Gain Bandwidth of Microstrip-Line-Feeding Waveguide Aperture Antenna on LTCC Substrate in the Millimeter-Wave Band

#Hiroki Hori, Kunio Sakakibara,
Nobuyoshi Kikuma and Hiroshi Hirayama
Department of Computer Science Engineering, Nagoya Institute of Technology,
Gokiso-cho, Showa-ku, Nagoya, 466-8555, Japan
E-mail: sakaki@nitech.ac.jp

1. Introduction

Mictostrip-feeding broadband directive antennas [1]-[3] are in highly demand for high bit-rate wireless communication systems and automotive UWB radars [4]. We have developed broadband microstrip-to-waveguide transitions composed of a multi-layer substrate [5]. To apply this to the microstrip-line-feeding broadband waveguide aperture antenna, the waveguide transmission line of the transition is replaced by a waveguide with an aperture. Low profile, broad bandwidth and good connection with microwave circuits can be expected by using the antenna with a multi-layer substrate. A novel antenna was proposed to operate over broad frequency bandwidth in the millimeter-wave band [6]. Here, the bandwidth of gain is evaluated as well as the bandwidth of return loss in this work. Important geometrical parameters are indicated to control the resonant frequency and the bandwidth of gain and return loss. Loss causing degradation of gain is discussed from the simulated electromagnetic distribution.

2. Structure of the waveguide aperture antenna

A microstrip-line-feeding waveguide aperture antenna is developed for broad frequency bandwidth in the millimeter-wave band. The aperture antenna is composed of the double-layer LTCC substrates ($\varepsilon_r = 7.1$) with conductor patterns on its both sides set on the other aperture of the metal radiation waveguide (WR-10, 2.54mm×1.27mm), which results in low-profile. The structure of the aperture antenna with double-layer substrate is shown in Fig. 1. The probe at the end of the microstrip line (MSL) is inserted into the waveguide. An input signal from microstrip line (MSL) printed between the two substrates couples strongly to the waveguide mode via a quasi back-short waveguide in the substrate. The quasi waveguide is structured by surrounding via-holes in the lower substrate. Therefore, the thickness t of the lower substrate is identical to the length of the back-short waveguide. Provided that the width of the back-short quasi-waveguide are the same with the standard waveguide WR-10 in the substrate, unnecessary higher-order mode is generated, since the effective wavelength is shorter in the substrate than the wavelength in the hollow waveguide. The cut-off frequencies are $1/\sqrt{\varepsilon_r}$ times of those in the hollow waveguide and the higher-order mode propagates in the waveguide, where ε_r is the relative permittivity of the substrate. The cut-off frequency can be controlled by the broad-wall width of the waveguide. Equivalent broad wall width $a' = a / \sqrt{\varepsilon_r}$ is used to prevent generating higher-order mode (where a is the broad wall width of WR-10). Moreover, taper structure is supplied for matching at the connection between the feeding microstrip line and a grounded co-planar line, as shown in Fig. 2.

3. Simulated Performance

The antenna is designed on the conditions of the dielectric constant ε_r and thickness t from the commercially supplied substrates and of the size limitations of the printed patterns and the via-holes for manufacturing. The reflection S_{11} and gain is calculated by using electromagnetic simulator Ansoft HFSS of the finite element method. The broad wall width a' of the quasi-waveguide is 1.2 mm, while width a of the standard waveguide WR-10 is 2.54 mm. The dimensions of the quasi-waveguide in the substrate are designed to be small due to high relative permittivity $\varepsilon_r = 7.1$.

In the aperture antenna, the thickness t of the lower substrate and the length h of the radiation waveguide are important parameters. They are optimized to obtain high gain over broad bandwidth. Figure 3 shows the simulated gain in the broadside direction. The bandwidth of gain higher than 4 dBi is 14 GHz from 81 to 95 GHz. Figures 4 and 5 show the reflection characteristics S_{11} in changing the thickness t of the lower substrate and the length h of the radiation waveguide, respectively. The solid line indicates S_{11} for the optimum parameters ($h = 4.3$ mm, $t = 0.25$ mm). A triple resonance is observed. The reflection level is almost lower than −10 dB except for the frequency higher than 94 GHz in the bandwidth of gain higher than 4 dBi. For design of the broadband antenna, it is required to control resonant frequencies. From Fig. 4, the middle resonant frequency can be controlled by changing t. From Fig. 5, the middle and higher resonant frequencies can be controlled by changing h. Consequently, middle and higher resonant frequencies can be controlled by changing these parameters t and h.

On the other hand, the lower resonant frequency does not change by these parameters. Furthermore, gain is quite low around 75 GHz which is the lower resonant frequency of the reflection characteristic S_{11}. To investigate the reason for low gain, the electric field distribution in the substrate is calculated by electromagnetic simulation, as shown in Fig. 6. The strong electric field is observed in the substrate transmitting along the edge next to the input port at 75 GHz in contrast at 84.9 GHz. This parallel plate mode could cause the loss and gain degradation at the lower resonant frequency.

4. Conclusion

A microstrip-Line-Feeding broadband waveguide aperture antenna is developed and performance is evaluated by simulation. The antenna bandwidth of the simulated gain higher than 4 dBi is 14.3 GHz. Both middle and higher resonant frequencies can be controlled by changing the thickness t of the lower substrate and the length h of the radiation waveguide. The reason for the loss around the lower resonant frequency is investigated in this work.

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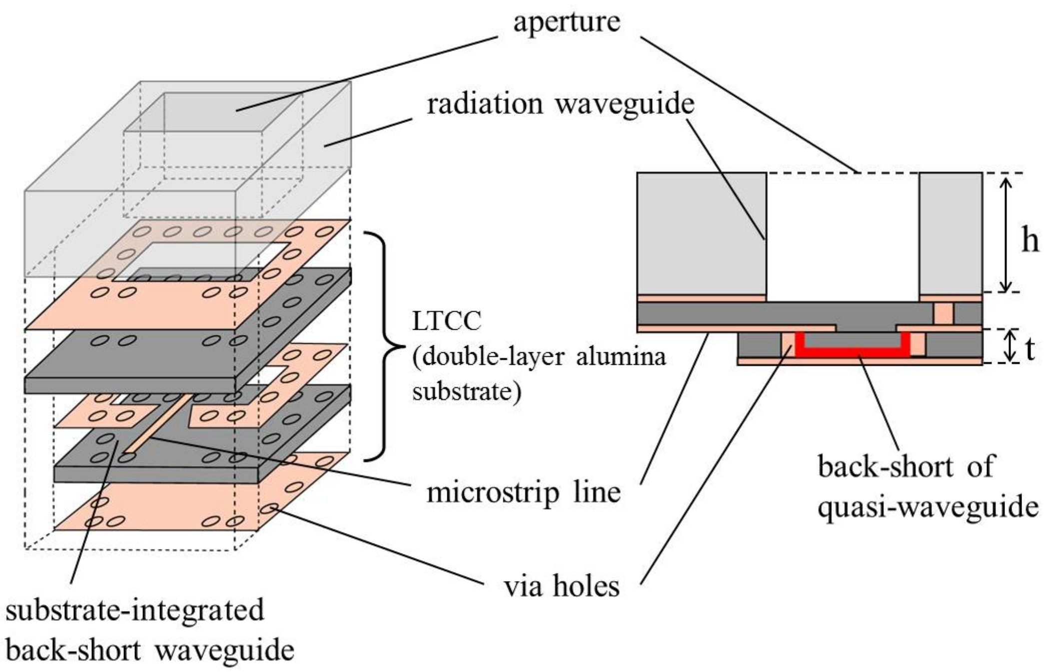


Fig. 1 Structure of the developed antenna.

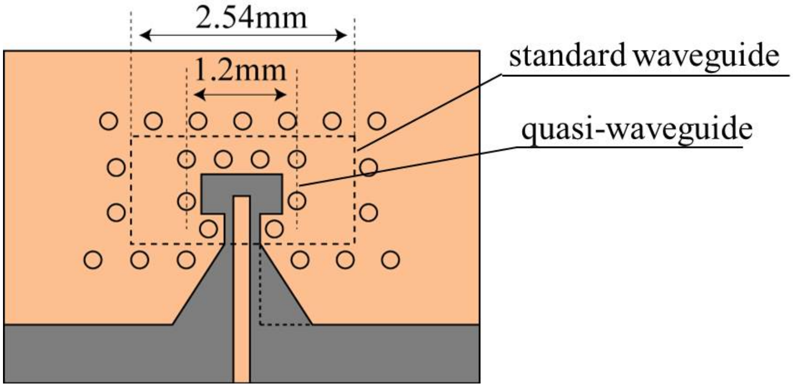


Fig. 2 Printed pattern between the two substrates.

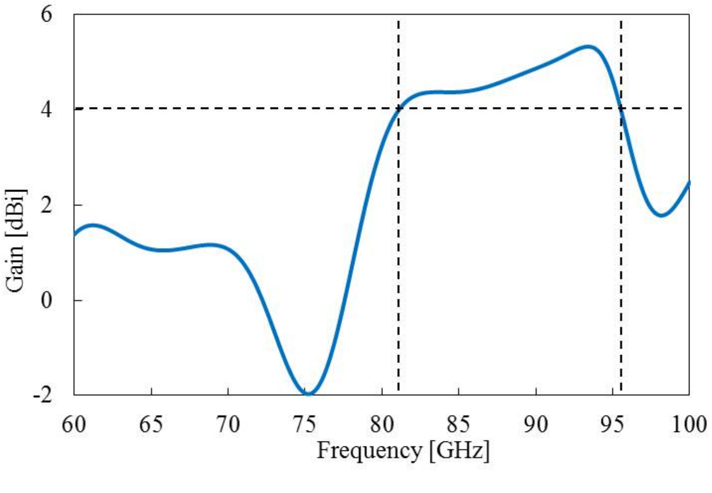


Fig. 3 Simulated gain in the broadside direction.

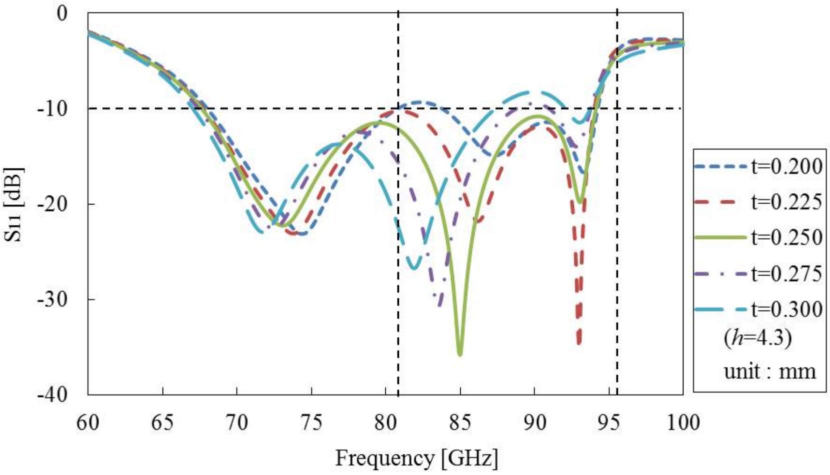


Fig. 4 Simulated reflections S_{11} in changing the thickness *t* of the lower substrate.

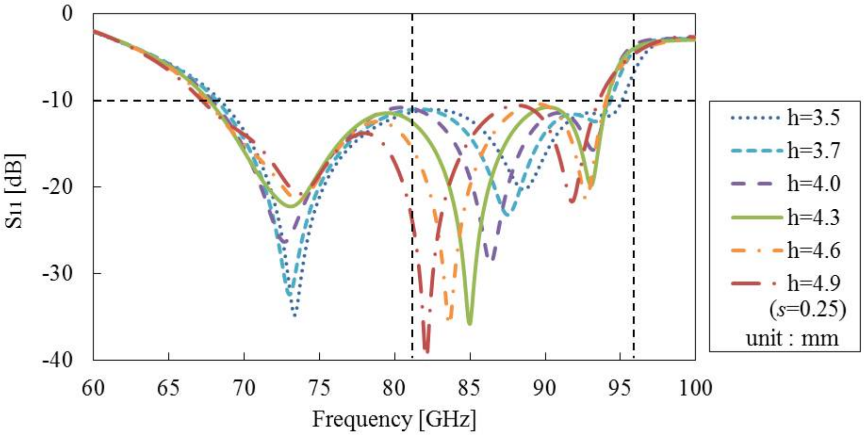
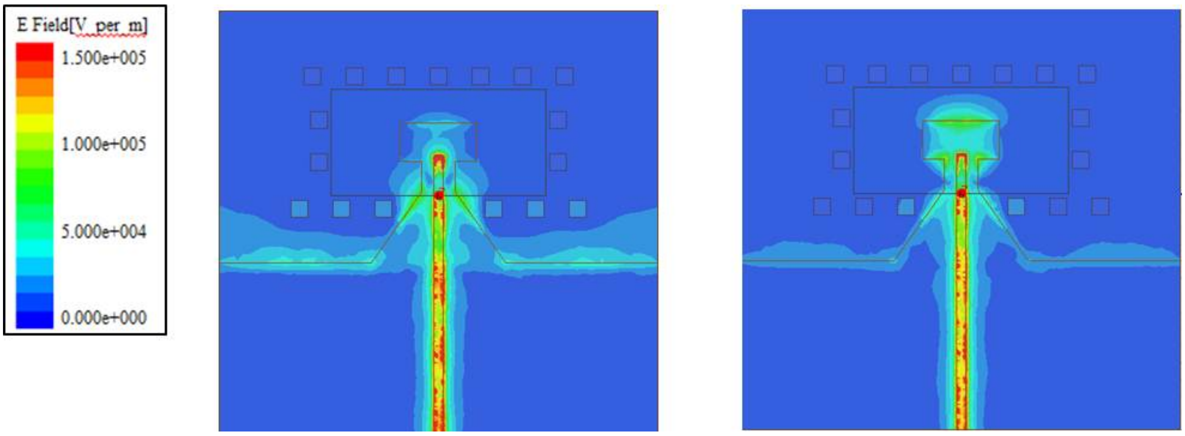


Fig. 5 Simulated reflections S_{11} in changing length *h* of the radiation waveguide.



(a) 75 GHz

(b) 84.9 GHz

Fig. 6 Electric field distributions in the substrate.