Broadband Operation of Microstrip-Line-Feeding Waveguide Aperture Antenna in the Millimeter-Wave Band

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Abstract

Microstrip-line-feeding waveguide aperture antenna is developed in the 70-90 GHz band. A double-layer LTCC substrate is attached to the waveguide aperture opened on the wall of the metal package. The bandwidth over 20 GHz is observed in the simulation and the experiment.

Keywords : Millimeter-wave antennas Broadband antennas Aperture antennas LTCC substrate

1. Introduction

Millimeter-wave technologies are expected to realize broadband high-speed wireless communication systems for home server and HD video transmission [1]. Antennas for mobile stations require the properties of small size, low loss and high integration with microwave circuits. Many kinds of millimeter-wave antennas have been developed for wireless communication systems. Multi-layer substrate such as LTCC configuration is one of the promising candidates for integration of an antenna with microwave circuits [2]-[4]. An RF module composed of an antenna and microwave circuits is in a metal package for shielding from noises and interferences of other circuits. An antenna aperture is formed for a wireless communication channel from the outside of the package through the waveguide in the metal wall of the package as shown in Fig. 1. Therefore, the microstrip-line-feeding waveguide aperture antenna is attractive to connect with microwave circuits directly.

Broad bandwidth is required for communication systems in the millimeter-wave band [1]. We have already developed two types of broadband microstrip-to-waveguide transitions. One transition is composed of a microstrip substrate between the two metal plates of a waveguide transmission line and a back-short waveguide [5]. Quite broad frequency bandwidth 30 % for reflection lower than −15 dB is obtained although the metal block is necessary for the back-short waveguide. The metal block for the back-short waveguide is replaced by another dielectric substrate to compose a multi-layer substrate in the other transition [6]. The metal block is not necessary, which is superior in integration with microwave circuits. The waveguide transmission line of the transition is replaced by a waveguide with an aperture to realize the microstrip-line-feeding waveguide aperture antenna. Low profile, broad bandwidth and good connection with microwave circuits can be expected by using the antenna with a multi-layer substrate. The performance of the fabricated antenna is demonstrated by simulations and experiments in this paper.

2. Configuration of the waveguide aperture antenna

The low-profile waveguide aperture antenna is composed of the multi-layer LTCC substrate set on the waveguide with the aperture. The multi-layer LTCC substrate consists of two alumina substrates stuck together. The structure of the aperture antenna with multilayer substrate is shown in Figs. 2 (a), (b) and (c). The back-short quasi-waveguide is structured by surrounding via-holes along the waveguide profile in the lower substrate. Therefore, the thickness s of the substrate is identical to the length of the back-short quasi-waveguide. The cut-off frequencies of the dominant and the higher-order modes in the substrate are $1/\sqrt{\varepsilon_r}$ times of those in the hollow waveguide, where ε_r is the relative permittivity of the substrate. Provided that the widths of the back-short waveguide are the same with the standard waveguide WR-10 (2.54 X 1.27 mm) in the substrate, unnecessary higher order mode is generated in the quasi-waveguide. The cut-off frequency of TE_{20} second higher order mode 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(c).

3. Simulations and measurements

The antenna is designed on the conditions of the dielectric constant ε_r and thickness s from the commercially supplied substrates and of the size limitations for the printed patterns and the via-holes. The reflection S_{11} and directivity is calculated by using electromagnetic simulator Ansoft HFSS of the finite element method. Measurement is carried out by using the vector network analyzer ME7808A (Anritsu) feeding by using the probe station system M150 (Cascade Microtech) for microstrip line input.

The printed pattern is shown in Fig. 2 (c) and the photographs of the fabricated aperture antenna with the multilayer substrate are shown in Fig. 3. 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 $\varepsilon_r = 7.1$. The thickness s of the substrate corresponds to the length of the back-short waveguide and is 0.28 mm chosen from the commercially supplied substrate close to the optimum dimension.

The measured and simulated reflections S_{11} is shown in Fig. 4. The bandwidth of the simulated reflection S_{11} lower than −10 dB is 25.7 GHz around the 70-90 GHz band, when the taper structure is applied to the feeding. Reflection level is slightly higher when the taper structure is not applied. Almost similar reflection characteristic is obtained by measurement. Simulated directivity of the aperture antenna with multi-layer substrate at 84.9 GHz is shown in Fig. 5. Peak directivity 5.4 dBi is observed in the front direction.

4. Conclusion

Low-profile aperture antenna is developed to use in the millimeter-wave package. Frequency dependency of reflection coefficient S_{11} and directivity are evaluated by simulations and experiments. The bandwidth of the antenna for reflection lower than −10 dB is 25.7 GHz. The dimensions of the quasi-waveguide in the multi-layer substrate are designed to prevent higher order mode. Moreover, the taper structure is used at the feeding to reduce reflection.

References

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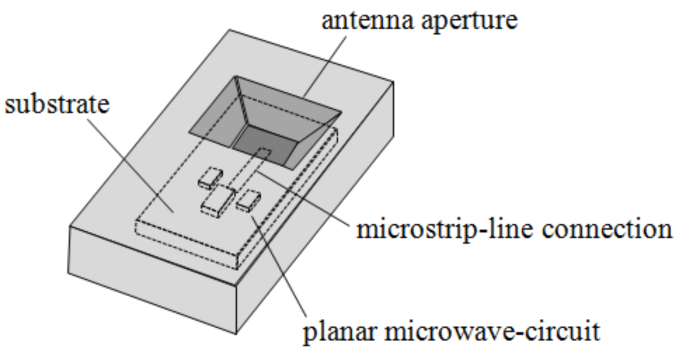


Fig. 1 RF module composed of the planar microwave circuit and the microstrip-line-feeding waveguide aperture antenna in the metal package.

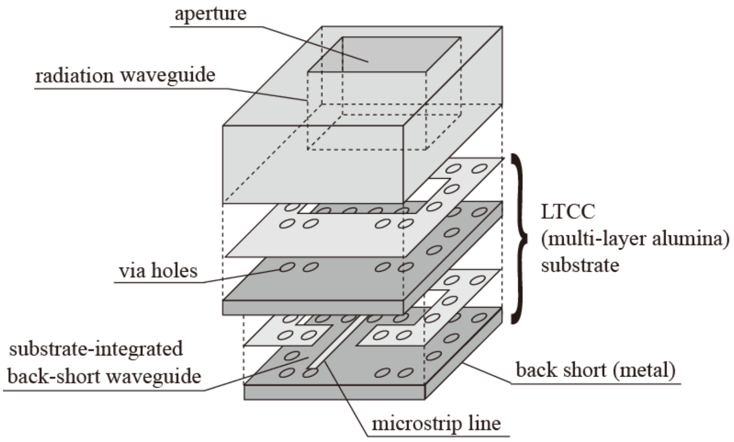


Fig. 2 (a) Structure of the aperture antenna with the multi-layer LTCC substrate.

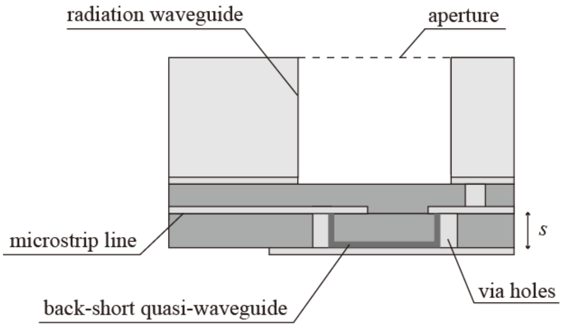


Fig. 2 (b) Cross-sectional view to show the back-short waveguide in the substrate.

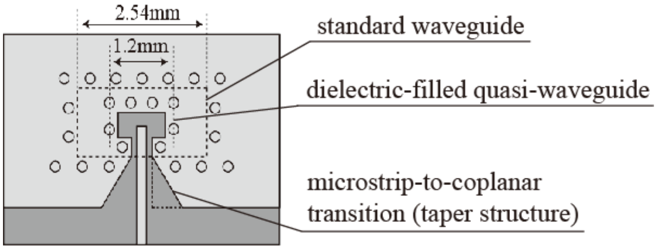
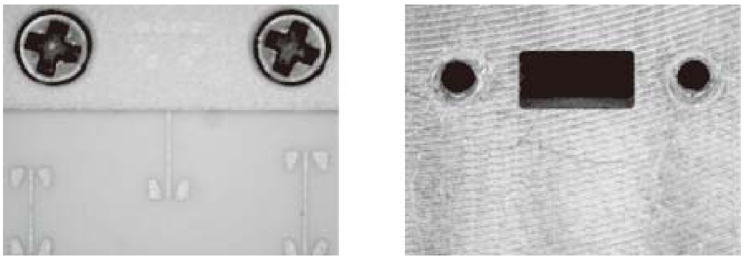
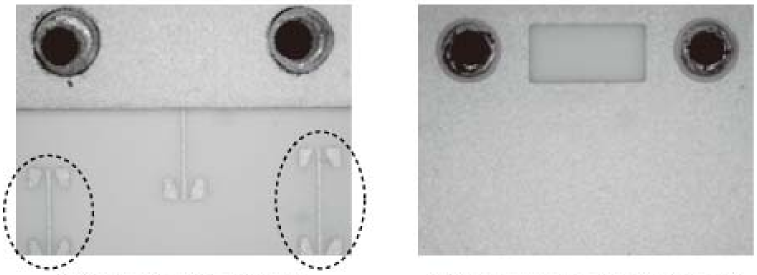


Fig. 2 (c) Printed pattern on the substrate.



(a) Feeding plane (b) Waveguide aperture



(c) Calibration lines (d) Ground pattern (back)

Fig. 3 Photographs of the fabricated antenna.

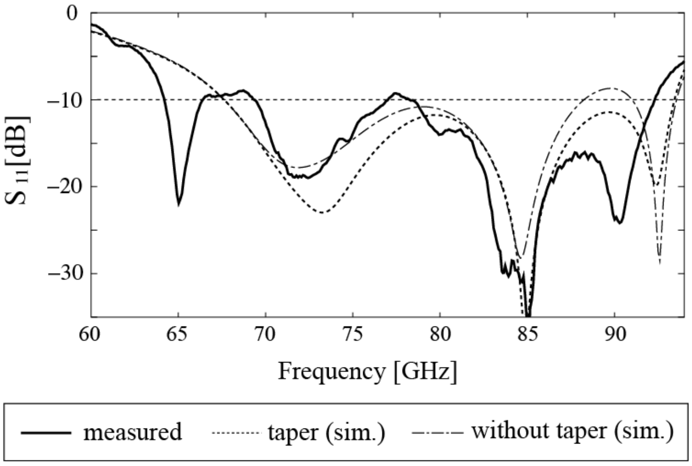


Fig. 4 Measured and simulated reflections S_{11}.

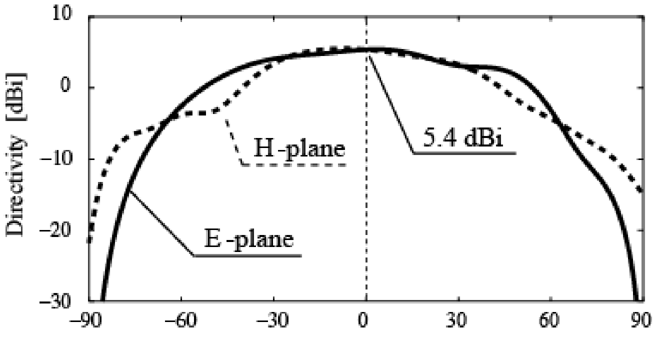


Fig. 5 Simulated directivity and radiation patterns.