Propagation Characteristics of Substrate Integrated Waveguide Based on LTCC

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***Abstract*: Substrate integrated waveguide (SIW) is a new type of guided wave structure fabricated with periodic metallic via holes in multilayered LTCC substrate. The SIW takes the advantage of both the waveguide and microstrip structures, like the high-Q factor, high power capacity, small size, and the possibility of integration. In this paper, propagation characteristics of the SIW are investigated based on a finite difference method by using appropriate absorbing boundary conditions. A special treatment has been made in the interaction of the incident wave with the SIW structure. Simulated results are given to test the validity and efficiency of the proposed method, from which very interesting phenomena have been found in the SIW.**

I. Introduction

Multi-layered printed circuit boards (PCB) and low-temperature co-fired ceramics (LTCC) circuits are the two low-cost RF fundamental building blocks. Traditionally, the rectangular waveguides play an important role in realizing the high performance RF passive components due to their high Q-factor and high power capacity. However, the conventional waveguides have the disadvantage of large sizes and are difficult to integrate. Hence, it is important to look into alternatives with multilayered LTCC or PCB. Recently, some works [1-4] have been reported to discuss such structures, called substrate integrated waveguides (SIW), which is part of substrate integrated circuits (SIC) [5]. The basic idea of SIW is shown in Figure 1. Clearly, SIW takes the advantage of both waveguide and microstrip structures, like the high-Q factor, high power capacity, small size, and the possibility of integration. In this paper, we propose an efficient method to analyze the SIW structures in order to obtain more physical insights using the finite difference frequency domain (FDFD) scheme, where the field distribution inside the structures, and the propagation and attenuation constants are all determined. Very interesting phenomena have been observed in the simulation results and the corresponding physical insights have been discussed.

II. Analysis Methods and Numerical Results

Consider the SIW structure as shown in Figure 2, where the geometrical parameters are listed in Table 1. Suppose that the operating frequency is 10.0 GHz. Under these conditions, only the dominant mode, i.e. H_{10} mode, could propagate along the conventional rectangular waveguide because all higher modes are cut off. In the Cartesian coordinate system as shown in Figure 2, the H_{10} wave travels along the z-direction. Hence, the incident electric field is written as:

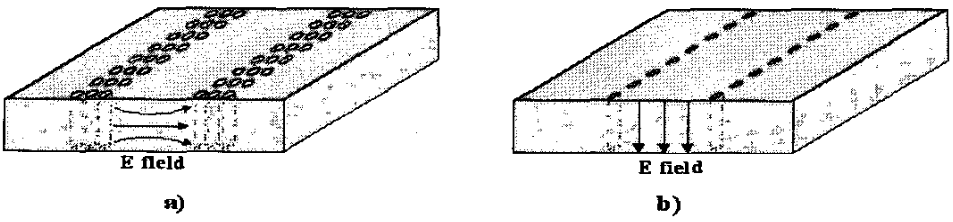

Figure 1 SIW structures: a) integrated NRD, b) integrated rectangular waveguide

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$$E_z = \sin(\pi \cdot x / a)\exp(-jk_z z),$$

where,

$$k_z^2 = k_0^2 - (\pi / a)^2.$$

In order to simulate the above SIW structure efficiently, we use the finite different frequency domain (FDFD) method, where appropriate absorbing boundary conditions have been used around the structure and a special treatment has been made in the interaction of the incident electric field with the SIW structure. The numerical results simulated from the FDFD method are illustrated in Figure 3. Here, the phase constant and the dissipation factor are given in different cases. From Figure 3, we notice that the leakage energy is nearly zero if the dimension of the aperture s in the SIW structure in Figure 2 is less than 0.2λ. As the dimension s increases, the power leakage becomes remarkable, see Figures 3c and 3d. We also notice that the phase constant increases with the size d when s is fixed, as illustrated in Figures 3a and 3b. According to the Floquet theorem, the fields in a periodic structure could be expressed in the following:

$$E_z = \sum_n A_n(x)\exp(-j\beta_n - \alpha_n)z$$

in which,

$$\beta_n = \beta \pm 2n\pi / d \,,$$

$$\alpha_n = \alpha$$

Because the waves traveling along the conventional rectangular waveguide are fast waves, they turn to be leaky waves when traveling into the periodic region. Thus the dissipation factor α exists anyway along the periodic region. As shown in Figure 3, a stop band occurs when the Bragg condition, i.e., $\beta d = n\pi$, is satisfied. Modes conversions are also found at some points where high modes appear. As frequency of the incident wave varies, the end-fire radiation turns to be the back-fire radiation, showing a well-known frequency-scan property that appears in leakage wave antennas.

In the above simulations, the influence of thickness of the conductor in the rectangular waveguides and SIW is not considered. When a thickness W is included, the SIW structure is illustrated in Figure 4, where the other dimension parameters are the same as those in Figure 2 and Table 1.

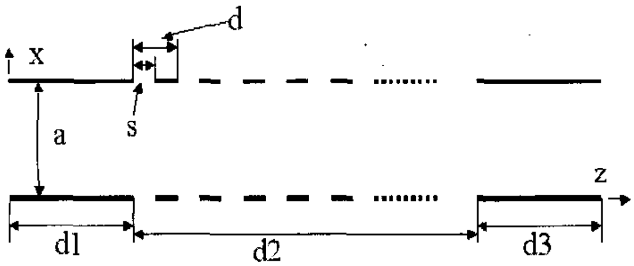
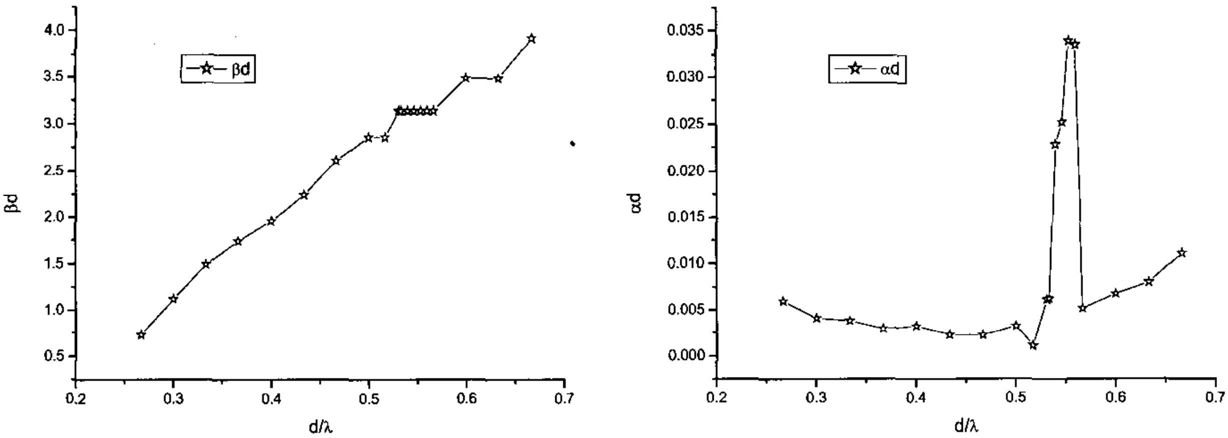


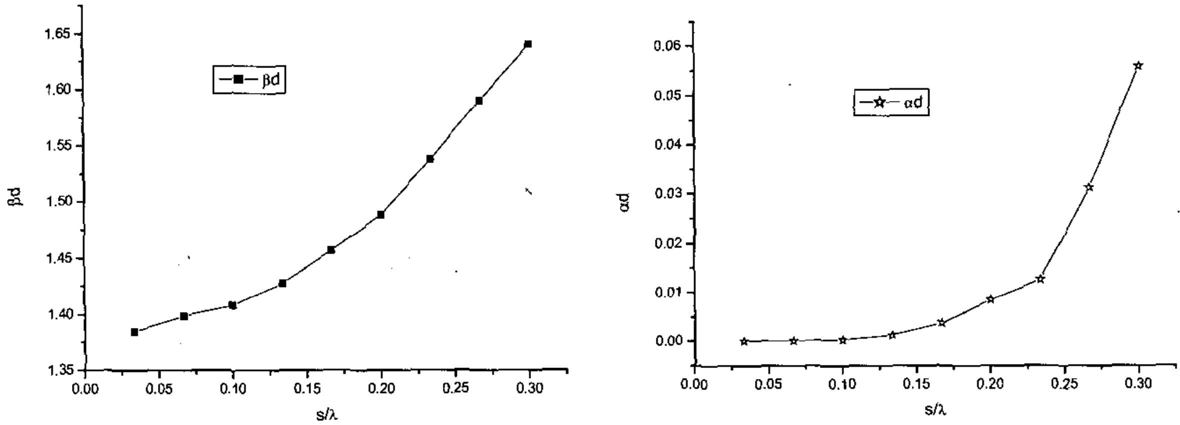
Figure 2 Periodic structure as a rectangular waveguide

Table 1 geometric parameters

a	20.0mm
d1	80.0mm
d2	320.0mm
d3	80.0mm
s	5.0mm
d	10.0mm

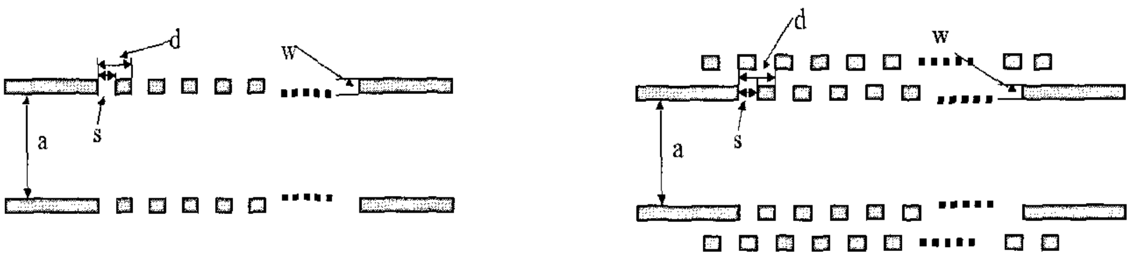


(a) (b)



(c) (d)

Figure 3 Propagation parameters in the periodic region. (a) The phase constant versus frequency. (b) The dissipation factor versus frequency. (c) The phase constant β versus the dimension of aperture s. (d) The dissipation factor versus the dimension of aperture s.



(a) (b)

Figure 4. Periodic structure with finite thickness: (a) single layer (b) double layers

Numerical simulations of the above structures show that the leakage power considering the influence of the thickness of the conductor is much less than that ignoring the thickness. This phenomenon is due to the fact that the aperture itself acts as another rectangular waveguide in which the waves are cut off. Hence, only a fraction of the power is leaked away. This phenomenon can be easily observed in Figure 5. Here, Figure 5a shows the picture of the electric field distribution inside the SIW structure with zero thickness, Figures 5b and 5c show the picture of the field distribution with and without thickness for different *s/d*. From Figure 5c, we also find that the wave is bounded around the interior region and little leakage takes place when two layers of periodic structures are embedded, although the dimension of the aperture has been increased to its maximum value. Hence, we have much freedom in manufacturing the SIW structures.

III. Conclusions

With the analysis of periodic structures embedded within rectangular waveguides, we could conclude that characteristics of the conventional rectangular waveguide could be realized in substrate if we adequately choose the dimension of the structure and the working frequency band. Based on this idea, many types of functional modules such as filters, couplers, resonant cavities, etc. could be integrated in a single multi-layers circuits board.

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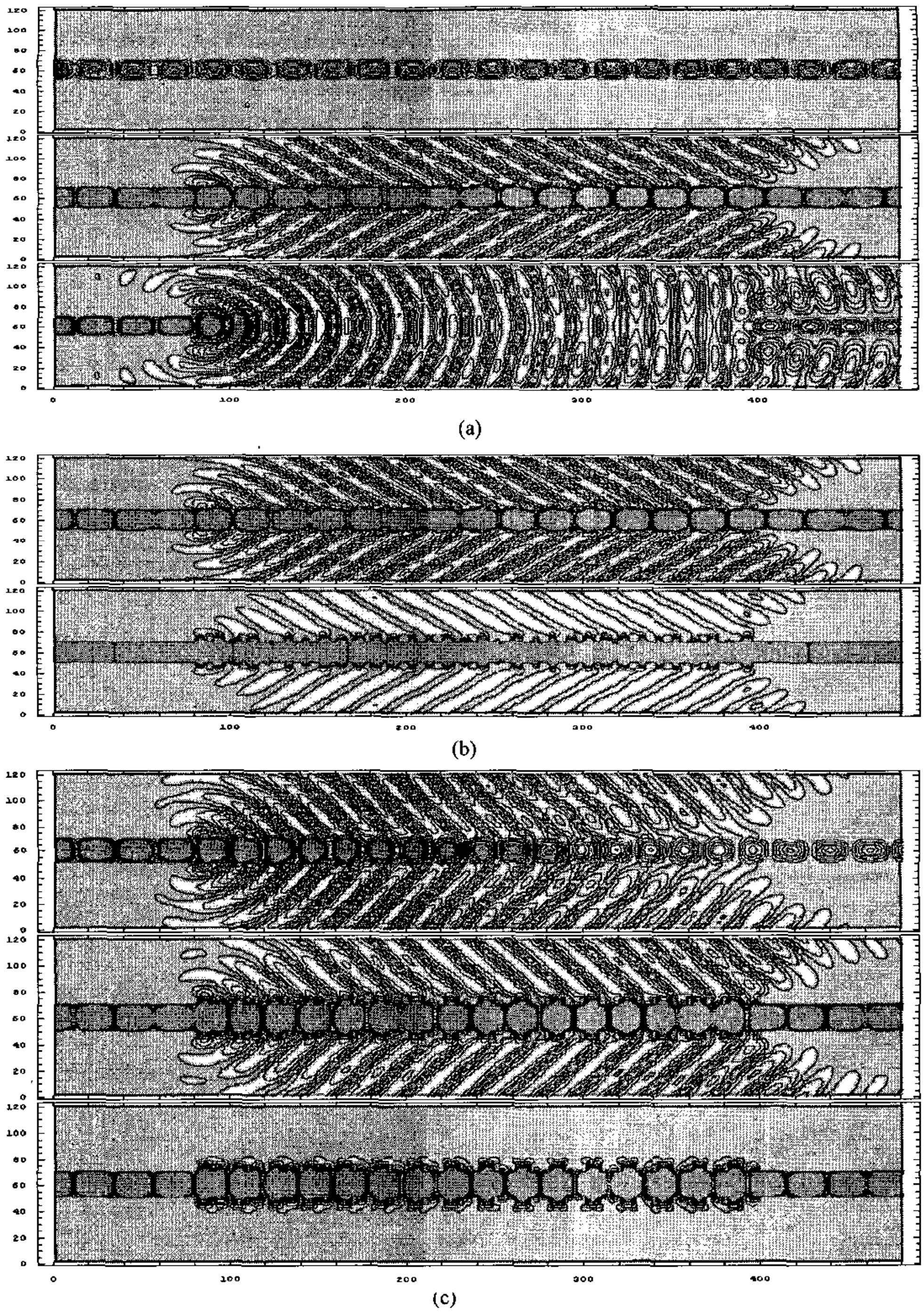

Figure 5. The electric field distribution inside the SIW structure. (a) The upper picture is the H_{10} mode in the conventional rectangular waveguide, the middle picture is the field distribution when s/d=0.5, and the lower picture is the field distribution when s=0. (b) s/d=0.5 (fixed). The upper picture shows the field distribution when the thickness of conductor is zero, and the lower picture shows the field distribution when the thickness of conductor is finite. (c) s/d=0.9 (fixed). The upper picture shows the field distribution when the thickness of conductor is zero, the middle picture shows the field distribution when the thickness of conductor is finite, and the lower picture shows the field distribution when the thickness of conductor is finite and there are two layers of periodic structures.