MEASUREMENT OF COMPLEX PERMITTIVITY AND COMPLEX PERMEABILITY OF MATERIALS

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Time Domain measurement of complex permittivity and complex permeability in the 8 to 18 GHz frequency band is considered. Some methods for determination of permittivity and permeability are presented.

The measuring system is intended to measure complex permittivity and permeability in the 8-18 GHz frequencies range. To measure complex permittivity and permeability a system of measurement of reflection coefficient from objects is used. The scheme of measurement is shown in Fig. 1.
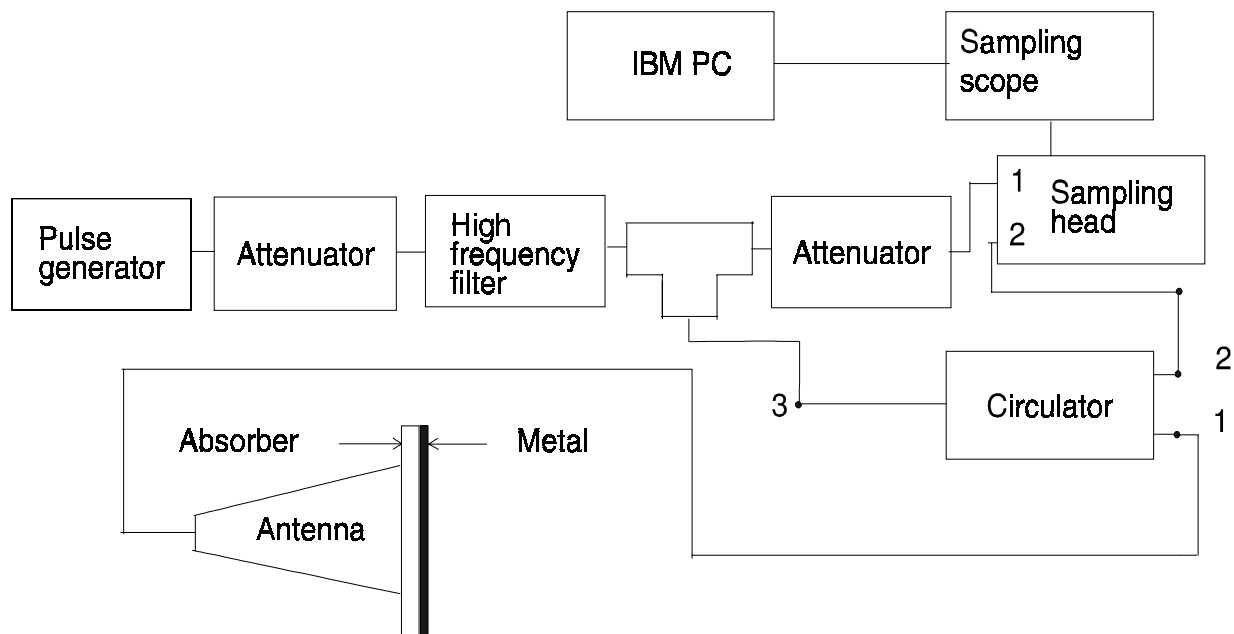

Fig. 1.

The principle of the system operation is based on forming short picosecond pulse, transmitting it by transmitting antenna, receiving reflected from object signal by receiving antenna, and transforming it by sampling head of sampling oscilloscope. Pulse generator forms short picosecond pulse. High frequency filter is used to cut off low frequency of signal that is multiply reflected between circulator and coaxial-waveguide adapter that allows to eliminate a large background.

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Circulator in the direction from generator to sampling head (3-2) decreases amplitude of signal by 15 dB in the 8-18 GHz band. Pulse in the direction 3-1 is applied to pyramidal horn antenna with aperture 10x15 cm for the 8-12.4 GHz band and 8x12 cm for the 12-18 GHz band. The signal reflected from object under test is transformed by sampling oscilloscope using one of it's channels. Other channel of oscilloscope is used for phase stabilisation to eliminate a signal's drift during long time measurement for great amount of absorbers. The sampling oscilloscope SD 018 produced by Geozondas Ltd. was used for these measurements. That is a computer-based fully programmable two-channels oscilloscope with a frequency band to 18 GHz. A rise time 15 ps and small noise factor (r.m.s. is equal 1.7 mV) allows to use it widely in time and frequency domains measurements.

The range of measurement of a real part of dielectric constant is up to 30. The range of measurement of an imaginary part of dielectric constant is up to 1 (Is available an opportunity to measure up to 15 with smaller accuracy). The error of measurement of dielectric constant is no more than 10 %. The range of measurement of a real part of magnetic constant is up to 5. The range of measurement of an imaginary part of magnetic constant is up to 5. The error of magnetic constant measurement is no more than 10 %.

The operation principle of system for measuring complex dielectric and magnetic constants is based on measurement of reflection coefficient from samples under test and calculation of required values on their basis [1].

Four various techniques of measuring complex dielectric and magnetic constants are offered.

1. Definition of dielectric and magnetic constants using two samples of various thickness with one-sided metallization.

Reflection coefficient when an electromagnetic wave is incident from the air on a plate with one-sided metallization, is equal:

$$S_{11} = \frac{iZtg(\beta d) - 1}{iZtg(\beta d) + 1}, \qquad (1)$$

where: i - imaginary unit, $Z = \sqrt{\dfrac{\mu}{\varepsilon}}$ - normalized impedance, ε - complex relative dielectric constant of a material, from which the sample is made:

$$\varepsilon = \varepsilon' + i\varepsilon'' , \qquad (2)$$

μ - complex relative magnetic constant:

$$\mu = \mu' + i\mu'', \qquad (3)$$

β - propagation constant, which is equal:

$$\beta = \beta_0 \sqrt{\varepsilon\mu} , \qquad (4)$$

where: $\beta_0 = \dfrac{2\pi}{\lambda}$, λ - a wave length in free space, d - thickness of the sample.

By measuring reflection coefficient from two plates of various thickness with one-sided metallization, from the system of equations:

$$\begin{cases} S_{11} = \dfrac{iZtg(\beta d_1) - 1}{iZtg(\beta d_1) + 1} \\ S'_{11} = \dfrac{iZtg(\beta d_2) - 1}{iZtg(\beta d_2) + 1} \end{cases}, \qquad (5)$$

where: d1, d2 - the thickness of plates, it is possible simultaneously to define the values β and Z. From them it is possible to define relative dielectric and magnetic constant:

$$\begin{cases} \varepsilon = \dfrac{\beta}{\beta_0} \dfrac{1}{z} \\ \mu = \dfrac{\beta}{\beta_0} z \end{cases}. \qquad (6)$$

2. Definition of dielectric and magnetic constants using two samples of various thickness.

Reflection coefficient when an electromagnetic wave is incident from the air on a plate, is equal:

$$S_{11} = \dfrac{\Gamma(1 - T^2)}{1 - \Gamma^2 T^2}, \qquad (7)$$

where: $T = e^{-i\beta d}$, d - thickness of the plate, $\Gamma = \dfrac{z - 1}{z + 1}$.

By writing the equation (7) for two plates of various thickness and by carrying out necessary transformations, it is possible to receive the following system of the equations:

$$\begin{cases} S_{11} = \dfrac{2i(z^2 - 1)tg(\beta d_1)}{4z + 2i(z^2 + 1)tg(\beta d_1)} \\ S'_{11} = \dfrac{2i(z^2 - 1)tg(\beta d_2)}{4z + 2i(z^2 + 1)tg(\beta d_2)} \end{cases}, \qquad (8)$$

where: d1, d2 - thickness of the plates, from which it is possible to define a normalized impedance z and propagation constant β, from which, using the equation (6), it it is possible to define the meanings of relative dielectric and magnetic constants.

3. Definition of dielectric and magnetic constant using metallized and nonmetallized samples of the same thickness.

To definite dielectric and magnetic constant it is possible to use two samples of the same thickness made from material under test, one of which has one-sided metallization. In this case for reflection coefficient we have expressions:

$$\begin{cases} S_{11} = \dfrac{\Gamma(1-T^2)}{1-\Gamma^2 T^2} \\ S'_{11} = \dfrac{\Gamma-T^2}{1-\Gamma T^2} \end{cases} \qquad (9)$$

where: S_{11} - reflection coefficient for nonmetallized sample, and S'_{11}- reflection coefficient for metallized sample.

The system of the equations (9) can be solved in relation to z and T:

$$\begin{cases} z^2 = \dfrac{(1+S_{11})(1+S'_{11})}{S_{11}S'_{11}+S'_{11}-3S_{11}+1} \\ T^2 = \dfrac{\Gamma-S'_{11}}{1-\Gamma S'_{11}} \end{cases} \qquad (10)$$

Having value for T, it is possible from expression $T = e^{-i\beta d}$ to define the meaning $\dfrac{\beta}{\beta_0}$:

$$\frac{\beta}{\beta_0} = -\frac{c}{wd}\left(\Phi - 2\pi n + i\ln\left|\frac{1}{T}\right|\right), \qquad (11)$$

where: $n = 0,\pm1,\pm2,...$, Ô - phase T, represented as:
$$T = |T|e^{i\Phi}. \qquad (12)$$

Under condition of $\dfrac{d}{\lambda} < 1$ it is necessary to choose n=0, and the meaning of the

phase in limits $-2\pi < \Phi < 0$. By defining from (10) and (11) the meaning z and $\dfrac{\beta}{\beta_0}$, it is

possible by the formulas (6) to find the meanings of dielectric and magnetic constant.

4. Definition of dielectric constant using a sample with one-sided metallization.

It is possible to define dielectric constant of a material with $\mu = 1$, by measuring reflection coefficient from the sample with one-sided metallization, which is expressed by

formula (1), where: $z = \dfrac{1}{\sqrt{\varepsilon}}$, $\beta = \beta_0\sqrt{\varepsilon}$. The equation (1) is solved in relation to ε.

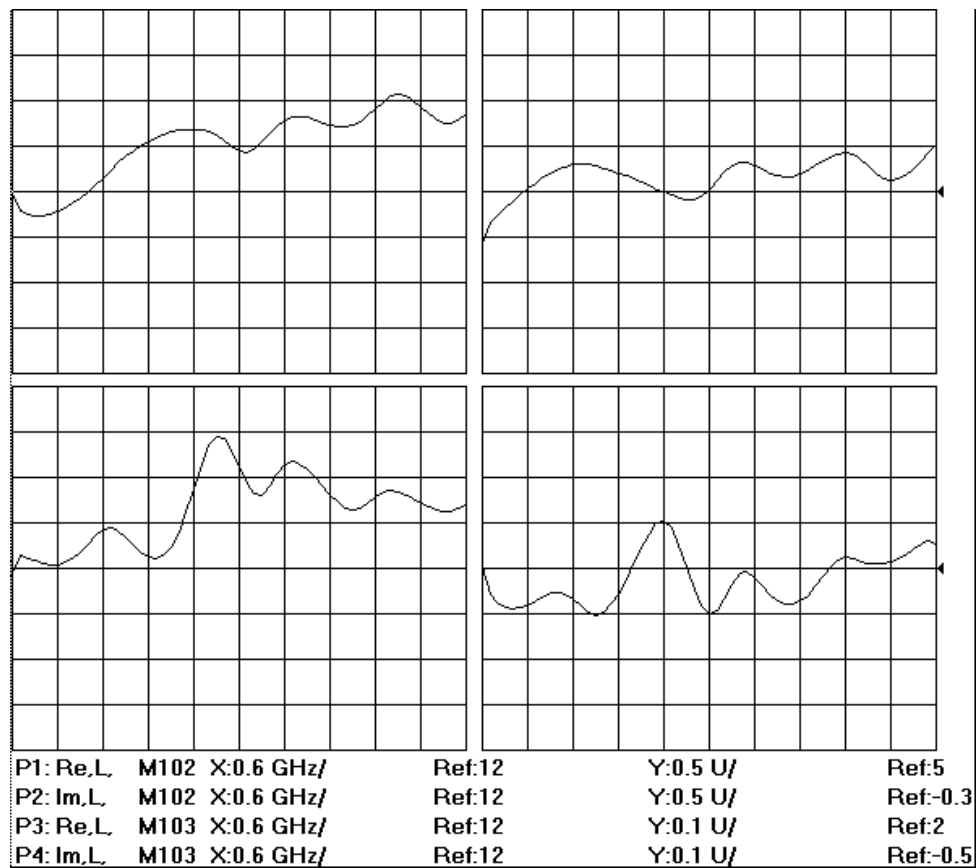| P1: Re,L, | M102 X:0.6 GHz/ | Ref:12 | Y:0.5 U/ | Ref:5 |
P2: Im,L,	M102 X:0.6 GHz/	Ref:12	Y:0.5 U/	Ref:-0.3
P3: Re,L,	M103 X:0.6 GHz/	Ref:12	Y:0.1 U/	Ref:2
P4: Im,L,	M103 X:0.6 GHz/	Ref:12	Y:0.1 U/	Ref:-0.5

Fig. 2.

The measurements of dielectric and magnetic constants of different materials were made. At Fig. 2 some results are presented. The measurement system is advanced to measure in frequency band from 2 to 8 GHz. For this purpose a new antennas are designed.

REFERENCES

1. D.K. Ghodgaonkar, V.V. Varadan, V.K. Varadan. Free-Space Measurement of Complex Permittivity and Complex Permeability of Magnetic Materials at Microwave Frequencies./ /IEEE Transactions on Instrumentation and Measurement. - April 1990. - pp. 387-394.