A Transition from Microstrip to Dielectric-Filled Rectangular Waveguide in Surface Mounting

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***Abstract* — This paper presents a design method for the transition from microstrip to dielectric-filled rectangular waveguide. It is based on the theory of the coupled transmission line, and is verified by a fabrication. The dielectric-filled rectangular waveguide is made of synthetic quartz and is mounted on a substrate. Experimental results in a back-to-back construction show good performances. The insertion loss becomes 0.3dB at the design frequency of 26GHz, and the return loss becomes better than 15dB from 23GHz to 30GHz.**

I. Introduction

The transition from microstrip to rectangular waveguide has been one of the important issues for a long time, and many transition structures have been proposed in literatures [1]-[3]. The conventional hollow rectangular waveguide has excellent characteristics in transmission loss, but it has difficulty in mounting on a surface of the substrate due to its thick metal walls.

Recently, integrated structures embedding the waveguide into a substrate have been proposed [4][5]. They have adavnatages in using waveguide components with planar circuits, but dielectric materials commonly used for substrates have large dissipation factors. Consequently, the waveguide components made of substrate materials become lossy, hence it is undesirable for low-loss circuits.

In this paper, the dielectric-filled rectangular waveguide is studied to realize both the easy connection to microstrip and low-loss. As a material of the dielectric waveguide, synthetic quartz is used due to its very low dissipation factor. The dielectric constant of quartz about 4.5 is favorable for the miniaturization of the waveguide components so that sizes become suitable for mounting on a surface of the substrate at 26-GHz frequency.

A proposed transition structure from microstrip to dielectric waveguide is very simple. It needs no complex machine processing. The design is based on the theory of the coupled transmission line, and it is possible by simple calculations.

Finally, the experimental results in a back-to-back construction are presented to show good performances of the fabricated transitions.

II. Design of Transition

The transition from microstrip to dielectric-filled rectangular waveguide as shown in Fig.1 is discussed. It can be divided into three parts, microstrip, transition and waveguide. In the part of transition, a conductive strip is inserted between the substrate and the waveguide. This structure is similar to a stripline except a difference that consists of two dielectric materials. The strip is connected with the microstrip and terminated at the beginning of the waveguide part. The width of the strip is slilghtly narrower than the microstrip so that the characteristic impedance matches with 50ohm of the microstrip. Though side walls of the substrate are metallized in the transition part, the electro-magnetic field concentrates in the direction of substrate thickness, thus the matching of electro-magnetic field is kept at the connection of the microstip and the transition.

In this paper, RT/duroid 5880 and y-cut synthetic

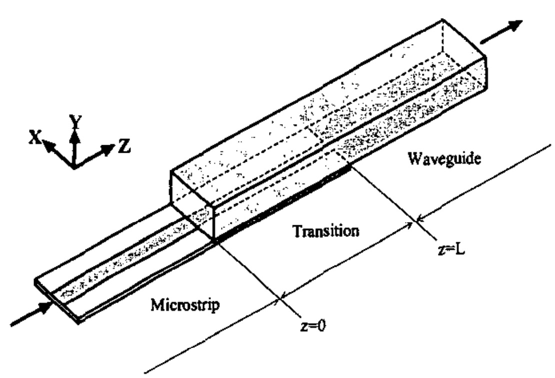

Fig.1. Schematic view of the transition from microstrip to dielectric-filled rectangular waveguide.

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quartz are used respectively as materials of the substrate and the dielectric-filled rectangular waveguide, and their dielectric constants at the frequency of 26GHz are 2.2 and 4.47 respectively. As for dimensions, the substrate thickness is 0.381mm, and the waveguide is 4.0mm in width and 2.5mm in height.

The dominant and the second transmission mode of the transition part are analyzed. Fig.2 shows the calculated electric fields of two transmission modes, and their dispersion characteristics are shown in Fig.3 with those of the microstrip part and the waveguide part. These calculations are done by Ansoft HFSS™ with lossless. It is evident that the dominant transmission mode is the quasi-TEM mode transmitted along the conductive strip. The second transmission mode is almost the same to the waveguide mode when the conductive strip is removed from the transition part. By removing the conductive strip, the transition part can be regarded as a rectangular waveguide made of two dielectric media with height of 2.881mm. The phase constant becomes smaller than that of the waveguide part because its effective dielectric constant is smaller than the homogeneous waveguide of synthetic quartz.

There are thousands of modes in the transition, but in this case, third and more higher modes have no relation in the design of the transition from the following reasons. The third mode can't couple to the microstrip mode because its electric field mainly consists of x component, and more higher modes start to propagate above 30GHz. Consequently, the electro-magnetic field of the transition part can be expressed by a linear combination of the electro-magnetic fields of the dominant and the second mode. Then the field of the transition is given by

$$\mathbf{F}(\mathbf{r}) = \mathbf{F}_1(\mathbf{r}) \cdot e^{-j\beta_1 z} + \mathbf{F}_2(\mathbf{r}) \cdot e^{-j\beta_2 z} \qquad (1)$$

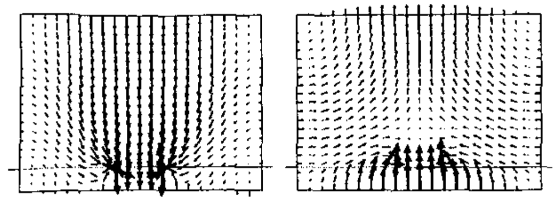
where $\mathbf{F}_1(\mathbf{r})$ and $\mathbf{F}_2(\mathbf{r})$ are the fields of the dominant and the second mode, respectively, and β_1 and β_2 are each phase constant.

The dominant and the second mode in the transition correspond to the even mode and the odd mode of the coupling line. On the assumption that discontinuities of connections at z=0 and z=L are small enough so that reflections can be neglected, the following relations exist.

$$\left.\begin{array}{l}\mathbf{F}_1(\mathbf{r}) + \mathbf{F}_2(\mathbf{r}) = \mathbf{M}(\mathbf{r}) \\ \mathbf{F}_1(\mathbf{r}) - \mathbf{F}_2(\mathbf{r}) = \mathbf{W}(\mathbf{r})\end{array}\right\} \qquad (2)$$

where $\mathbf{M}(\mathbf{r})$ and $\mathbf{W}(\mathbf{r})$ are the fields of the waves propagate in the microstrip part and in the waveguide part, respectively.

Then, $\mathbf{F}(\mathbf{r})$ equals $\mathbf{M}(\mathbf{r})$ at z=0, and equals $\mathbf{W}(\mathbf{r})$ at



(a) Dominant mode (b) Second mode

Fig.2. Electric field distributions of the transmission modes in a cross section of the transition

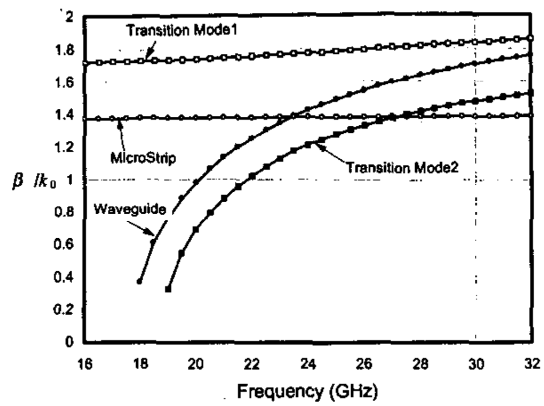


Fig.3. Dispersion characteristics of the transmission modes in the three parts.

$$z = \frac{\pi}{\beta_1 - \beta_2}. \qquad (3)$$

The above z corresponds to the optimum length of the transition because the supplied microstrip mode at z=0 is totally transformed to the waveguide mode at that position.

Here, taking 26GHz as a design frequency, β_1/k_0=1.79 and β_2/k_0=1.32 are chosen from Fig.3, and k_0=544.9(rad/m). Then the length of the transition is determined to L=12.2mm from equation (3).

III. Analysis and Simulation

Fig.4 shows the time-averaged electric field intensities in the center lines of the bottom surface of the substrate medium (y=-0.381mm) and the top surface of the waveguide medium (y=2.5mm) when the power of 1W is supplied from the microstip. It is calculated by HFSS at the frequency of 26GHz with the analysis model constructed with connecting the microstrip and the transition at z=0, and the transition has infinite length. Fig.4 shows that the electric field intensity in the

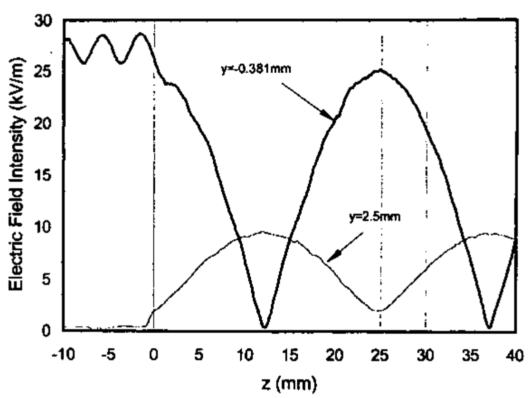


Fig.4. Distributions of electric field intensities at the bottom of the substrate (y=–0.381mm) and at the top of the waveguide (y=2.5mm).

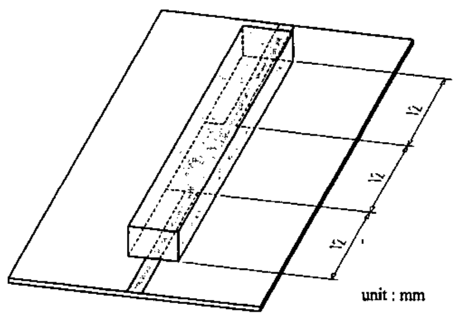


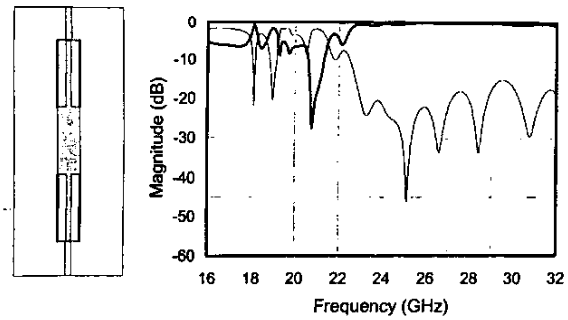
Fig.5. Simulation model of the transitions in a piece of back-to-back construction.

substrate medium becomes nearly zero at z=12.2mm, and at the same z position, the intensity becomes maximum in the waveguide medium. These intensities vary with 24.4-mm period in the direction of z. It means the electro-magnetic energy is transmitted with moving between two modes alternately [6].

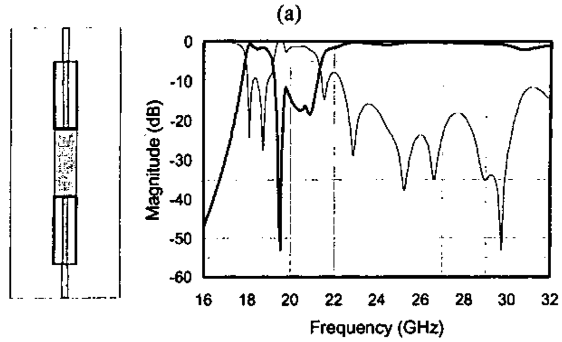
Because most electro-magnetic energy is transformed from the microstrip mode to the waveguide mode at z=12.2mm, the transition can be terminated at that z position.

Analysis models of the transitions in a back-to-back construction as shown in Fig.5 are tested by HFSS simulations. Fig.6 shows the simulation results of the three analysis models. These analysis models are essentially the same but have a difference in the setting of the metal walls inside of the substrate.

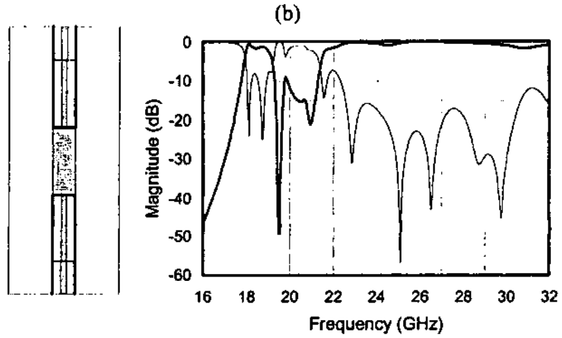
Fig.6(a) is the most basic structure that has metal walls only in both sides of the transitions. The cut off frequency of the waveguide is 17.7GHz, but the transmission exists in the lower frequency region because the wave is transmitted inside of the substrate under the waveguide in this structure.



(a)



(b)



(c)

Fig.6. Simulation responses of the transitions for different settings of the metal walls inside of the substrate.
(a) Basic structure. (b) Metal walls are added at the connections of the transition and the waveguide.
(c) Metal side walls are extended to the ends of the microstrips.

As for Fig.6(b), metal walls are added at the connecting positions of the transition part and the waveguide part. In this case, the cut off of the waveguide is observed because the transmission under the waveguide is stopped. However, the importance is that the response near the design frequency of 26GHz of both Fig.6(a) and Fig.6(b) have no significant difference. This means the transition allows various termination conditions, and it has practical value.

As for Fig.6(c), the metal side walls are extended to the ends of the microstrip parts. The response is almost the same as Fig.6(b), thus the substrate can be made in the same width as the waveguide.

After all, three analysis models show that the return losses are better than 15dB from 23GHz to 30GHz.

IV. FABRICATION AND MEASUREMENT

As a low-loss dielectric material, y-cut synthetic quartz is chosen. It has the dielectric constant of 4.47 at 26GHz, and its dissipation factor is less than 1.0×10^{-4} is favorable for low-loss circuits. To ensure conductivity of the waveguide surfaces enough high, thick metal platings with silver are used on the surfaces of quartz. That conductivity is estimated about 4×10^{7}(s/m).

Fig.7 shows the fabricated transisions in a piece of back-to-back construction. The metal side walls of the transitions are formed with linear arrays of metallized via holes. All of the transition parts and the waveguide part have length of 12mm.

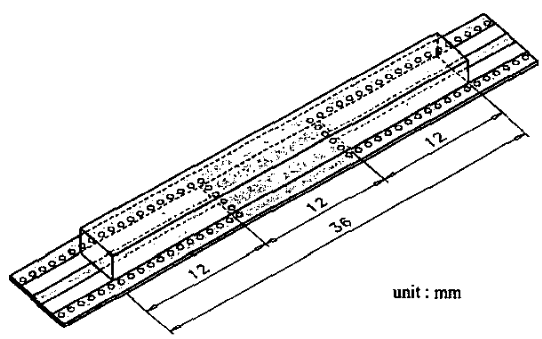


Fig.7. Fabricated transitions in a piece of back-to-back construction.

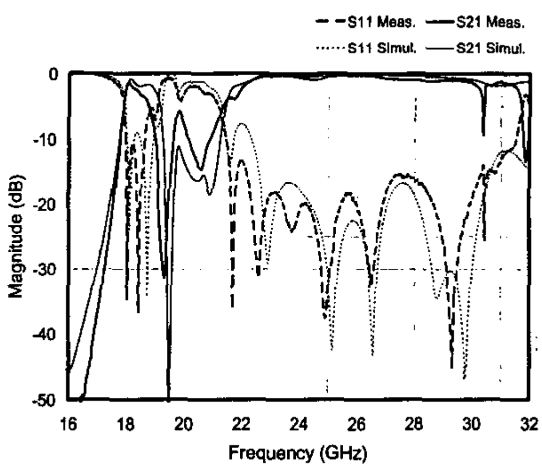


Fig.8. Measurement and simulation responses of the transitions in a back-to-back construction.

The measurement response is shown in Fig.8. Anritsu Vector Network Analyzer 37269B and Universal Test Fixture 3680K are used in this measurement. The overlaid simulation responses are the same as Fig.6(c).

The measurement and the simulation responses show good agreement. The return loss becomes better than 15dB in the frequency region from 23GHz to 30GHz, thus the bandwidth is over 26%, and the insertion loss is 0.3dB at 26GHz.

V. CONCLUSION

A design of the transition from microstrip to dielectric-filled rectangular waveguide is presented. It is based on a simple calculation from two phase constants of the transmission modes in the transition structure. The calculations of these constants need no long time and no much cost because the three-dimensional numerical analysis isn't necessary for the design.

By using this transition structure, surface mountings of the low-loss components based on dielectric waveguides become easy.

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