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Losses measurement method for transmission lines at mmWave

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An experimental method was developed to determine losses in microstrip and coplanar transmission lines for devices operating in the frequency range of 77−81 GHz. The parameters of the scattering matrices are obtained using a vector network analyzer and frequency upconverters. The calculation of losses in waveguide−coplanar and coplanar−microstrip adapters is made.

Keywords: losses, attenuation, microstrip line, coplanar waveguide, electrodynamic parameters.

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Specific attenuation in the transmission lines of radiofrequency devices is used to calculate the power characteristics of the output signal. This parameter depends on many factors, e. g., on the dielectric loss tangent of the substrate, materials and profile of the printed transmission line, metallization surface roughness, etc. Parameters of the obtained layouts depend to a high extent on the technologies used in producing the printed circuit boards and can vary, including variations within different batches; therefore, important is to control the line-specific attenuation at real samples. Direct measurement of losses in the line implies using a probe station for connecting directly to the section under study, which is a rather high−cost solution.

This paper presents a technique allowing the measurement of the specific attenuation in microstrip and coplanar transmission lines operating in the frequency range of 77 to 81 GHz without using a probe station. Frequency characteristics of losses in coplanar and microstrip transmission lines in the 77−81 GHz frequency range were studied.

The measurements were performed at the vector network analyzer R&S ZVA50 with frequency upconverters enabling measuring the entire scattering matrix of a dual−port device in the 75−110 GHz range using the WR10 waveguide transmission line. Transmission lines of the studied types were connected to the measurement system waveguide input via the coplanar line−waveguide adapters WR10.

To calibrate the measurement system, the UOSM calibration technique [1] (Unknown through–Open–Short–Match) was used, which implies accomplishment of two full one-port OSM calibrations using conventional waveguide calibration measures: short-circuit (SC), offset SC, match and pass−through measurements using an arbitrary transmission line to which the requirement of mutuality of forward and backward characteristics are imposed. The pass−through line standard which consists of a section of the microstrip line with minimal length connected to the waveguide via the coplanar–waveguide adapter was used.

As research objects, coplanar and microstrip transmission lines of different lengths were used; they are presented in Fig. 1. Three samples were measured for each line length. Using the lines of different lengths, it is possible to calculate the line attenuation per unit length. Most interesting are such scattering matrix parameters as reflection S_{11} and S_{22} and transmission S_{21} coefficient [2] since they allow total characterization of the studied sample with respect to the quality of line fabrication (reflection index) and effects of the dielectric substrate structure and metallization methods (transmission coefficient).

The proposed experimental procedure consists in measuring transmission coefficients of the different−length lines, after which losses per unity length and losses in all the line type converters were calculated.

First, the samples of the coplanar transmission line were studied. Fig. 2, *a* presents average values of the

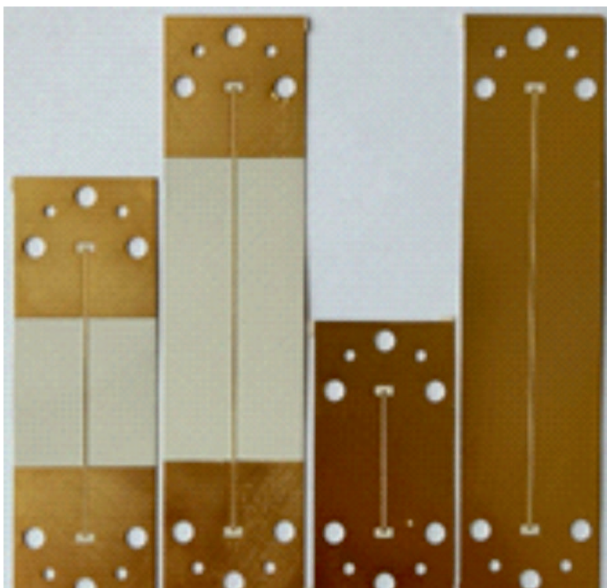

Figure 1. The transmission lines under study are: microstrip lines (left) and coplanar lines (right).

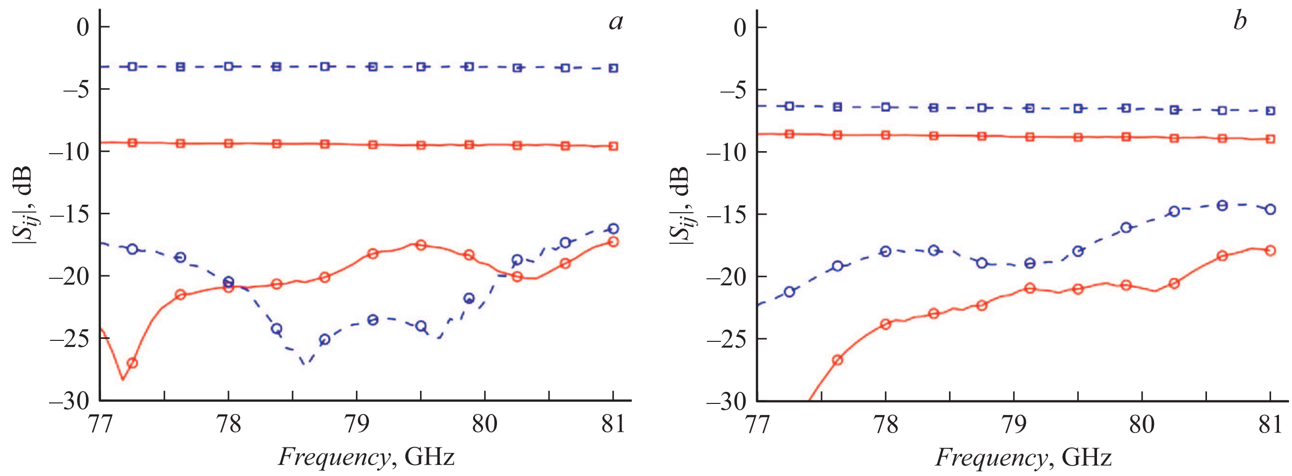

Figure 2. Modules of reflection S_{11} (circles), transmission S_{21} (squares) coefficients for coplanar lines 61.35 mm long (solid line) and 18.85 mm long (dashed line) (*a*), and for microstrip lines 43 mm long (solid line) and 21 mm long (dashed line) (*b*).

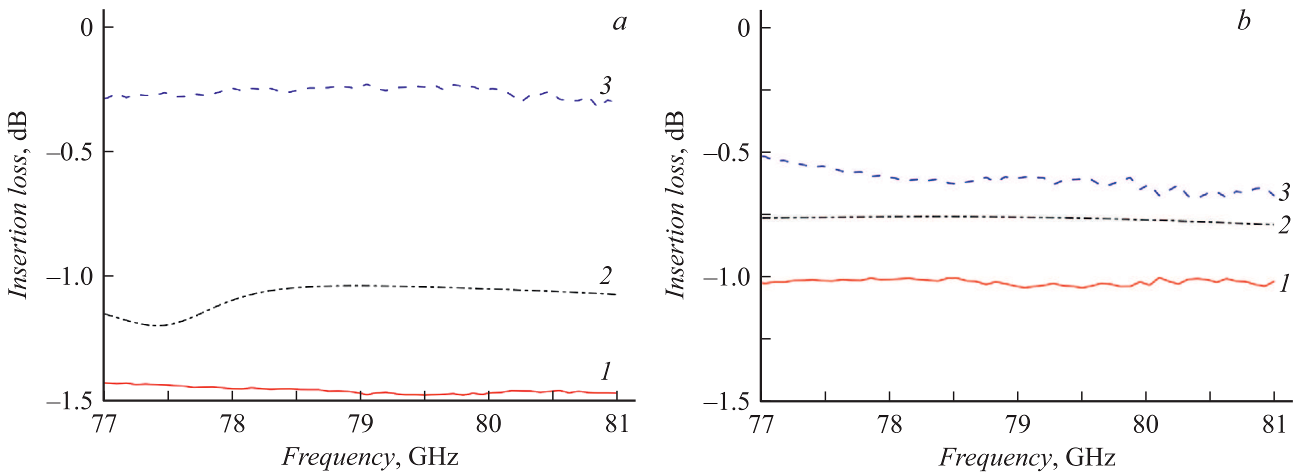

Figure 3. Inserted loss in the 10 mm coplanar line section determined experimentally (*1*), by simulation (*2*), and in the waveguide–coplanar line junction (*3*) (*a*), and that in the 10 mm microstrip line section determined experimentally (*1*), by simulation (*2*) and in the coplanar–microstrip line junction (*3*) (*b*).

transmission and reflection coefficients for three samples. The measured reflection coefficients are quite low; the nonlinearity of their characteristics may be explained by the waveguide–coplanar adapter having a resonance structure. Regardless of the widebandness of the used adapter, the resonance character of its structure may manifest itself in the reflection coefficients. The influence of this effect on the measurements of the inserted attenuation may be ignored due to its minuteness.

After that, the coplanar–line specific attenuation per 10 mm was determined. For this purpose, the difference between the transmission coefficients of the long coplanar line and the short coplanar line was calculated at the same frequencies. Then the obtained result was divided by the difference in the lengths. The length of the long coplanar line was 61.35 mm, and the short line was 18.85 mm. Further, the losses induced by the used coplanar–waveguide adapters were calculated based on the measured specific attenuation and the coplanar line length between two coplanar–waveguide adapters. The obtained calculations are presented in Fig. 3, *a*.

According to the above–proposed procedure, parameters of the microstrip transmission line were calculated (Fig. 2, *b*), and then the loss in the coplanar–microstrip adapters was calculated (Fig. 3, *b*). The presented results demonstrate that coplanar line losses are greater than those in the microstrip line. This dependence may be explained by the fact that the coplanar line width is less than that of the microstrip line. In addition, in gold-plating a nickel layer is applied whose conductivity is less than that of copper, gold, or silver. The skin–layer thickness may be defined as follows:

$$\Delta = \sqrt{2\rho/\omega\mu}.$$

Here ρ is the resistivity equal to $2.44 \cdot 10^{-8}\,\Omega \cdot \mathrm{m}$ (gold), μ is the absolute magnetic permeability, $\omega = 2\pi f$, where

f is the frequency [Hz]. The gold skin–layer thickness at the frequency of 79 GHz is 0.28 μm, while for the immersion gold-plating the manufacturers declare the gold layer thickness of 0.05–0.1 μm. Thus, the high–frequency signal undergoes considerable attenuation in the nickel sublayer. The results of the 3D electromagnetic loss simulation for the relevant transmission lines, which are presented in Fig. 3, also demonstrate the prevalence of the coplanar line loss over those in the microstrip line. The difference in absolute losses is 0.3–0.4 dB for each of the transmission line types according to both the measurement and simulation results. Such a difference in the losses is caused by the fact that the used model assumes certain simplifications, for instance, ignoring the conductor surfaces roughness, the possible difference of the conductor thicknesses and widths from those of real samples because of the process tolerances, etc.

The obtained results have demonstrated the necessity of experimental investigation of the transmission lines in order to take into consideration all the factors affecting specific attenuation in the line. It has been shown that it is possible to use the proposed experimental procedure for measuring losses in microstrip and coplanar lines and line type converters in the millimeter range of wavelengths with the use of a vector network analyzer and frequency upconverters, which allows excluding high–cost equipment for connection to the test line. The proposed procedure enables total characterization of the test sample with respect to the fabrication quality.

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Conflict of interests

The authors declare that they have no conflict of interests.

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