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Thermal gradients in linear antenna array

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Abstract

The thermal modeling results of phased antenna arrays are presented. It shows the possible occurrence of temperature gradients along the arrays, which may affect the overall emissivity and its instability.

1 Introduction

Synthetic aperture radars occupy a special place in systems for radar monitoring of the earth's surface, along with optical systems. Most modern onboard systems are based on active phased antenna arrays (APAA), which make it possible to enhance the abilities by the use of electronic beam scanning [1].

The most important parameter of foiled dielectrics in the design of high-frequency circuits are the values of dielectric permeability and dissipation factor. These parameters are temperature-dependent. Though change of temperature dependence of these values can seem not essential, nevertheless, this property at wide use of resonant chains (for example, filters, resonant printing antennas) with the distributed parameters can essentially influence characteristics of the device.

2 Thermal non-stationarity and emissivity

The influence of temperature on antenna array parameters is more significant compared to a single transmitter. In particular, in antenna arrays with sequential excitation phase error of each element is accumulated from element to element. As result, the temperature dependence of dielectric permeability in multi-element arrays can affect seriously the characteristics, especially in the millimeter frequency range [2].

The temperature rise reasons in APAA in terms of design can be divided into two groups. For the first, the printed circuit board (PCB) temperature changes due to environmental changes, for the second one, the PCB temperature changes due to inevitable electrical losses in conductors and the dielectric substrate of the PCB.

It should be noted that different substrate materials have both positive and negative thermal expansion coefficients.

Modern high-speed digital devices, as well as microwave and millimeter-range devices, use foiled dielectrics (laminates) as the basis for printed circuit boards, which differ in a variety of substrate materials. The best known of them is FR-4. Its use is mainly limited by digital and power circuits. For flexible printed-circuit boards the polyimide material is used. In the microwave and millimeter frequency range another class of materials is used, mainly based on Teflon.

The foil dielectrics are used mainly based on plastic fluor for creating the millimeter range and microwave range APAA. Its temperature changes due to inevitable electrical losses in conductors and the dielectric substrate of the PCB.

3 Modelling

The series-fed linear antenna array made on Taconic with 400 mm length and 21 mm width with centrally located power supply was considered. The radiating arrays are practically conductively isolated from the other part of heat-conducting structure (the thermal conductivity through the terminals can be neglected) and are cooled by open radiation and convection. If necessary, convective heat transfer can be ignored, for example, in outer space. Previously, the distribution of radiated power along the array was determined (Figure 1).

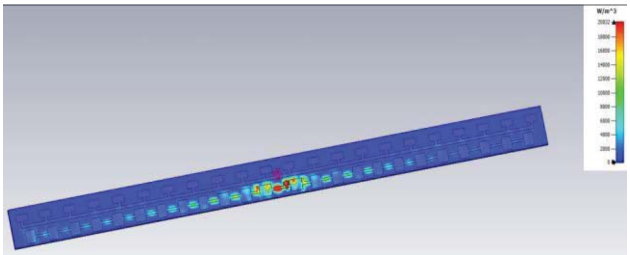

Figure 1. Microwave power distribution, $f = 9{,}65$ GHz

The heat sources are unevenly distributed due to the central location of the source and the inhomogeneous strip structure. Obviously, the greatest heat losses are in the center region, where the initial power is supplied. Thereby, the heat model with distributed heat sources was used. Each source may be described by pulsed power dissipation. Since the emitted power is irregular in time, the chip case is represented as a pulsed power source P_0 in the rectangular parallelepiped form with side lengths a, b, c, and the heat equation particular solution by the Green's function for the temperature instantaneous value at time temperature looks like this [3]:

$$T(t) = T_0 + \frac{P_0}{\rho C_p\, K} \int_0^t \operatorname{erf}\left(\frac{a}{4\sqrt{\chi\tau}}\right) \operatorname{erf}\left(\frac{b}{4\sqrt{\chi\tau}}\right) \times \times \operatorname{erf}\left(\frac{c}{4\sqrt{\chi\tau}}\right) dt, \tag{1}$$

where K, r, C_p, χ are respectively the thermal conductivity coefficient, the material density, the semi-finite body heat capacity and heat-transfer coefficient; T_0 is the ambient temperature.

4 Results

The thermoelectric modeling of heating for considered series-fed linear antenna array was carried out. By using of numerical methods to solve the heat transfer tasks with the sources described an equation (1), the temperature distribution in dielectric was received (Figure 2).

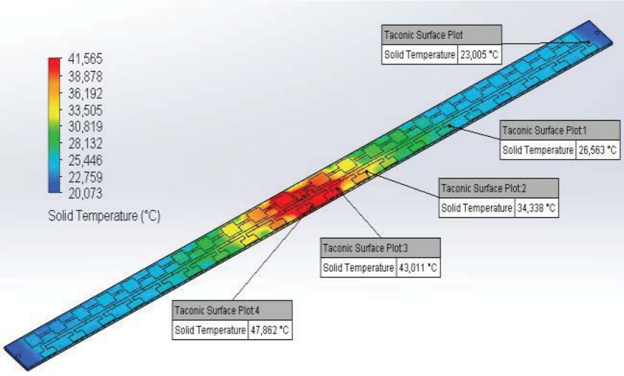

Figure 2. Temperature distribution along the array

Analysis of calculated thermal field distribution shows the presence of sufficiently large temperature gradients along the entire array due to some irregularity of the radiated power (Figure 3).

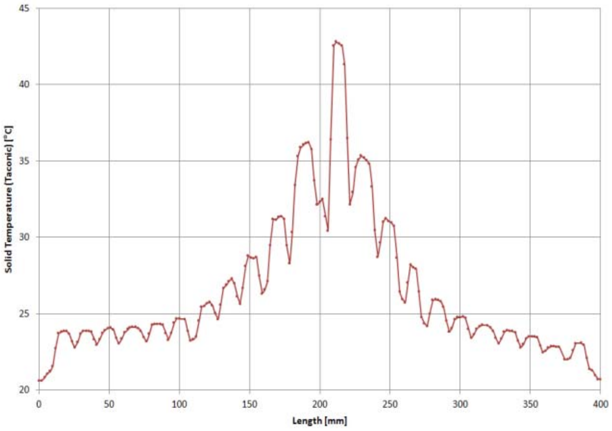

Figure 3. The dependence of the PCB temperature on the array length coordinate

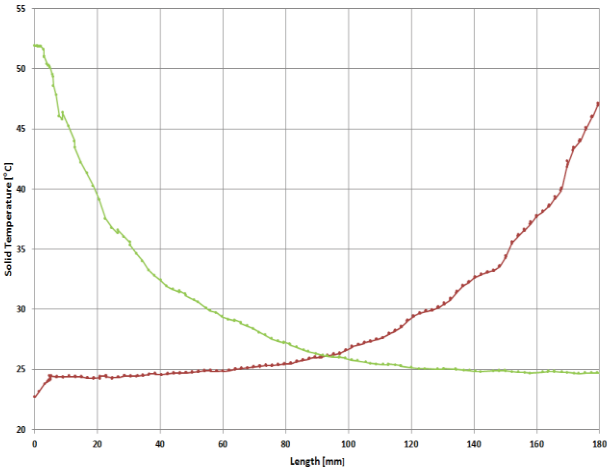

Figure 4. The dependence of the foil temperature on the distance from the center source

The temperature distribution in the foil was calculated (Figure 4) for comparison with dielectric modeling result. As can be seen, the temperature gradient is also present. Its occurrence can be explained by a rather thin foil thickness and an inhomogeneous form of radiating elements. However, the temperature distribution is smoother here, since the copper foil has a much higher thermal conductivity than the dielectric base.

These differences in the distribution of temperature gradients can subsequently lead not only to a decrease in the planned radiated power, but even to array mechanical damage. This may be caused by inhomogeneous thermal expansion of the foil dielectric and the occurrence of thermomechanical stresses. At the same time, it should take into account the possible wide temperature ranges of environment for APAA operation.

Thus, the temperature gradients may affect the emissivity of each array in APAA, which may be taken into account at APAA designing.

5 References

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