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DETERMINING THE RELATIVE PERMITTIVITY OF FOILED DIELECTRIC

N.O. Shatalov, BSc student at Dept. of Microwave and Quantum Radio Engineering; A.K. Nesterenko, PhD student at Dept. of Microwave and Quantum Radio Engineering

Scientific supervisor V.P. Kosteletskii, associate professor at Dept. of Microwave and Quantum Radio Engineering, TUSUR, PhD in Engineering Science

Tomsk, TUSUR, nikita.o.shatalov@tusur.ru

The paper presents a method for determining the relative permittivity of FR-4 foiled laminate using a microstrip ring resonator. The method is based on a comparison of the *S*-parameters obtained from the experiment and electrodynamic simulation performed in CST Studio Suite software. The result is achieved by tuning the ε_r of the electrodynamic model of the ring resonator. The actual value of ε_r = 4.67 was determined.

Keywords: relative permittivity, ring resonator, vector network analyzer, reflection coefficient, transmission coefficient.

The design of modern microwave devices implemented on strip and microstrip transmission lines imposes high demands on the accuracy of the material models used. The key parameter determining the characteristic impedance of the line and the phase velocity of signal propagation is the relative permittivity (ε_r) of the substrate material. The nominal values of relative permittivity given in the technical documentation can differ significantly from the actual parameters of the material due to technological spread, frequency dispersion, and the influence of manufacturing processes [1, 2].

The aim of this work is to experimentally refine the relative permittivity of the substrate material based on the results of *S*-parameter measurements of a test board and data from electrodynamic simulation of a ring resonator.

Structure, Materials, and Simulation Parameters. The ring resonator is a microstrip structure (Fig. 1) [3]. FR-4 foiled fiberglass laminate was chosen as the dielectric substrate material, with copper foil thickness $t = 0.018$ mm, dielectric thickness $h = 1.5$ mm, and $\tan\Delta = 0.025$. Since the electric field lines propagate not only within the dielectric but also partially outside it, the value of the effective relative permittivity ε_{eff} is used, which is calculated as shown in [4]. According to the Kramers-Kronig frequency dependence, the relative permittivity of the material at frequency $f = 2$ GHz is $\varepsilon_r = 4.41$ [5]. The wavelength in this case is $\lambda = 82$ mm. The resonator is designed as a closed ring conductor with a mid-line radius $R = 13$ mm and a strip width $w = 2.8$ mm, which determines the 50 Ohm characteristic impedance. The radius of the resonator along the midline was calculated based on the circumference being equal to λ. The resonator is excited through capacitive gaps of size $g = 0.5$ mm, formed between the microstrip feed lines of width w and the resonator. The lengths of the feeding lines and the coupling lines are $\lambda/4$.

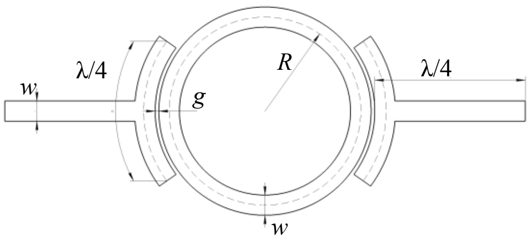

Fig. 1 Schematic diagram of the ring resonator

The simulation was performed in the CST Studio Suite electromagnetic simulation environment using a frequency domain solver. The calculation was carried out in the range of 1–3 GHz with automatic selection of frequency points (5 adaptive samples).

Fabrication and Experiment. The printed circuit board was fabricated using negative photoresist. The topology pattern was transferred onto the substrate by ultraviolet exposure through a transparent photomask, followed by development and subsequent chemical etching of the copper.

The *S*-parameter measurement of the fabricated board was carried out using a P4M–18 vector network analyzer in the frequency range from 1 to 3 GHz. Prior to the measurements, SOLT calibration of the device was performed using a calibration kit, which made it possible to compensate for the parasitic parameters of the connecting cables and adapters.

Results. The frequency dependences of the reflection coefficient (S_{11}) and transmission coefficient (S_{21}) obtained from the electrodynamic model and measured in the experiment are shown in Fig. 2. The resonant frequency of the electrodynamic model is 1.992 GHz, and that of the fabricated board is 1.921 GHz.

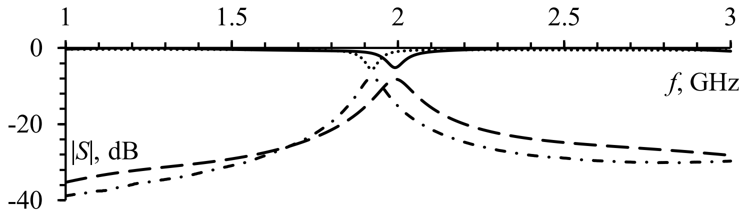

Fig. 2. Parameters: S_{11} of the model (——) and the board (· · · ·), S_{21} of the model (– – –) and the board (– · – ·)

An increase in ε_r of the substrate material leads to a decrease in the phase velocity of electromagnetic wave propagation in the transmission line. Since the resonant frequency of an oscillatory system is proportional to the propagation velocity, an increase in ε_r causes a shift of the resonant frequency towards lower values. The ε_r of the electrodynamic model was adjusted iteratively until it matched the resonant frequency of the ring resonator measured in the experiment. The ε_r of the board substrate was found to be 4.67.

Conclusion. In this work, the frequency dependences of S_{11} and S_{21} for the electrodynamic model and the fabricated board were obtained. An experimental refinement of the ε_r of the FR-4 substrate material was carried out using the method of iterative adjustment of the electrodynamic model parameters to match the measured *S*-parameters of the ring resonator. It was established that the actual ε_r value of the investigated foiled laminate sample at a frequency of 2 GHz is 4.67, which differs by 5.9% from the value used in the initial calculations.

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INFLUENCE OF SUBSTRATE MATERIAL ON THE CHARACTERISTICS OF A RHOMBIC PATCH ANTENNA

A.K. Nesterenko, PhD student at Dept. of Microwave and Quantum Radio Engineering, N.O. Shatalov, student at Dept. of Microwave and Quantum Radio Engineering

Scientific supervisor V.P. Kosteletskii, Ph. D. in Engineering Sciences, associate professor at Dept. of Microwave and Quantum Radio Engineering

Tomsk, TUSUR, aleksei.k.nesterenko@tusur.ru

This paper studies the influence of dielectric substrate materials (AD255C, FR4, FSD1020T) on patch antenna characteristics. Results show that increasing substrate height raises gain and axial ratio for AD255C and FR4, while for FSD1020T gain increases but AR decreases. AD255C demonstrated the best performance.

Keywords: patch antenna, planar antenna, reflection coefficient, gain, axial ratio.

Modern wireless communication systems, particularly 5G networks and subsequent 3GPP standards [1, 2], impose increased requirements on the efficiency and compactness of antenna systems. A critically important direction is the implementation of Direct-to-Device/Direct-to-Cell communication technologies [3, 4], which require high-performance and compact transceiver modules. Patch antennas remain one of the most preferable solutions because they are easy to manufacture and feature high degree of integration. The key element that determines the main characteristics of any planar antenna is the dielectric substrate. The substrate parameters, specifically the relative permittivity (ε_r) and thickness (h), have a significant impact on the frequency-dependent characteristics of the antenna. The aim of this study is to investigate the influence of different types of dielectric substrate materials on the characteristics of a patch antenna using electrodynamic simulation.

Structure, Materials, and Simulation Approaches. The simulation was performed in the CST Studio Suite electromagnetic simulation environment using the frequency domain solver. The calculation was carried out in the frequency range of 1–3 GHz with 10 frequency points. The external