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LOCALIZED THERMAL EFFECT OF MICROWAVE ENERGY DISSIPATION OF CHIRAL BASED ELECTROMAGNETIC SHIELDS

BY

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Abstract. Energy distribution can be controlled by adequate simulation of optimum locations with higher energy concentration.

Key words: hexachiral structure; microwave shields; thermal effect; energy loss.

1. Introduction

One of the important properties of the auxetic materials is the thermal expansion, desired to be zero or negative. In thermal expansion studies the main assumption is a homogenous increase in temperature in the entire volume of the material (Hong *et al*., 2003). In the microwave shielding applications, where high absorption of the electromagnetic energy is desired, we may find

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ourselves, in a certain situation where high power level waves interact rapidly with the structure. The hexachiral honeycomb interacts at microscopic level with the incident electromagnetic waves; as a result the power dissipation is not equally distributed inside the structure (Damian *et al*., 2007). One of advantages of these metamaterials in microwave shielding is their intrinsic sparse nature, giving them good heat dissipation properties but thermal phenomena are slow comparing to the electromagnetic interaction that generates them, so we can expect temporary and localized temperature increase (Orfanidis, 2008).

2. Energy and Localized Thermal Effect

The electromagnetic energy dissipation inside the structure can be expressed locally, in an elementary volume, in terms of the power loss density

$$\mathrm{d}Q = \frac{\mathrm{d}P}{\mathrm{d}V}\,\mathrm{d}V\,\mathrm{d}t = P_V\,\mathrm{d}V\,\mathrm{d}t. \tag{1}$$

In the same elementary volume, this energy dissipation will generate an increase in temperature

$$\mathrm{d}Q = \mathrm{d}m\; c_p \mathrm{d}t = \rho \mathrm{d}V\; c_p \mathrm{d}t. \tag{2}$$

In these relations we use the parameters for Epoxy fiberglass which is the basic material for the panel under test: density, $\rho \approx 1{,}800$ kg/m^3, and specific heat capacity, $c_p \approx 1{,}255$ J/kg·K.

A concentration of the energy dissipation will generate a temperature increase in certain points. However this energy is not accumulated, the most significant heat transfer mechanism being thermal conduction

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = kA\frac{\Delta T_0}{x}. \tag{3}$$

The speed of the heat transfer through a portion of material of transversal area, A, and length, x, depends on the steady state temperature difference. As well, the material data is for Epoxy fiberglass, the thermal conductivity in eq. (3), $k \approx 0.29$ W/m.K.

Heat is generated differently in two points according to the electromagnetic energy concentration pattern (eq. (1)). We can estimate the steady state for the thermal phenomenon when the difference between the generated heat in every point equals the heat transferred by conduction between the same points

$$\Delta\left(\frac{\mathrm{d}Q}{\mathrm{d}t}\right) = \left.\frac{\mathrm{d}Q}{\mathrm{d}t}\right|_1 - \left.\frac{\mathrm{d}Q}{\mathrm{d}t}\right|_2 = \Delta P_V\,\mathrm{d}V \quad (4), \qquad \left.\frac{\mathrm{d}Q}{\mathrm{d}t}\right|_{1-2} = kA\frac{\Delta T}{x}. \quad (5)$$

While accurate description of the thermal conductivity in the presence of inhomogeneous power dissipation would require integration of eqs. (2) and (3) in the entire structure and is beyond the aims of this paper, we can make an estimate of the thermal effects, considering the situation where the thermal conductivity and power dissipation occur in the same elementary volume, with length x.

Typically, in microwave illuminated structures, the distances are in the centimeter range, so we can take $x = 10^{-2}$ m,

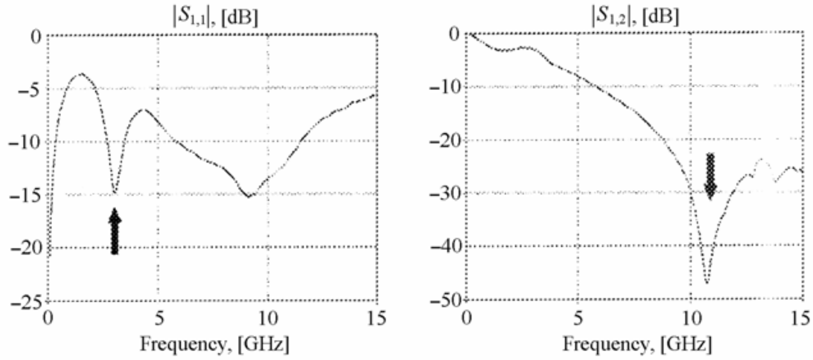
$$\Delta T \approx 3.45\times 10^{-4}\,\Delta P_V \;\left[\mathrm{W/m^3}\right],\; \left[\mathrm{K}\right], \tag{6}$$

as most appropriate for the structure under test and the frequency range of interest. Field strength distributions inside the structure are found to behave correspondingly (as a longitudinal concentration) and the transversal distribution will be imposed by the geometry of the structure, again in the centimeter range.

Eq. (6) can be used to estimate the temperature gradient which will appear inside the hexachiral structure we investigate at normal electromagnetic illumination .

3. Energy Loss Distribution Inside the Hexachiral Structure

Simulations have been performed in order to identify the energy absorption characteristics inside the material. The first results emphasize an energy concentration depending solely on the hexachiral geometry. The power loss density inside the ligaments of the hexachiral honeycomb is an indication



a *b*

Fig. 1 – Minimum reflectance at: *a* – 3.06 GHz; *b* – 10.69 GHz.

of energy dissipation inside the structure. The two frequencies chosen, 3.06 GHz and 10.69 GHz, are those corresponding to a minimum of the reflectance (Fig. 1 *a*) and transmittance (Fig. 1 *b*), respectively, as the frequencies at which maximum thermal effect is expected.

The same software suite (CST Microwave Studio) described in the Computer Simulations section was used, with the difference that in single frequency analysis the FDFD (Finite Differences in Frequency Domain) solver was used to compute the fields inside the structure. The computation is full 3D, Figs. 2 and 3 show the power loss density in different longitudinal sections through the panel (A Software Suite..., 2006).

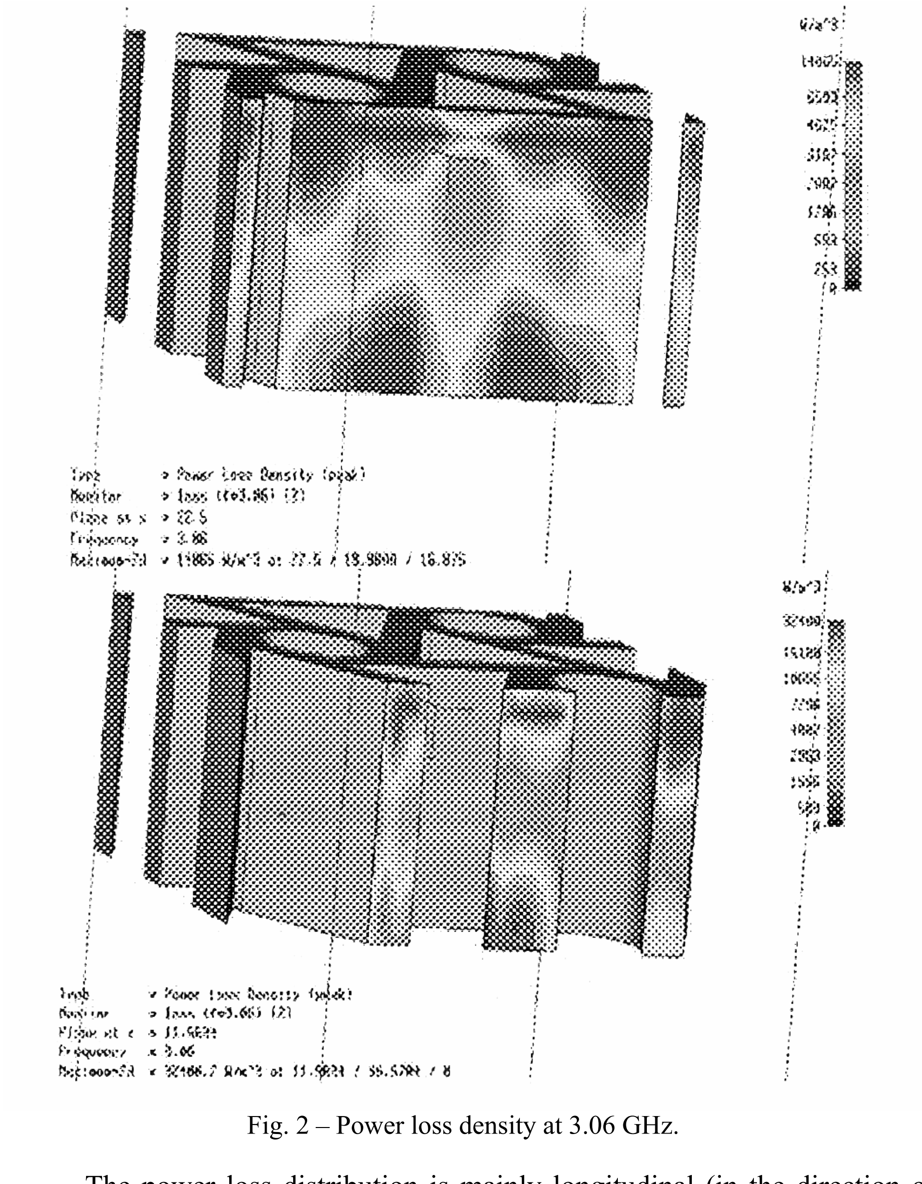


Fig. 2 – Power loss density at 3.06 GHz.

The power loss distribution is mainly longitudinal (in the direction of the incident wave). The incident illumination is 320 W/m^2 (normalization: 1 W over the surface of the input port), a rather high value if we consider that the safety limit for RF workers is 50 W/m^2. While such a situation is not usually encountered, we can use eq. (6) to estimate the temperature gradient which will appear inside the hexachiral structure. At 3.06 GHz (Fig. 3) we have maximum $\Delta P_V \approx$ 12,000 W/m^3 and $\Delta P_V \approx$ 30,000 W/m^3 inside the cylinder and inside the ligaments, respectively. The maximum temperature variation is $\Delta T \approx$ 4 K and $\Delta T \approx$ 10 K, respectively. As the power losses are related to transmission behaviour; we expect greater effect when the transmittance reaches a minimum

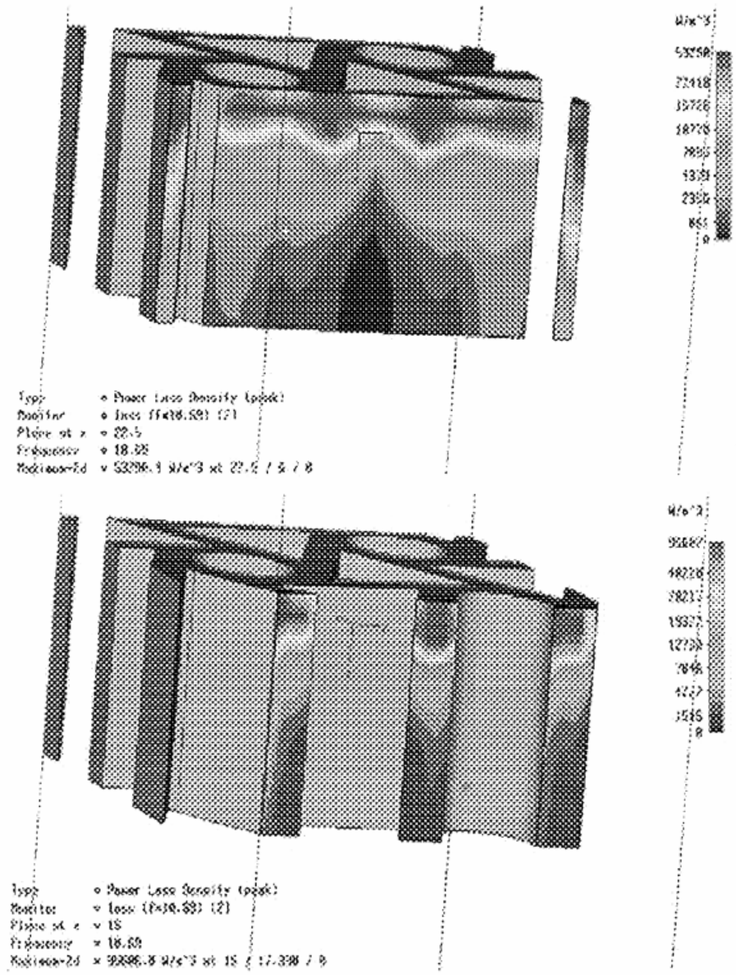


Fig. 3 – Power loss density at 10.69 GHz.

(Fig. 1 *b*). At 10.69 GHz (Fig. 3) we have maximum $\Delta P_V \approx$ 53,000 W/m^3 and $\Delta P_V \approx$ 95,000 W/m^3 inside the cylinder and inside the ligaments, respectively, the corresponding temperature variation being $\Delta T \approx$ 18 K and $\Delta T \approx$ 33 K, respectively.

The second set of results is obtained with the chiral panel included in a Salisbury screen configuration (Fig. 4). An aluminum foil was placed on one side of the panel, and a resistive sheet on the other side. The electromagnetic

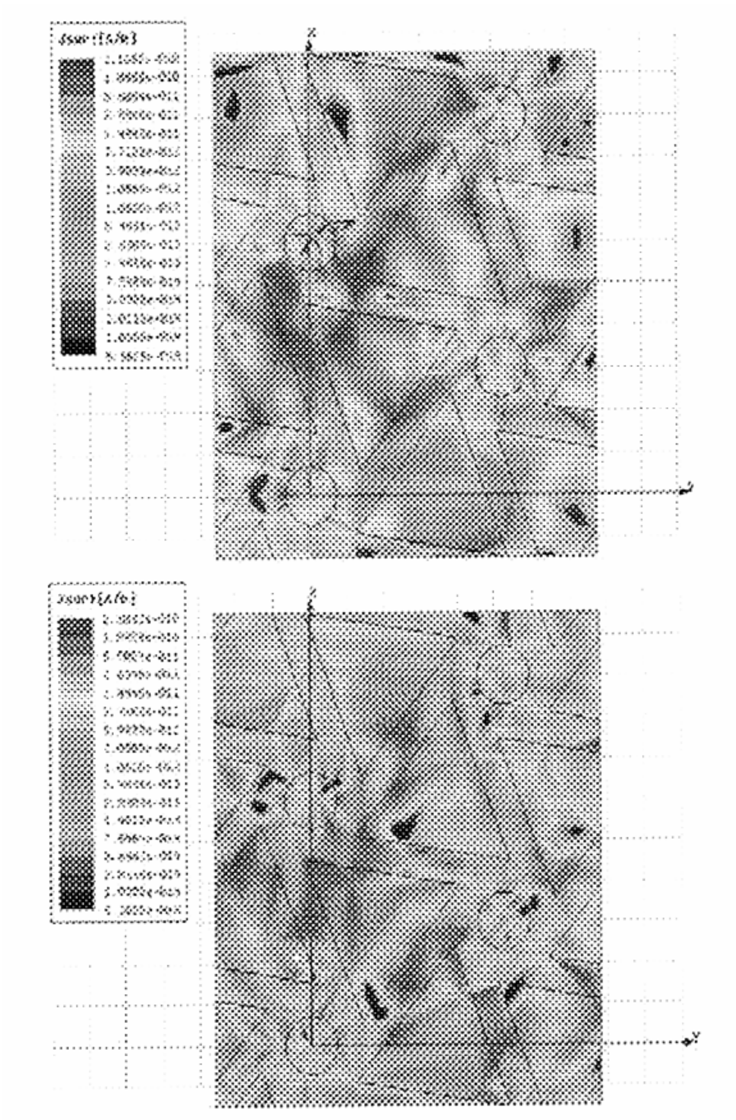


Fig. 4 – Surface current in Salisbury shield configuration;
2.94 GHz (left) and 6 GHz (right).

illumination was made on a direction normal to the foils from the resistive side. In this configuration most of the power dissipation takes place inside the resistive sheet, thus implying a transversal energy concentration mainly.

The surface current in the resistive sheet is plotted in Fig. 4 as an indication of transversal power dissipation distribution. The two frequencies: 2.94 GHz (up) and 6.01 GHz (down) correspond to the first minimum and second maximum of the reflectance (with the same justification: at resonance we expect maximum energy concentration) (CHISMACOMB, 2008). At each

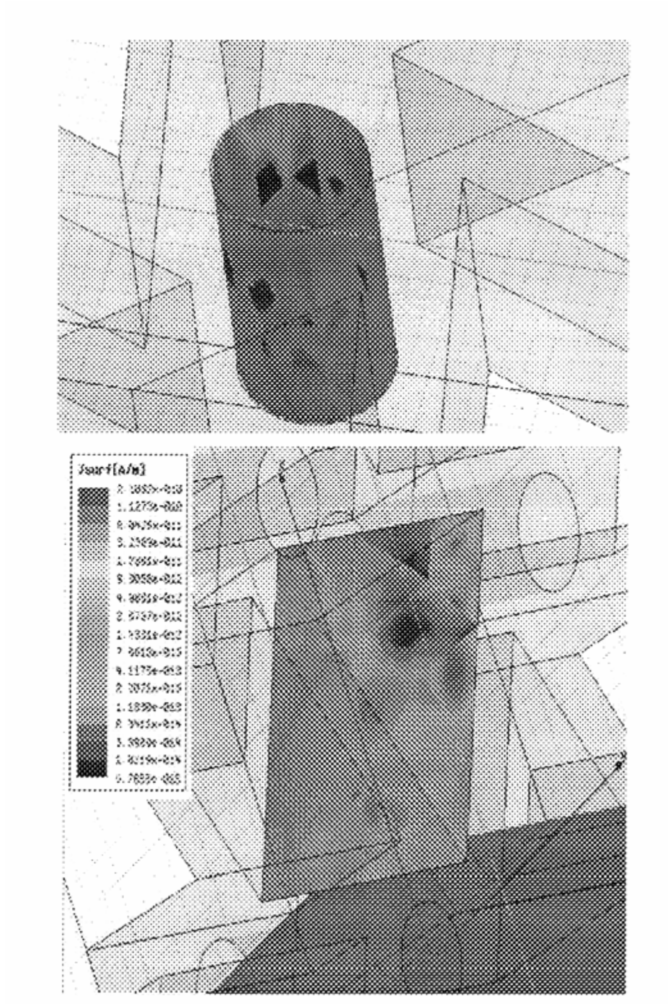


Fig. 5 – Surface current on the cylinder and on the ligaments.

frequency, the current on the internal surface of the cylindrical node and of the ligament (Fig. 5) denote much lower (down to a factor of 10^{-3}) power dissipation inside the hexachiral structure. Because of the dissipative effect in the resistive foil, the Salisbury screen is less susceptible to the geometrical symmetries of the panel used between the foils.

4. Conclusions

In typical applications (10 to 50 W/m^2 – safety limits) the effect is less important (up to 5 K temperature differences) but the differences in temperature can reach 100 K at 1 kW/m^2 illumination (Fig. 6). Wireless Power Transmission can use up to 30...90 kW/m^2 at the space reflectors.

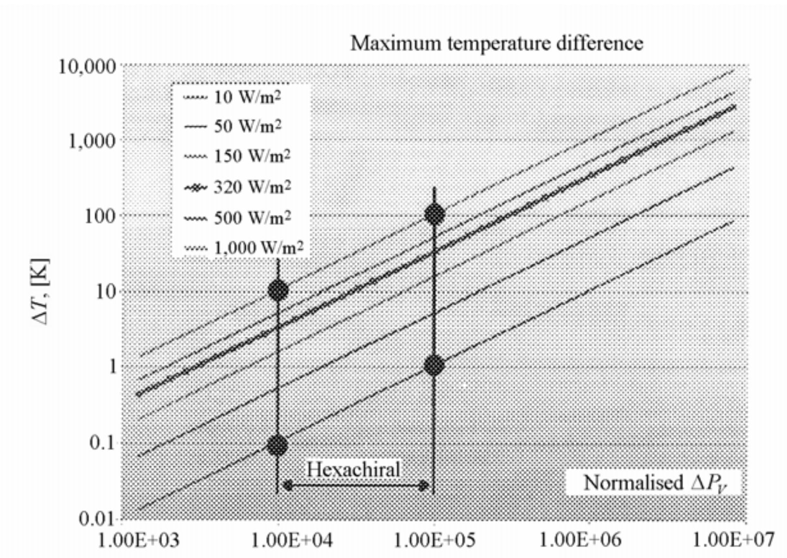


Fig. 6 – Dependence of the temperature gradient *vs.* the normalized power loss density.

Structural microwave absorbents have transversal power dissipation, mainly on foils, and are less susceptible to thermal influence on structural integrity, but they also have an energy concentrating behavior.

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REFERENCES

Damian R.F., Ciobanu R., Brînzila M., Olariu M., *Stability Considerations and Efficient Computing in Chiral Materials Electromagnetic Simulations*. 15th IMEKO TC4 Symp. on Novelties in Electr. Meas. a. Instr., Iaşi, Romania, Sept. 19-21, 2007, 110-114.

Hong Y.K., Lee C.Y., Jeong C. K., Lee D.E., Kim K., Joo J., *Method and Apparatus to Measure Electromagnetic Interference Shielding Efficiency and its Shielding Characteristics in Broadband Frequency Ranges*. Rev. of Sci. Instr., **74**, *2*, 1098-1102 (2003).

Orfanidis S.J., *Electromagnetic Waves and Antennas*. Online book, ch 5, 160-166, http://www.ece.rutgers.edu/~orfanidi/ewa/, 2008.
* * * *A Software Suite with Total Synergy.* CST of America, Microwave Journal, **49**, *1* (2006).
* * * CHISMACOMB, A FP6 Specific Target Research Project, FP6-EU-013641, http://www.chismacomb.eu/, 2008.

EFECTELE TERMICE ALE DISIPĂRII ENERGIEI MICROUNDELOR ÎN ECRANE ELECTROMAGNETICE BAZATE PE STRUCTURĂ CHIRALĂ

(Rezumat)

Se efectuează simulări în scopul identificării caracteristicilor de absorbție a energiei în interiorul unei structuri chiral-fagure material. Cele două frecvențe alese, de 3,06 GHz şi 10,69 GHz, corespund unui minim al reflectanței, respectiv transmitanței. Softul utilizat a fost CST Microwave Studio cu specificația că pentru analiza la o singură frecvență a fost folosit solverul FDTD pentru a estima câmpurile în interiorul structurii testate.