Measured Performance of Microstrip-Line-Fed Broadband Waveguide Aperture Antenna

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1. Introduction

Millimeter-wave technologies are expected to realize broadband high-speed wireless communication systems for home server and HD video transmission. Multi-layer substrate such as LTCC configuration is well-known to integrate many RF-circuits into small area of the substrate [1]. We have already been developed broadband microstrip-to-waveguide transitions composed of a substrate and metal parts [2]. Furthermore, transitions on a multilayer substrate without the metal back-short waveguide block also have developed to prevent performance degradation due to shift of the back-short waveguide from the waveguide center [3]. Then, we apply former transitions to an antenna and microstrip-line-fed broadband waveguide aperture antenna is developed as a first step. A novel antenna is proposed to operate over broad frequency bandwidth in the millimeter wave band. Simulated and measured performances are presented in this paper.

2. Structure of the Proposed Antenna

A microstrip-line-fed waveguide aperture antenna is developed to perform broad frequency bandwidth. A configuration of the proposed antenna is shown in Fig. 1. An almina substrate ($\varepsilon_r = 9.8$, $\tan\delta = 0.0035$) with conductor patterns on its both sides is placed between the metal radiation waveguide (WR-10, 2.54 mm$\times$1.27 mm) and the metal back-short waveguide block. The probe at the end of the microstrip line (MSL) is inserted into the waveguide. Figure 2 shows cross-sectional views of the proposed antenna. The microstrip line on BB'-plane is perpendicular to the waveguide axis. Via holes are surrounding the waveguide in the substrate to reduce leakage of parallel plate mode transmitting into the substrate. A short circuit of the back-short waveguide is spaced by essentially $\lambda_g/4$ (λ_g: guided wavelength of the waveguide) below the microstrip line. Consequently, electric current on the probe couples to magnetic field of TE_{10} dominant mode of the radiation waveguide. Electromagnetic wave radiates from the aperture of the radiation waveguide. Arrows indicate electric field in the transition. The antenna performs mode transformation from microstrip line to waveguide as is shown in Fig. 2 (c).

3. Simulated Performance

The microstrip-line-fed waveguide aperture antenna is designed in the millimeter wave band. Design frequency is 76.5 GHz. Reflection S_{11} is calculated by using an electromagnetic simulator of the finite element method. Thickness t of the substrate is an important parameter. Two variations of the thickness t = 0.15 mm and 0.28 mm are investigated in this paper for limitation in the thickness variety of commercially supplied substrates. The probe length l, the back-short block length s and the length h of the radiation waveguide are optimized to operate broad frequency bandwidth for each t.

When t = 0.15 mm, length l of the probe inserted into the waveguide is designed to be 0.68 mm. Figures 3 (a) and (b) show reflection S_{11} of the proposed antenna. Structural parameters are optimized as h = 4.3 mm and s = 0.4 mm. Bandwidth of lower than –14 dB (VSWR: 1.5) is 11.2 GHz (14.6 %) because of the double resonance as indicated by solid line in Fig. 3 (a). Figure 3 (a) also shows the reflection S_{11} in changing length h of the radiation waveguide, where back-short length s is fixed on 0.4 mm. Both resonant frequencies change when h changes. Next, Fig. 3 (b) shows the reflection S_{11} in changing back-short length s, where length h of the radiation waveguide is fixed on 4.3 mm. In this case, only higher resonant frequency shifts toward lower when s increases. Both resonant frequencies can be controlled by changing the length h of the radiation waveguide and s of the back-short waveguide.

Next, when t = 0.28 mm, length l is designed to be 0.70 mm. Figures 4 (a) and (b) show simulated reflection S_{11}. Structural parameters are optimized h = 4.3 mm and s = 0.09 mm. Bandwidth of S_{11} lower than –14 dB (VSWR: 1.5) is 12.6 GHz (16.4 %) as indicated by solid lines in Fig. 4 (a). Bandwidth for t = 0.28 mm is wider than that of 0.15 mm as well as ordinary microstrip antennas. Figure 4 (a) shows the reflection S_{11} in changing length h of the radiation waveguide, where back-short waveguide length s is fixed on 0.09 mm. Only lower resonant frequency changes for variety of h and the influence of changing h for t = 0.28 mm is larger than the case of t = 0.15 mm shown in Fig. 3 (a). Figure 4 (b) shows the reflection S_{11} when back-short length s changed, where length h of radiation waveguide is fixed as 4.3 mm. Higher resonant frequency changes for variety of s. Each resonant frequency could be controlled by h and s independently.

Back-short block length s is optimized as 0.09 mm which is quite shorter than $\lambda_g/4$ (1.54 mm). Electric field distributions at higher resonant frequencies are examined. When t = 0.15 mm and s = 0.4 mm, microstrip line mode is directly transformed to waveguide mode as is shown in Fig. 5 (a). On the other hand, when t = 0.28 mm and s = 0.09 mm, since a ground plane at the same plane with the back-short is quite close to the signal line, triplate waveguide is formed between the microstrip line and the waveguide. Thus, microstrip line mode is transformed to triplate mode once and next to the waveguide mode, as is shown in Fig. 5 (b).

Figure 6 shows the directivity when t = 0.15 mm and s = 0.4 mm. 3-dB beamwidth is 96 degree in E-plane and 79.5 degree in H-plane. Absolute gain is 5.2 dBi in 0-degree direction. Ripples are observed in radiation pattern. It is due to diffraction at the edges on the top of metal radiation waveguide.

4. Experiment

The proposed antenna is fabricated for experiment. Figure 7 shows a photograph of the printed pattern the BB' plane of the substrate shown in Fig. 2 (b). The measured S_{11} is shown in Fig. 3 (b) as well as the simulated S_{11}. Solid line is the measured results when back-short waveguide length s = 0.4 mm. Double resonance is observed and it cause wide bandwidth in both simulation and measurement. Although the simulated lower resonant frequency almost agrees well with the measured one, measured higher resonant frequency nearly correspond to the simulated one for s = 0.5 mm. As we mentioned before, higher resonant frequency depends on the back-short length s since electromagnetic field concentrates strongly between the probe and the back-short as shown in Fig. 5 (b). So, the frequency error could be caused by the tightness of screw for the back-short block. It is necessary to maintain constant tension of screw during measurement.

5. Conclusion

Microstrip-Line-Fed broadband waveguide aperture antenna is developed and performances are evaluated by simulations and measurements. The antenna bandwidth is broad because of the double resonance. The simulated results indicate that broad bandwidth of S_{11} lower than –14 dB is 12.6 GHz (16.4 %). The future studies are replacement of the metal block to a multi-layer substrate and increasing directivity by forming the aperture into horn.

References

[1] J. Lee, J. Hirokawa, M. Ando, “Bandwidth Enhancement of Aperture Feed by an Air Rectangular Cavity Backing in a LTCC Post-Wall,” IEICE Trans. Electronics, vol.E92-C, No.1, pp.121-126, 2009

[2] Y.Deguchi, K.Sakakibara, N.Kikuma, H.Hirayama, “Design and Optimization of Millimeter-Wave Microstrip-to-Waveguide Transition Operating over Broad Frequency Bandwidth,” IEICE Trans. Electronics, vol.E90-C, No.1, pp.157-164, 2007

[3] M.Hirono, K.Imai, K.Sakakibara, N.Kikuma, H.Hirayama, "Measured Performance of Broadband Microstrip-to-Waveguide Transition on Multi-Layer Substrate in the Millimeter-Wave Band," IEICE Trans. Commun., vol.J91-B, No.9, pp.1057-1065, 2008

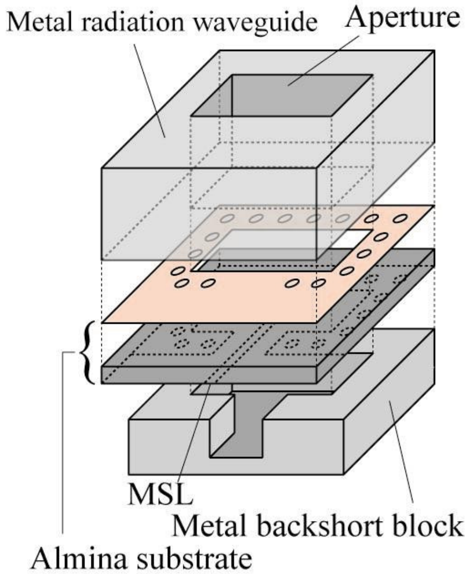

Figure 1: Configuration of the antenna

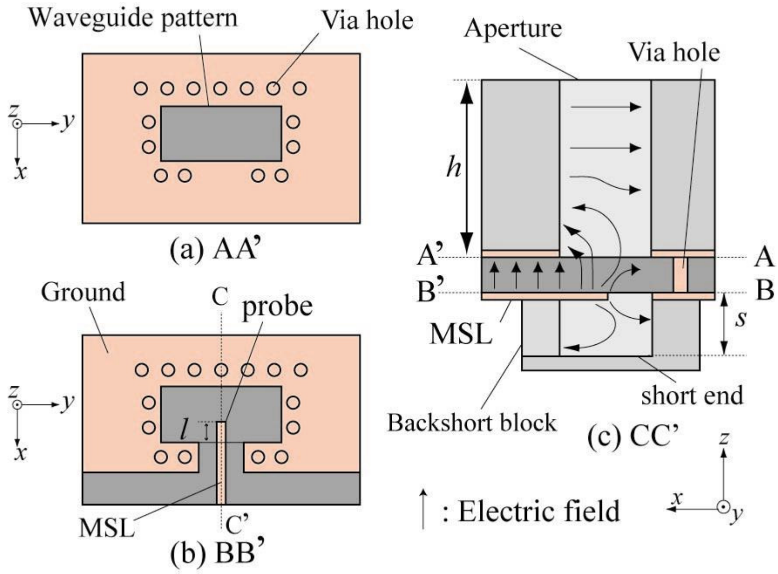

Figure 2: Cross section of the antenna

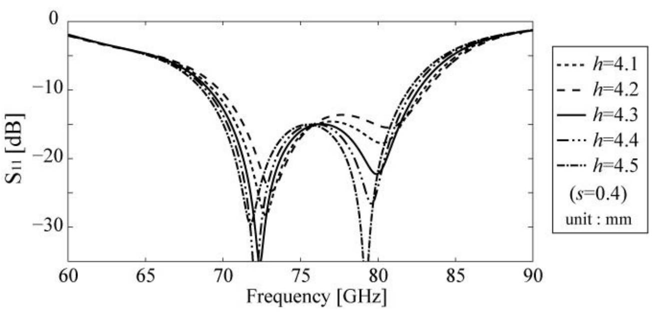

Figure 3 (a): Reflection S_{11} in changing length *h* of radiation waveguide (thickness of substrate 0.15 mm)

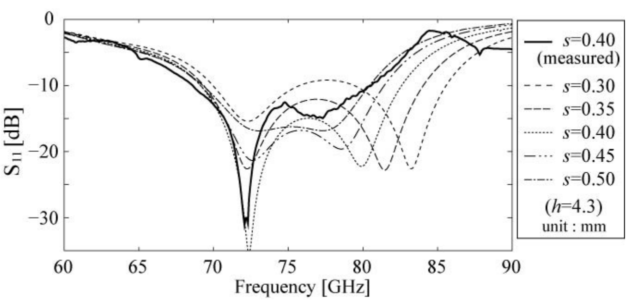

Figure. 3 (b): Reflection S_{11} in changing back-short block length *s* (thickness of substrate 0.15 mm)

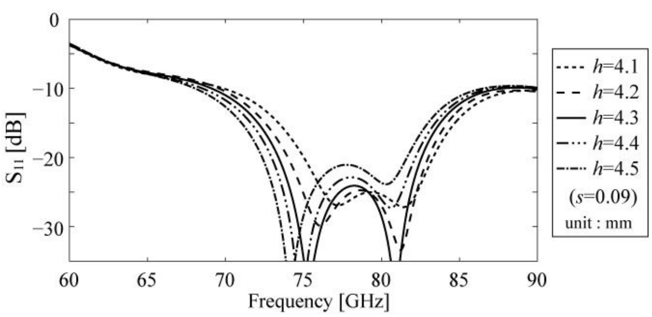

Figure 4 (a): Reflection S_{11} in changing length *h* of radiation waveguide (thickness *t* of substrate 0.28 mm)

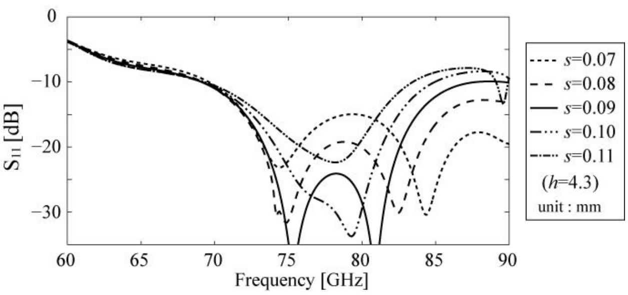

Figure 4 (b): Reflection S_{11} in changing back-short block length *s* (thickness of substrate 0.28 mm)

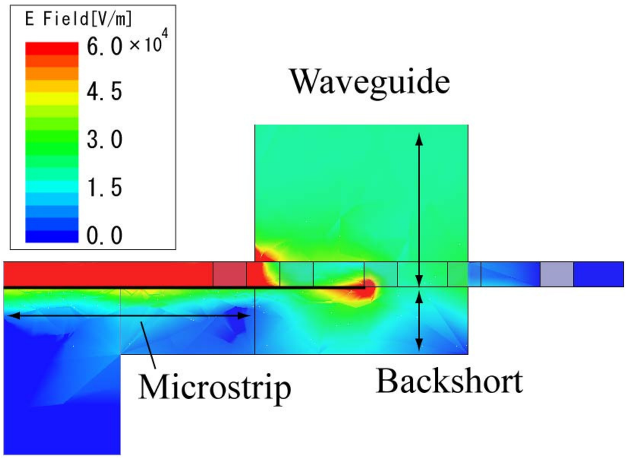

Figure 5 (a): Field distribution of antenna (thickness *t* of substrate 0.15mm at 79.9 GHz)

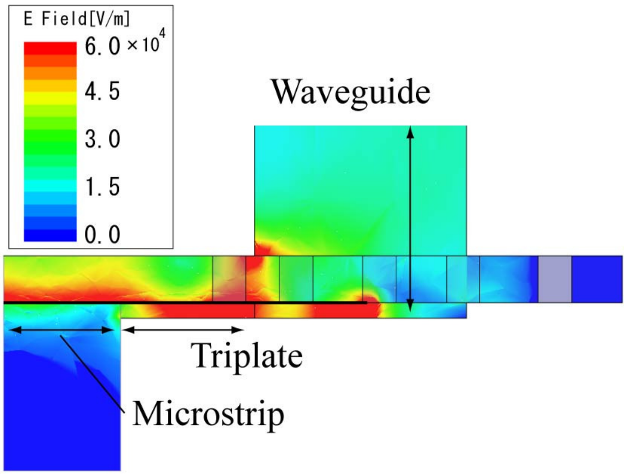

Figure 5 (b): Field distribution of antenna (thickness *t* of substrate 0.28 mm at 80.9 GHz)

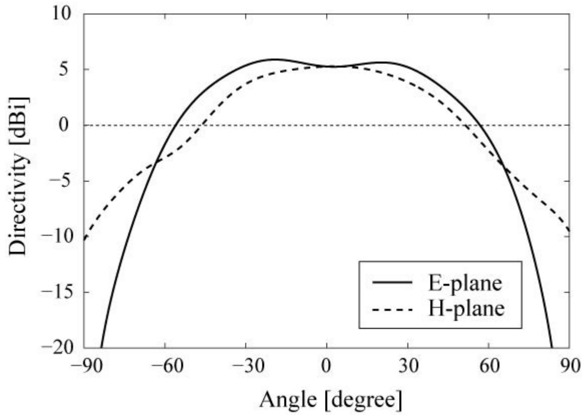

Figure 6: Directivity in E and H-plane

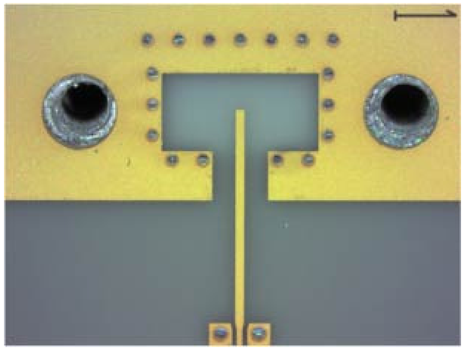

Figure 7: Printed pattern of the lower surface on the substrate (BB' horizontal plane in Fig. 2)