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Kazan National Research Technical

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Measuring the electromagnetic properties of a solid dielectric material

(radomes, printed circuit board substrates, layered and composite materials)

Master Thesis

Scientific supervisor

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Wave propagation in layered medium

Let half of the parameters ε_0, μ_0 in layered structure on the plane (Figure 2) a plane wave with a harmonic of the field dependence of the time $e^{i\omega t}$ and direction $\vec{r}_{0t}$. Cartesian coordinate system was introduced so that the plane, which is the vector $\vec{r}_{0t}$ and normal $\vec{z}_0$ to the border of the structure, called the fall of the plane, is aligned with the plane xoz. Parameters of the i-th layer and its thickness is denoted by ε_i, μ_i, d_i respectively. Options before half-structure and accordingly it is denoted by ε_0, μ_0 and ε_{N+1}, μ_{N+1}.

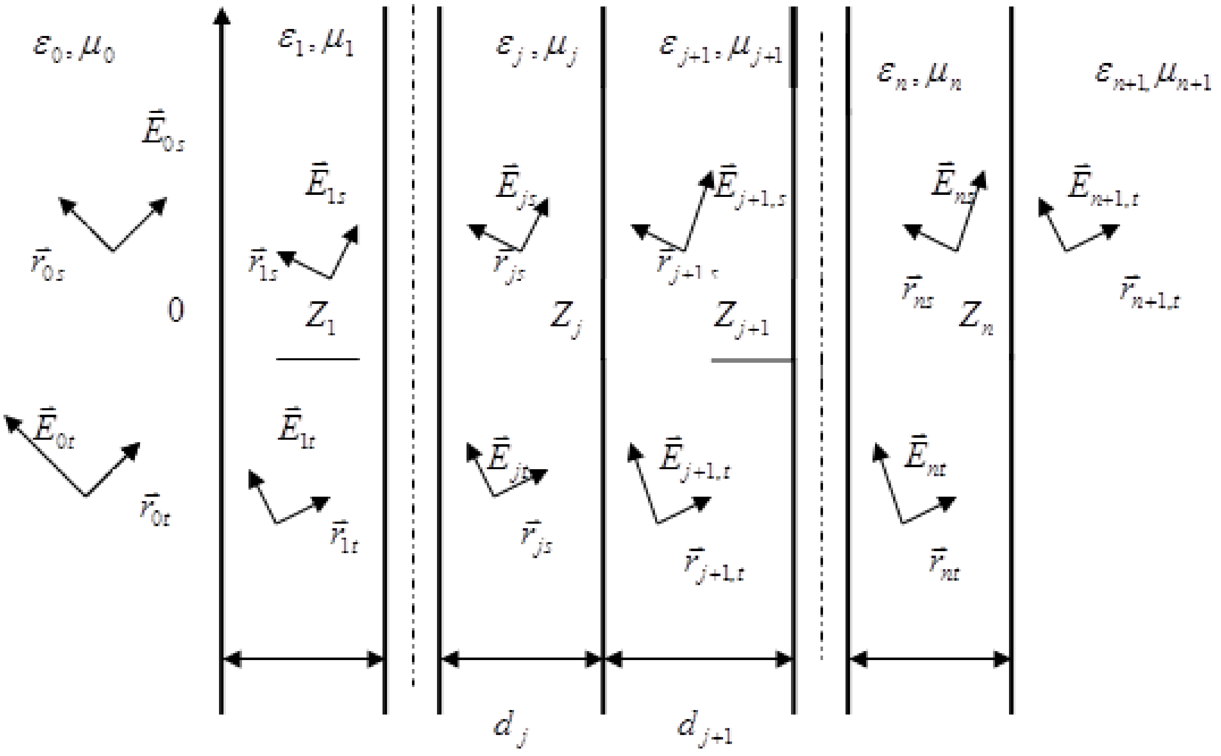


Fig. Diagram waves excited by a plane wave in a layered medium

The relationship between the values of the reflection coefficient in the i-th layer near the left and right borders:

$$R_{i\ell} = R_{ir} e^{-i2\kappa_i c_i d_i} \qquad (10.23)$$

$$\mathrm{R}_{\mathrm{ir}} = \frac{\mathrm{R}_{\mathrm{i,i+1}} + \mathrm{R}_{\mathrm{i+1},\ell}}{1 + \mathrm{R}_{\mathrm{i,i+1}} \mathrm{R}_{\mathrm{i+1},\ell}}, \qquad (10.22)$$

Transmittance of the layered structure:

$$\prod_{j=0}^{i} T_j = \frac{E_{1t\ell}}{E_{otr}} \cdot \frac{E_{2t\ell}}{E_{1tr}} \cdots \frac{E_{i+1,t\ell}}{E_{i,tr}}. \qquad (11.1)$$

The regrouping of the factors in the right-hand side, we get:

$$\prod_{\mathrm{j=0}}^{\mathrm{i}} \mathrm{T_j} = \mathrm{T}^{(\mathrm{i})} \frac{\mathrm{E}_{1\mathrm{t}\ell}}{\mathrm{E}_{1\mathrm{tr}}} \cdots \frac{\mathrm{E}_{\mathrm{i+1,t}\ell}}{\mathrm{E}_{\mathrm{itr}}} = \mathrm{T}^{(\mathrm{i})} \prod_{\mathrm{j=1}}^{\mathrm{i+1}} \frac{\mathrm{E}_{\mathrm{jt}\ell}}{\mathrm{E}_{\mathrm{jtr}}}. \qquad (11.2)$$

And so you can get to the frequency of the transmission coefficient:

$$\mathrm{T_i} = \frac{\mathrm{T}_{\mathrm{i,i+1}}}{1 + \mathrm{R}_{\mathrm{i,i+1}} \mathrm{R}_{\mathrm{i+1},\ell}}, \qquad (11.3)$$

$$\frac{\mathrm{E}_{\mathrm{jt}\ell}}{\mathrm{E}_{\mathrm{jtr}}} = \mathrm{e}^{\mathrm{i}\kappa_\mathrm{j} \mathrm{c_j} \mathrm{d_j}},$$

We obtain the final formula for the transmission coefficient i layers:

$$T^{(i)} = e^{-i \sum_{j=1}^{i} \kappa_j c_j d_j} \prod_{j=0}^{i} T_j \quad (i = 1, N). \qquad (11.4)$$

In the analysis of probing systems ratio (11.4) allows to quantify the degree of penetration of the incident field into a layered structure and the feasibility of each specific sensing schemes.

Included here are the Fresnel coefficients of performance:

$$R_{j,j+1} = \left\{ \frac{\dfrac{\dfrac{c_{j+1}}{c_j} - \dfrac{W_j}{W_{j+1}}}{\dfrac{c_{j+1}}{c_j} + \dfrac{W_j}{W_{j+1}}} - \text{для параллельной поляризации}}{\dfrac{1 - \dfrac{c_{j+1}}{c_j}\dfrac{W_j}{W_{j+1}}}{1 + \dfrac{c_{j+1}}{c_j}\dfrac{W_j}{W_{j+1}}} - \text{для перпендикулярной поляризации}} \right., \tag{11.5}$$

$$T_{j,j+1} = \left\{ \frac{\dfrac{2}{\dfrac{c_{j+1}}{c_j} + \dfrac{W_j}{W_{j+1}}} - \text{для параллельной поляризации}}{\dfrac{2}{1 + \dfrac{c_{j+1}}{c_j}\dfrac{W_j}{W_{j+1}}} - \text{для перпендикулярной поляризации}} \right.. \tag{11.6}$$

Results

data:

Speed of light $c := 299792458$

The magnetic permeability of free space

$$\mu o := 4 \cdot \pi \cdot 10^{-7}$$

The permittivity of vacuum $\qquad \varepsilon o := \dfrac{1}{\mu o \cdot c^2} \qquad \varepsilon o = 8.854 \times 10^{-12}$

Frequency $f := 12\cdot10^{9}$ $\lambda(f) := \frac{c}{f}$ $\lambda(f) = 0.025$ $\lambda\left(12\cdot10^{9}\right) = 0.025$

Glass thickness =2 mm fiberglass thickness = 8 mm

$\varepsilon_r = 3$ $\varepsilon_r = 4$

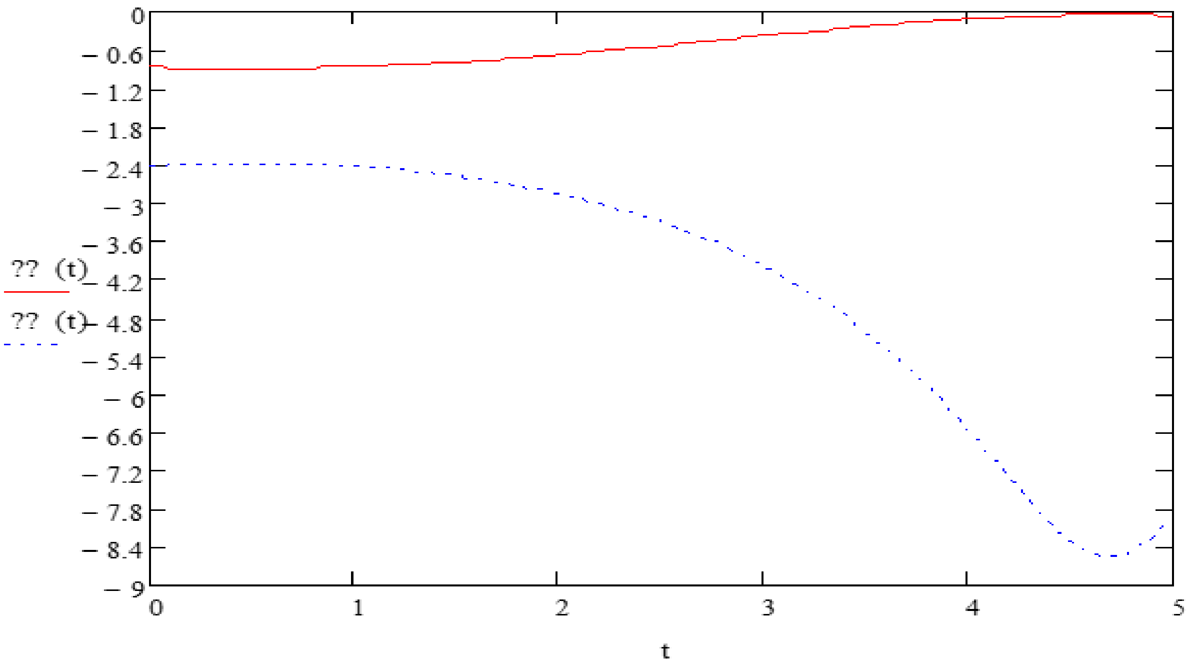
1. Model excitation two-layer structure of aplane wave with Mathcad program

$К\Pi(t) := 10\log\left(\left|T3\left(12\cdot10^{9} + t\cdot10^{9}\right)\right|\right)$

$КO(t) := 10\cdot\log\left(\left|Rl0\left(12\cdot10^{9} + t\cdot10^{9}\right)\right|\right)$

frequency(GHz)	(double layers)	
	Кп(Kt) in DB	Ко(kr) in DB
12	-0.9	-2.4
13	-0.7	-2.4
14	-0.6	-2.6
15	-0.3	-3.6
16	-0.1	-6.6

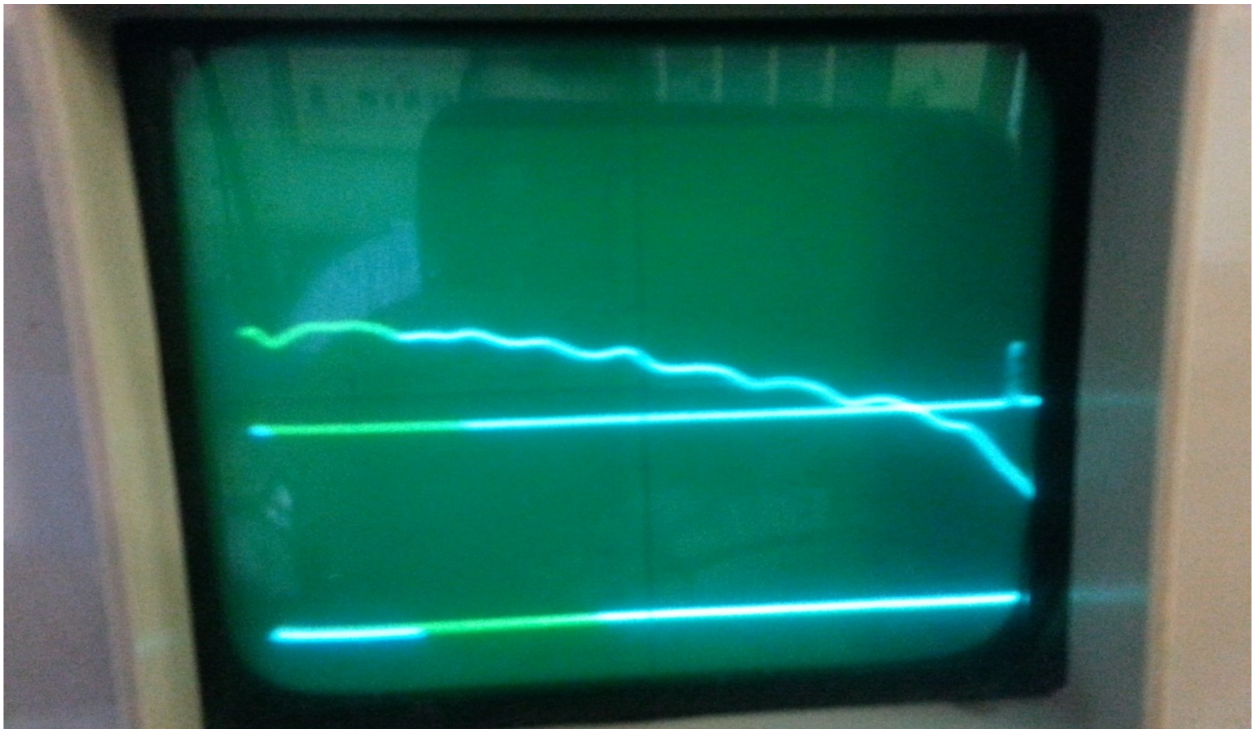
Table 1. Coefficient transmission



2. experimental measurements

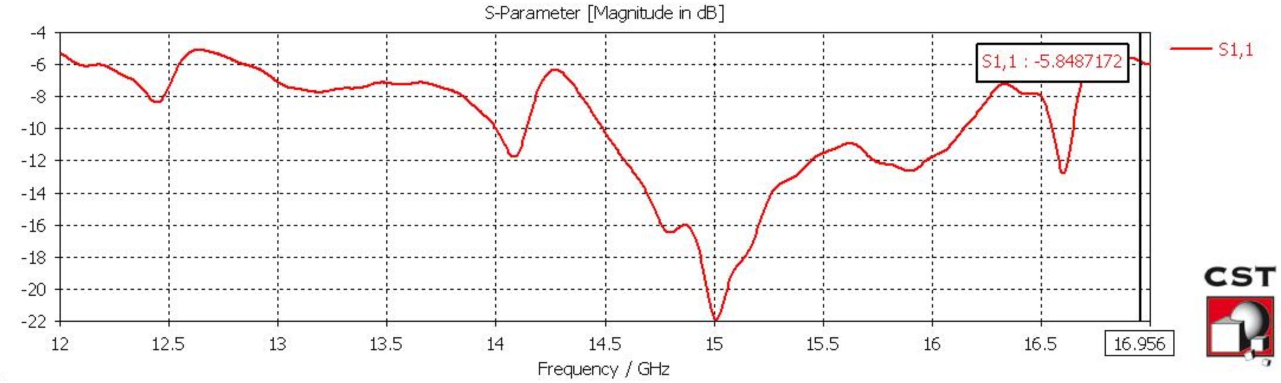
Частата(ггз)	(стекло)	(стеклопластик)	двух слоев	Пространство
	Кп(дб)	Кп(дб)	Кп(дб)	Кп(дб)
13	-0.8	-0.8	-0.25	0
14	-1.2	-1	-0.65	-0.25
15	-1.6	-1.5	-1.5	-0.5
16	-3	-3	-3.6	-1.7

Table 2. The transmission coefficient

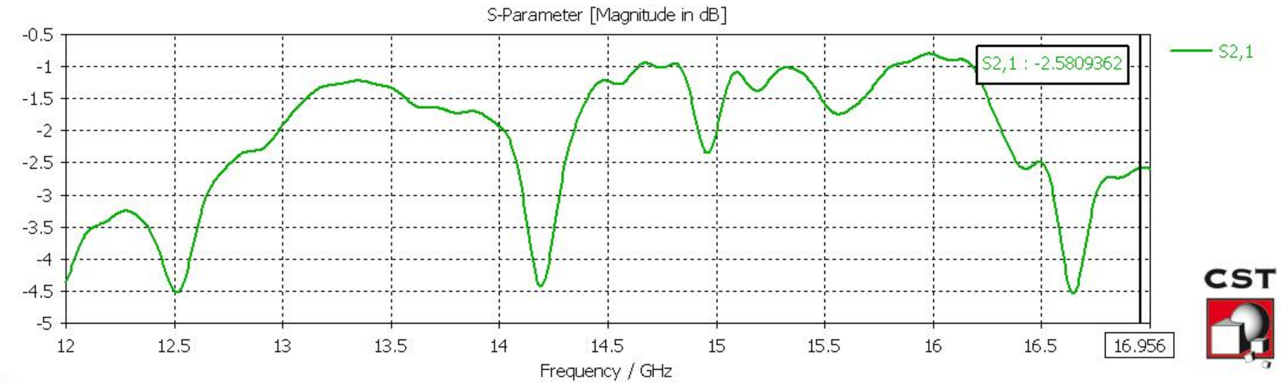


1. **Figure (2) for the glass and fiberglass**

3- Using CST



Рис(5). S11 двух слоя



fig(6). S21 Double layers

frequency (GHz)	(Glass)	(fiberglass)	Double layers
	Кt(DB)	Кr(DB)	КТ(DB)
12	-4.1	-1.9	-4
13	-3.8	-1.8	-1.9
14	-3.7	-3	-1.9
15	-4.9	-2.8	-1.9
16	-3.2	-3.7	-0.8
17	-4.6	-1.8	-2.5

Table 2. Transmission coefficient using CST program

conclusion

The results of the study can be summarized as follows:

1. Based on the analysis of the literature concluded the prospects for measuring the electrical parameters of the method of dielectric space.
2. Results of the polarization types and kinds of dielectric materials losses in the material which can be studied by the free space.
3. Implemented model of a two-layer dielectric material using MATHCAD program.
4. As a means of implementing the free space method proposed two horn system, which is suitable for the problem studied experimentally and using CST package. The necessity of adjusting the phase of the front horn emitter and receiver.

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