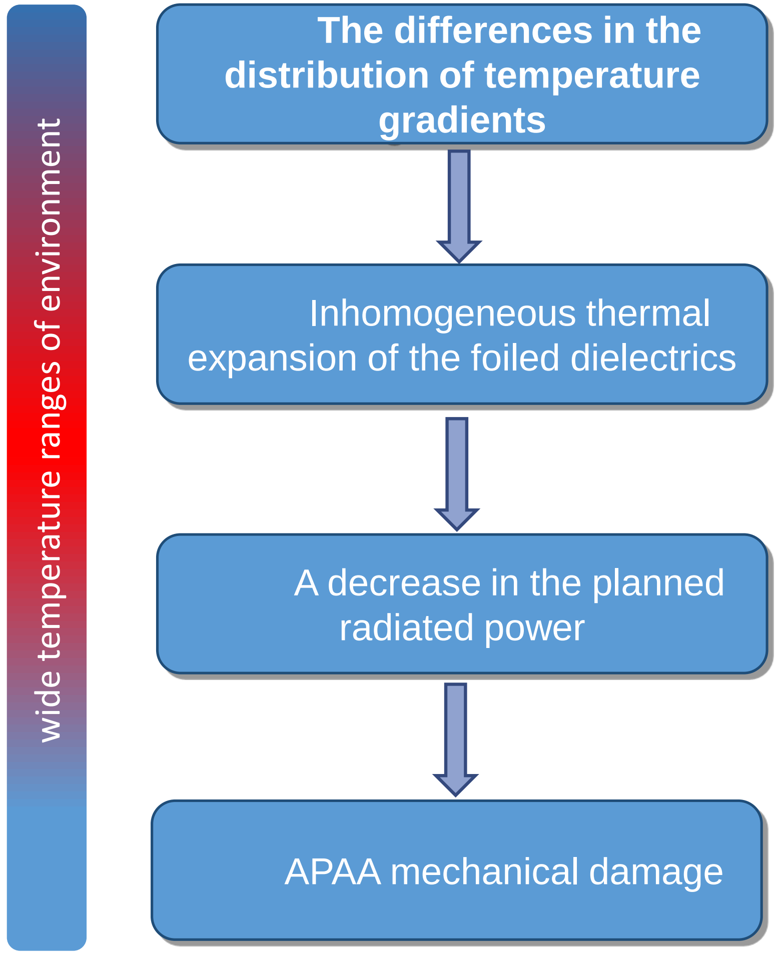

Conclusions:

- the inhomogeneous distribution of temperatures may lead to thermomechanical stresses
- the temperature gradients *can* affect the emissivity of each array in APAA, which may be taken into account at APAA designing

Thank you