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The Recognition of Dielectric Layered Slab from Power Measurements

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Introduction

The determination of wall electromagnetic parameters is necessary for evaluation and simulation of microwave propagation and penetration in rooms. For most cases only the thickness of wall can bee measured directly. The structure and electromagnetic parameters of the wall must be calculated from a field scattering measurements.

Problems of structure are discussed in papers [1,2]. In most cases for recognition of thickness, permittivity and conductivity a short pulse radiates the wall. Reflected or transmitted pulse contains information necessary for slab's parameters calculation [3], [4]. The duration of pulses is about nanosecond. Other method for obtaining the necessary information is to provide measurements for number of frequencies. Our experiments [5] are carried out with the spectrum analyzer FSP-30 and therefore measurements is based on power measurements at several frequencies considering permittivity and conductivity constant in selected frequency region. The experiment can be carried out as a measurement of reflected power from the slab and transmitted power through the slab. The measurement of transmitted and reflected power is preferable for the case with significant absorption in the slab. For the slab with a small conductivity it is convenient to provide measurements from one side of the slab. In this paper will be described measurements from one side with different situation behind the slab.

Measurements

For determination of wall parameters we measure the reflected power that is proportional to the square of the reflection coefficient $|R|^2$. For frequencies below 3 GHz we use FSP-30 embedded sweep generator (Fig.1.).

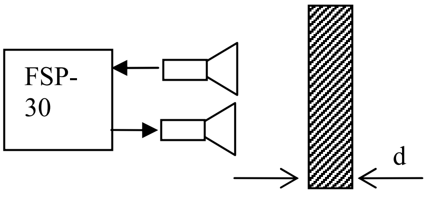

Fig.1. Measurement of reflection coefficient

The reflected power is measured for two cases: $|R_1|^2$ – power reflection factor from the slab and $|R_2|^2$ – power reflection factor from the slab covered with a metal plate on the other side (Fig.2.). The thickness of the slab d is measured directly. Every slab i can be determined by its thickness d_i [m], permittivity ε_i and conductivity σ_i [S/m]. The summary thickness of wall in our experiment is $d=d_1+d_2+\ldots+d_k+\ldots+d_n=0.55$ m.

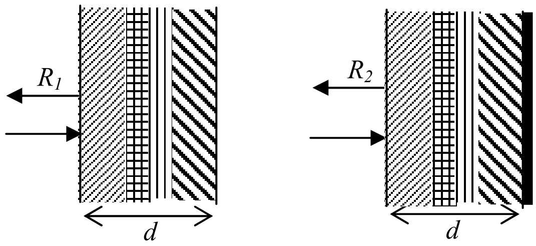

Fig. 2. Reflection coefficients R_1 and R_2

Results of measurements are summarised in Table 1. Power reflection factors from the slab are calculated from power measurements considering calibration [5].

Table 1. Power reflection factors from the slab and from the slab covered with a metal plate on the other side

f, GHz	$\|R_1\|^2$	$\|R_2\|^2$
2.0	0.142889	0.108143
2.1	0.0907821	0.289068
2.2	0.0717794	0.0550808
2.3	0.135519	0.069024
2.4	0.103276	0.205116
2.5	0.101158	0.141254
2.6	0.130017	0.0895365
2.7	0.0629506	0.107647
2.8	0.109144	0.170608
2.9	0.149968	0.0993116
3.0	0.041115	0.0303389

The recognition of structure and parameters for every slab will be discussed after introducing readers to the results of simulation.

The simulation of experimental measurements

The simulation is carried out for two purposes. First, inspect how many solutions satisfy measured power reflection factors. Second, inspect contribution of measurements errors in results of slab recognition. For both cases simulation reflection factors are calculated (in second case corrected too) for given slab structure and its parameters (permittivity and conductivity) and they are taken as standard. In simulation process, calculated reflection factors for all frequencies (standard) are compared with calculated reflection factors for variable slab parameters to search for a minimum deviation. For simulation we select structure with M slabs. Standards $|R_1(f_n)|_{st}^2$ and $|R_2(f_n)|_{st}^2$ are calculated for N frequencies.

$$Q=\sum_{n=1}^{N}\Big|\left|R_1(M,f_n,d_i,\varepsilon_i,\sigma_i)\right|^2-\left|R_1(f_n)\right|_{st}^2\Big|+$$

$$+\sum_{n=1}^{N}\Big|\left|R_2(M,f_n,d_i,\varepsilon_i,\sigma_i)\right|^2-\left|R_2(f_n)\right|_{st}^2\Big|\Rightarrow \min\cdot \quad (1)$$

Here d_i , ε_i,σ_i symbolise calculating reflection factors for M slabs with variable parameters for every slab.

For simplest case with M=1 and known thickness d_1=0.55 m we chose ε_1=4 and σ_1=0.005 S·m. Now over wide rang of parameters we must search permittivity and conductivity that give small difference of Q in Eq. (1).

Two parameters may be determined from $|R_1|^2$ and $|R_2|^2$ at one frequency. But in this case some other values of permittivity and conductivity also give small difference of *Q* from standard values (Fig.3.).

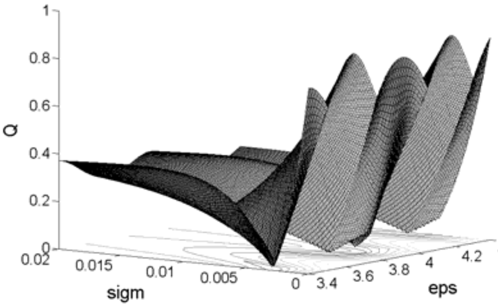

Fig.3. Variations from standard for slab M=1 and N=1

For *f*=2 GHz in addition to minimum at standard, small values of *Q* was observed for *Q*=0.00228, ε=3.46 , σ=0.003; *Q*=0.0053 ε=2.94 , σ=0.002; *Q*=0.00912, ε=4.41 , σ=0.008 and some others values. For determination of the slab parameters from measurements in Eq. (1) must be inserted measurement results and carried out a search of the minimum. If we have several small values of *Q* then incorrect values of parameters can be selected. This mistake can be eliminated by increasing measurements or, in our case, by increasing frequencies with defined standards.

Results of simulation for slab with M=1 at two frequencies are given on Fig.4.

For M=1 and N=2 we have additional small values of *Q*: *Q*=0.053, ε=4.55, σ=0.006; *Q*=0.0589, ε=3.48, σ=0.002.

For M=1and N=11 the nearest small value *Q*=0.6582, ε=4.42, σ=0.006 and unique parameters can be easily determined (Fig.5.).

The simulation was carried out also for pattern M=3 and d_1=0.15, ε_1=3.8, σ_1=0.02; d_2=0.1, ε_2=1.7, σ_2=0.005; d_3=0.3, ε_3=4.2, σ_3=0.01. The obtained results are like to the case with M=1. For N=4 the number of measurements and parameters of the slab are equivalent that gives additional small values of *Q*: *Q*=0.0083329, d_1=0.12, ε_1=3.8, σ_1=0.005; d_2=0.06, ε_2=3.5, σ_2=0.015; d_3=0.37, ε_3=4.2, σ_3=0.015

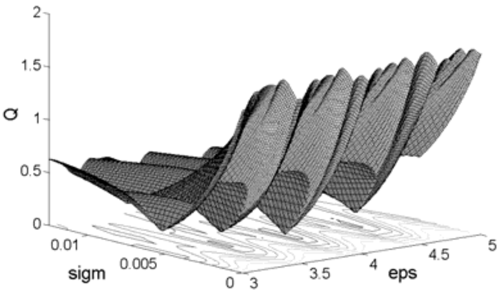

Fig.4. Variations from standard for slab M=1 and N=2

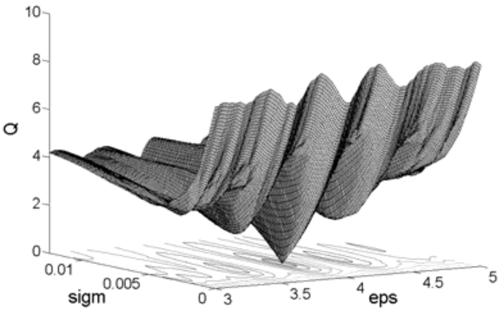

Fig.5. Variations from standard for slab M=1 and N=11

In case with M=3 and N=11 the nearest small value *Q*=0.137377, d_1=0.118, ε_1=3.82, σ_1=0.01; d_2=0.111, ε_2=3.02, σ_2=0.005; d_3=0.321, ε_3=3.64, σ_3=0.015.

From simulation we can conclude: for unique solution number of measurements must be greater than number of calculated parameters.

The contribution of measurements errors in the results of slab recognition can be inspected by simulation too. The simulation begins from a choice of the number of slab layers *M*. For every layer we choose thickness, permitivitty and conductivity. The chosen set of layer parameters will be named as pattern. For given pattern it is easy to calculate reflection factors named as standard. The simulation begins from distortion of standard reflection factors by normal distributed random number. The Gauss distributed random values are created with average corresponding to standard and given deviation ± α per cents with probability 0.95. In experiment α corresponds to measurements error. The simulation is searching a minimum of *Q* (1) for distorted standard by variation over wide range of layer parameters values. Of course with distorted standards we can not get *Q*=0. The nonzero minimum of *Q* can correspond to original pattern of parameters or to some other value of parameters in the case of large distortion . The range of distortion depends from α and corresponding accuracy of measurements. For many realisations of random distortions the simulation stores up values of Q and corresponding parameters of a set of layers. The stored up values allow evaluate the average and dispersion. Here presented results of simulation are obtained for N=11 frequencies. Average and dispersion of Q for different number of layers M and α are given in Table 2.

Table 2. Average and dispersion of Q for different M

α	M	Average	Dispersion
5	1	0.049413	$7.399\cdot10^{-3}$
5	2	0.046753	$7.614\cdot10^{-3}$
5	3	0.059098	$8.626\cdot10^{-3}$
5	5	0.065849	$1.221\cdot10^{-2}$
10	1	0.109244	$1.779\cdot10^{-2}$
10	2	0.113958	$2.054\cdot10^{-2}$
10	3	0.141236	$2.854\cdot10^{-2}$
10	5	0.136084	$1.304\cdot10^{-2}$
20	1	0.291955	$5.038\cdot10^{-2}$
20	2	0.273418	$3.711\cdot10^{-2}$
20	3	0.361699	$7.429\cdot10^{-2}$
20	5	0.367548	$7.617\cdot10^{-2}$

Results for α=1 are not given in Table 2. because average is small, parameters recognition give no aberration from the pattern and we have no measuring instruments with such an accuracy. For α=5 and α=10 simulation gives significant nonzero values of Q (see Table 2.), but there distortions create not important deviations from the pattern.

In action for different number of layers it is useful to know what exactness of calculated parameters can be obtained if power measurements are carried out with the accuracy α. Therefore simulation calculates the average and dispersion of layers parameters for distorted standards. Significant deviations from the pattern can be observed only for α=20. The original patterns and results of simulation are presented on Table 3 for M=1, M=3 and M=5.

Results of simulation in Table 3. shows for α=20 small deviations of calculated parameters from patterns. Only deviation for conductivity in some cases is near to 10%.

Determination of wall structure from measurements

Measured power reflection factors (Table 1.) now will be applied for recognition of wall parameters (choosing number of layers and determination of parameters for every layer). Solution of the problem is based on searching of minimum of Q (1) by parameters variation. Quite large minimum of Q indicates great measurements error or deficient number of layers for the model.

For calculation was used measurements at N=11 frequencies. The model M=1 gives Q=0.61665 and $d_1=0.55$, $\varepsilon_1=3.79$, $\sigma_1=0.007$.

The model M=2 gives Q=0.50253; $d_1=0.31$, $\varepsilon_1=3.42$, $\sigma_1=0.$; d_2=0.24, $\varepsilon_2=4.26$, $\sigma_2=0.015$.

The model M=3 gives Q=0.33985; $d_1=0.205$, $\varepsilon_1=3.79$, $\sigma_1=4.42\cdot10^{-3}$; d_2=0.104, $\varepsilon_2=2.90$, $\sigma_2=0.$; d_3=0.241, $\varepsilon_3=4.18$, $\sigma_3=11.09\cdot10^{-3}$.

Table 3. Results of simulation for different slab structures. Results of simulation in Table 3. shows that power measurements with $\alpha \le 20$ can be applied for recognition of wall structure and its parameters

M	par	Pattern	Average	Dispers.
1	d_1	0.55	0.55	0.
1	ε_1	4.	3.97	$9.29\cdot10^{-2}$
1	σ_1	0.01	0.0113	$4.35\cdot10^{-3}$
3	d_1	0.2	0.201	$2.98\cdot10^{-3}$
3	ε_1	3.8	3.76	0.1078
3	σ_1	$5.31\cdot10^{-3}$	$5.19\cdot10^{-3}$	$3.62\cdot10^{-4}$
3	d_2	0.1	0.0988	$2.70\cdot10^{-2}$
3	ε_2	2.5	2.53	0.1003
3	σ_2	$1.77\cdot10^{-3}$	$1.67\cdot10^{-3}$	$3.67\cdot10^{-4}$
3	d_3	0.25	0.251	$3.43\cdot10^{-3}$
3	ε_3	4.2	4.22	0.1157
3	σ_3	$3.54\cdot10^{-3}$	$3.55\cdot10^{-3}$	$3.16\cdot10^{-4}$
5	d_1	0.15	0.15	0.
5	ε_1	3.8	3.797	$1.56\cdot10^{-2}$
5	σ_1	0.002	$2.04\cdot10^{-3}$	$4.39\cdot10^{-4}$
5	d_2	0.05	0.05	0.
5	ε_2	1.7	1.692	$5.65\cdot10^{-2}$
5	σ_2	0.005	$5.25\cdot10^{-3}$	$1.920\cdot10^{-3}$
5	d_3	0.1	0.1	0.
5	ε_3	4.2	4.232	$6.85\cdot10^{-2}$
5	σ_3	0.01	$1.05\cdot10^{-2}$	$2.179\cdot10^{-3}$
5	d_4	0.15	0.15	0.
5	ε_4	1.6	1.58	$5.10\cdot10^{-2}$
5	σ_4	0.	0.	0.
5	d_5	0.1	0.1	0.
5	ε_5	4.	4.022	$7.24\cdot10^{-2}$
5	σ_5	0.015	$1.49\cdot10^{-2}$	$3.444\cdot10^{-3}$

The model M=5 gives Q=0.3336; $d_1=0.204$, $\varepsilon_1=3.8$, $\sigma_1=4.41\cdot10^{-3}$; d_2=0.007, $\varepsilon_2=2.90$, $\sigma_2=8.84\cdot10^{-5}$; d_3=0.035, $\varepsilon_3=2.6$, $\sigma_3=12.38\cdot10^{-5}$; $d_4=0.063$, $\varepsilon_4=3$, $\sigma_4=8.84\cdot10^{-5}$; $d_5=0.241$, $\varepsilon_5=4.2$, $\sigma_5=11.30\cdot10^{-3}$.

For M=1 and M=2 values of Q are too large. For M=3 and M=5 values of Q correspond to real measurements error. Because M=5 parameters for layers 2,3,4 are near to M=3 parameters of layer 2, significant discrepancy is not between results. Advantage of walls simulation is due to simple models and therefore small variations we can disregard.

Conclusion

Measurements of reflections factors of microwave power from the slab can be applied for recognition of the structure of layered dielectric slab. For obtaining unique results measurements must be provided for several frequencies.

The simulation of layered structure gives estimation for necessary number of measurements and allows estimate contribution errors of measurements on results accuracy.

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J. Ziemelis, T. Solovjova. Sluoksniuotos dielektrinės aplinkos struktūros ir parametrų nustatymas naudojant atspindėtos galios matavimo rezultatus // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2004. Nr. 5(54). – P. 33-36.

Visų sluoksnių struktūrai ir elektromagnetiniams parametrams nustatyti naudojami nuo sluoksnio atspindėtos galios matavimai. Nustatant sluoksnio parametrus yra tam tikrų problemų, kurios šiame darbe sprendžiamos skaitiniu modeliavimu. Norint gauti vienintelį sprendinį, būtina atlikti matavimus esant daugeliui dažnių. Modeliuojant įvertinama matavimo paklaidos įtaka apskaičiuotų ir išmatuotų galių palyginimui ir parametrų nustatymo tikslumui. Il. 5, bibl. 5 (anglų kalba, santraukos lietuvių, anglų ir rusų k.).

J. Ziemelis, T. Solovjova. The Recognition of Dielectric Layered Slab from Power Measurements // Electronics and Electrical Engineering. Kaunas: Technologija, 2004. – No.5(54). – P. 33-36.

To determine layered structure and slab parameters using spectrum analyser, at some frequencies was measured the reflected power from the slab. The slab parameters from measurements can be obtained by numerical comparison of measurements with those calculated from the model of reflected power. The calculation of slab parameters meets some problems that in this paper are solved by simulation of layered structure. To obtain unique solution of the problem the measurements must be carried out for enough number of frequencies. By simulation it is estimated contribution of measurements errors on the exactness of layers parameters determination. Ill. 5, bibl. 5 (in English; summaries in Lithuanian, English, Russian).

Ю. Зиемелис, Т. Соловьёва. Определение структуры и параметров диэлектрической слоистой среды по результатам измерений отраженной мощности // Электроника и электротехника. – Каунас: Технология, 2004. – № 5(54). – С. 33-36.

Для определения структуры и электромагнитных параметров всех слоев используются измерения отраженной от слоя мощности. Результаты измерений сравниваются с вычисленными по модели коэффициентами отражения. Определение параметров слоя содержит некоторые проблемы, которые в настоящей работе решаются при помощи численного моделирования. Для получения единственного решения необходимо проводить измерения при достаточно большом количестве частот. При помощи моделирования оценивается вклад ошибки измерений на процесс сравнения вычисленных и измеренных мощностей и на точность определения параметров. Ил. 5, библ. 5 (на английском языке; рефераты на литовском, английском и русском яз.).