Analysis of Square Coaxial Transmission Line With Additive Manufacturing Insulator Support

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***Abstract*—In this paper, a square coaxial transmission line partially filled with low-cost and additive manufacturing insulator support is presented. Two metal conductors and an insulator fabricated by additive manufacturing make up the proposed coaxial line. Additive manufacturing insulator is used to partially fill the space between two conductors to reduce the dielectric loss. In this case, the relative permittivity and loss tangent are measured, and the insulator is low-cost resin compared with traditional PTFE. The proposed transmission line's guide-wave characteristics are analyzed. Finally, the analysis is validated by the design and simulation of a transmission line.**

Keywords—square coaxial line, low-cost, additive manufacturing, guide-wave characteristics

I. INTRODUCTION

New microwave platforms are required to achieve competitive performance as the microwave markets expand due to the advancement of RF communication systems. Additionally, the most widely used platform for microwave applications is the transmission line. Several new transmission lines have emerged recent years, including metal integrated suspended line (MISL) [1], mode composite waveguide (MCW) [2], and empty substrate integrated coaxial line (ESICL) [3]. New microwave devices become possible by these innovative transmission line platforms. Numerous innovative microwave components by additive manufacturing have improved circuit performance [4], [5], [6]. Consequently, additive manufacturing can be used to design a new coaxial transmission line.

This paper presents a novel square coaxial transmission line that has an insulator support and two metal conductors. The insulator support partially fills the gap between the two conductors because the dielectric loss of the additive manufacturing resin is unacceptable. After that, a detailed analysis of the proposed novel transmission line's guide-wave characteristic is conducted. Lastly, the suggested approach is validated through simulation of a transmission line.

II. GUIDE-WAVE CHARACTERISTICS

The hollow inside view of the proposed square coaxial transmission line is shown in Fig. 1 where the outer conductor is hidden to better show the layout of the proposed coaxial transmission line and the additive manufacturing insulator is partially filled between the two conductors. Evidently, Fig. 1(a) displays the cross-sectional view of the proposed square coaxial transmission line with marked dimensions. Additionally, Fig. 1(b) shows the perspective view of the proposed square coaxial line. The proposed square coaxial line is uniform in size and shape along the propagation direction,

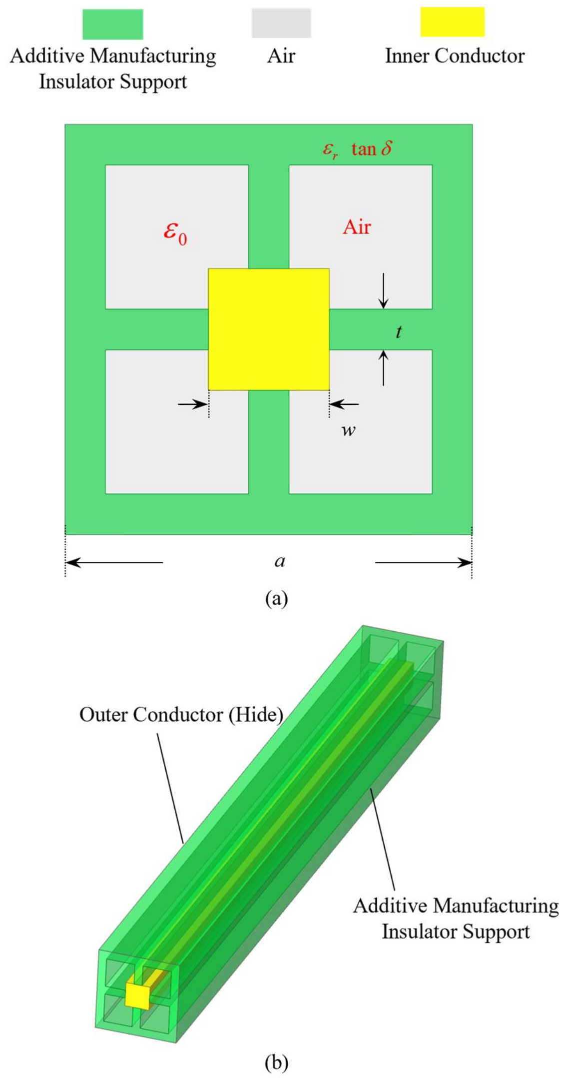

Fig. 1. (a) Perspective view of the proposed transmission line. (b) Cross-sectional view of presented transmission line.

as shown in Fig. 1(b). To analyze the guide-wave characteristics of the proposed square coaxial line, the relative permittivity and loss tangent are measured. The ε_r = 3.30 and the loss tangent $\tan\delta$ =0.04. To support the inner conductor and reduce the dielectric loss, the additive manufacturing insulator support is partially filled in the gap between the inner and outer conductors and thickness is t, which is denoted in Fig. 1(a).

Fig. 2 provides the guide-wave characteristics of the proposed square coaxial transmission line. Fig. 2(a) shows that the first higher-order mode appears at 10.0 GHz and the

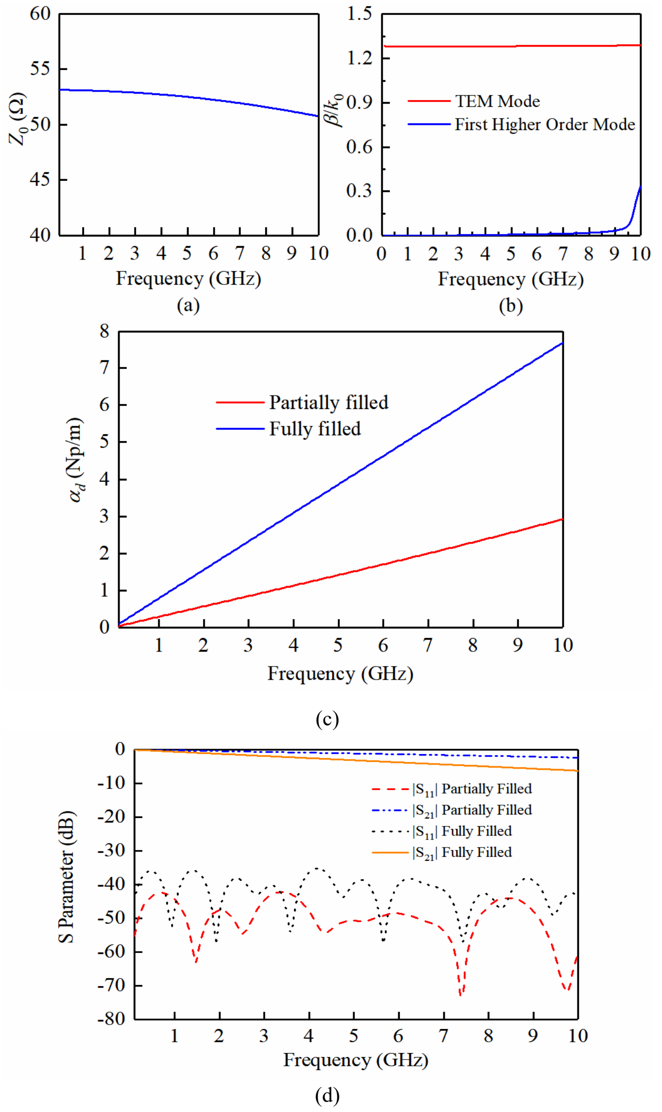

Fig. 2. Guide-Wave characteristics of proposed square coaxial line (a) Characteristic impedance. (b) Normalized phase constant. (c) Comparison of attenuation constant. (d) Comparison of S parameters.

normalized phase constant of the TEM mode is stable throughout the frequency range. The frequency range when the main mode of the transmission line is TEM mode is called the single-mode operating bandwidth [7]. Characteristic impedance Z_0 is also only meaningful within the single-mode operating bandwidth. Consequently, the range of the simulated characteristic impedance Z_0 is from 0.1 GHz to 10.0 GHz, and the simulated characteristic impedance Z_0 is around 50 Ω. The normalized phase constant can be calculated by

$$\frac{\beta_{TEM}}{k_0} = \sqrt{\varepsilon_r}. \tag{1}$$

In free space, the phase constant is denoted by k_0. Furthermore, the TE_{10} or TE_{01} mode for ridged waveguide is the first higher order mode in proposed square coaxial line [8]. A comparison of the dielectric attenuation constant α_d for a fully and partially filled insulator is shown in Fig. 2(c). The configuration of partially filled insulator can reasonably reduce the dielectric loss dramatically.

Precisely measuring the dielectric loss α_d of a lossy transmission line is not convenient. By designing and simulating a transmission line, it is possible to evaluate the dielectric loss using the insertion loss, which illustrates how the partial filling scheme improves dielectric loss. The following parameters are the proposed square coaxial line's dimensions: a = 10.1 mm, w = 3.0 mm, t = 1.0 mm, and l = 94.0 mm. After that, Fig. 2(d) displays the comparison of S parameters.

The frequency performance of the proposed novel square coaxial transmission line is competitive. The insertion loss reaches 2.39 dB at 10.0 GHz, while $|S_{11}|$ is less than -30 dB between 0.1 GHz and 10.0 GHz. Moreover, for the fully filled transmission line, its insertion loss is 6.26 dB at 10 GHz. Therefore, the simulated results validates our approach.

III. Conclusion

This work introduces a novel square coaxial transmission line made up of an low-cost partially filled additive manufacturing insulator support, an outer conductor, and an inner conductor. Comprehensive research is done on the guide-wave characteristics. An insulator solution that is partially filled is shown and simulated to make further use of the low-cost resin. Therefore, a square transmission line is designed and simulated. The reduction of both insertion and dielectric loss validates the proposed method.

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