RF Performance of Layer-Structured Passive Millimeter-wave Imaging Module

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1 Introduction

Simple configuration and broadband characteristic are required for RF module in passive millimeter-wave imaging. We propose a layer-structured imaging module for simple structure, low profile and easy manufacturing [1]. This module is composed of lens antenna and detector module as shown in Fig.1. Lens and feeding horn antenna are designed to realize high-gain lens-antenna which operates over broad frequency bandwidth. Detector circuit and waveguide-to-microstrip (WG-MS) transition are also designed to obtain highly-sensitive detector-module with waveguide input which can be connected with waveguide fed horn antenna of the lens antenna. Since a printed substrate with detector circuit is fixed between two metal plates, the module forms a layer structure, which contributes to low profile and easy manufacturing. Designs of the lens antenna and the detector module are indicated and RF performances of these components are reported in this paper.

2 Lens antenna

The lens antenna is composed of a microwave lens and a number of horn antennas arranged around the focal point of the lens. In order to receive incident wave through lens by horn antenna efficiently, transformation coefficient is employed in the design [2]. The microwave lens is designed by using the refraction law on lens contour and equalizing the electric path length of incident waves so that the all the incident waves are focused at the focal point. In order to obtain high transformation efficiency, the horn antenna is designed to match the 10 dB beamwidth of the horn antenna with 52 degrees which is the projection angle of lens. Figure 2 shows the radiation pattern of the center horn antenna in 5×5 element arrangement with intervals by 14.3 mm in both E- and H-plane at the design frequency 76.5 GHz. Measured 10 dB beam width of both E- and H-plane are approximately 52 degrees which is identical to the projection angle of the lens. Figure 3 shows frequency dependency of 10 dB beam width. 10 dB beam widths of E- and H-planes agree well over 60 to 90 GHz both in the simulation and experiment. Figure 4 shows the measured radiation pattern of the lens antenna at the design frequency. 3 dB beam width is 1.6 degrees in broadside direction while it is 1.3 degrees in simulation. Figure 5 shows the frequency dependency of measured gain and antenna efficiency from 60 GHz to 90 GHz. The gain is 43.0 dBi and the antenna efficiency is 75.3 % at 76.5 GHz. Gain is higher than 40 dBi from 60 to 90 GHz.

3 Detector module

A photograph of the developed detector module is shown in Fig.6. The detector module is composed of detector circuit and WG-MS transition to connect planar detector circuit and waveguide horn antenna of lens antenna. Detector circuit is composed of diode, matching circuit, two low pass filters (LPF) and two DC probing pads. Diode is placed between open-ended RF signal line and LPF with short input impedance. The other LPF with open input impedance is connected on the signal line between the input and the matching circuit to isolate DC probing pad from the effect of RF characteristic. In order to transmit RF signal efficiently to diode, matching circuit is necessary at the input of the diode. We adopted line stub for matching circuit. Stub length and spacing between stub and diode are optimized by using circuit simulator to operate with low reflection over wide frequency bandwidth. Figure 7 shows sensitivity in measurement and S_{11} in simulation and measurement of detector circuit. The bandwidth of reflection below -5 dB is 4.0 GHz in simulation and 2.6 GHz in measurement. The peak sensitivity is 1752 V/W at 74.5 GHz. The bandwidth of sensitivity above 1000 V/W is 5.0 GHz.

WG-MS transition is composed of a printed substrate on an open-ended waveguide with a back-short waveguide on the top. Height of back-short waveguide is approximately $\lambda_g/4$ (λ_g : guided wavelength of the waveguide) [3]. Since S_{11} of detector circuit resonates at 73 GHz shown in Fig.7, the design frequency of WG-MS transition is set at 73 GHz. Figure 8 shows simulated and measured S-parameters of WG-MS transition. The resonant frequency is 73 GHz. The bandwidth for reflection lower than -20 dB is 4.8 GHz. S_{21} at 73 GHz is -0.94 dB in measurement and -0.78 dB in simulation

Measured S_{11} and sensitivity of overall detector module with waveguide input are shown in Fig.9. The bandwidth of reflection below -5 dB is 4.5 GHz. The peak sensitivity is 2153 V/W at 72.5 GHz. The bandwidth of sensitivity above 1000 V/W is 7.0 GHz. The sensitivity is high where the reflection is low.

4 Conclusion

We proposed simple layer-structured passive millimeter-wave imaging module. We designed the lens antenna and the detector module and their RF performances are measured. The sensitivity of detector module is over 1000 V/W from 70.5 to 77 GHz and over 1900 V/W from 72.0 to 75.5 GHz. In this frequency range, the gain of lens antenna is over 40 dBi. Therefore, the developed module can be used for our future imaging test in this frequency band.

References

[1] Takahiro Suzuki, Kunihiko Ohkawa, Masashi Ikeda, Kunio Sakakibara, Yutaka Aoki, Nobuyoshi Kikuma and Hiroshi Hirayama, "Design of Lens Antenna and Detector Circuit for Layer Structured Imaging Module," Proc. ISAP2007, POS 2-4, pp.1114-1117.

[2] Minkyoo Joung, Yoichi Suzuki, Kentaro Kanari, Naoto Arai, Hiroyasu Sato, Soonkoo Kim, Yukio Yamanaka, Yoshihiko Wagatsuma and Koji Mizuno, "A Design of Antenna for Passive Millimeter-Wave Imaging Arrays," Proc. 2002 Asia-Pacific Microwave Conf., pp.253-256, 2002.

[3] Y.Deguchi, K.Sakakibara, N.Kikuma and H.Hirayama, "Millimeter-Wave Microstrip-to-Waveguide Transition Operating Over Broad Frequency Bandwidth," in IEEE MTT-S Int. Symp. Dig., 2005.

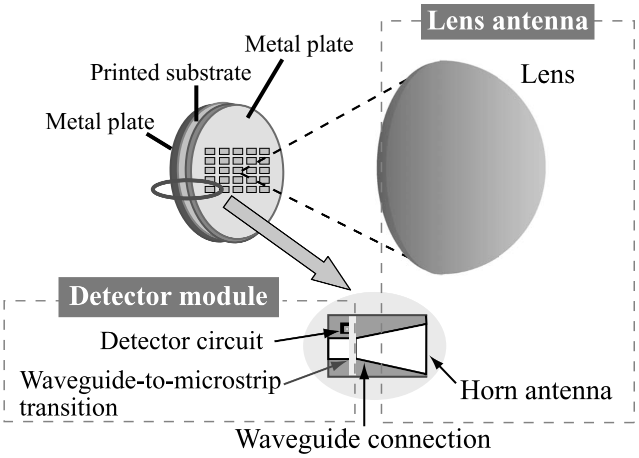

Figure 1: Configuration of layer-structured imaging module.

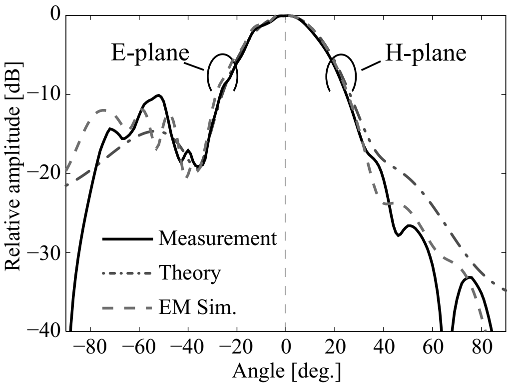

Figure 2: Radiation pattern of center horn antenna in 5 × 5 arrangement (76.5 GHz).

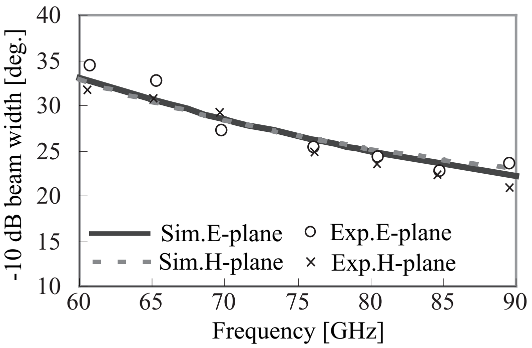

Figure 3: Frequency dependency of 10 dB beam width.

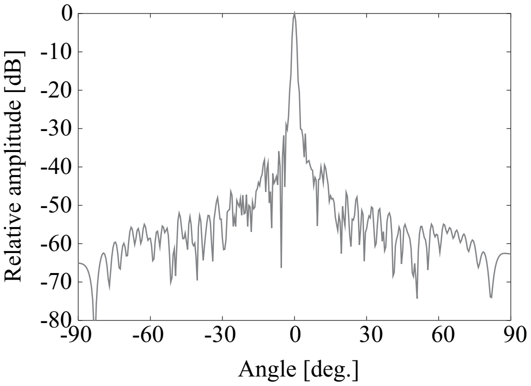

Figure 4: Measured radiation pattern of lens antenna (76.5 GHz).

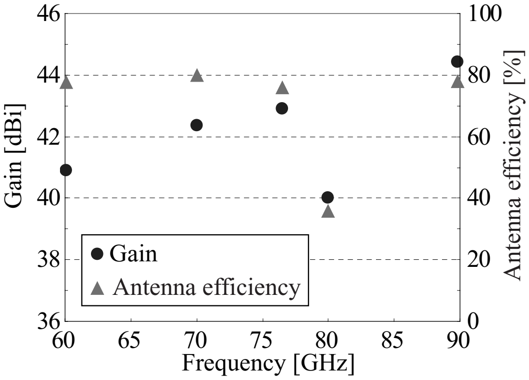

Figure 5: Measured gain and antenna efficiency of lens antenna.

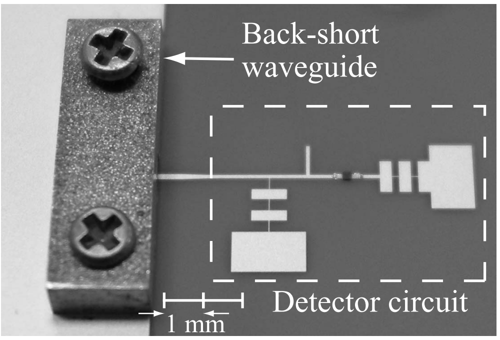

Figure 6: Photograph of detector module.

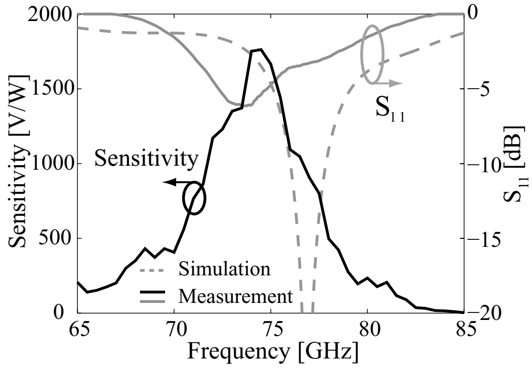

Figure 7: Sensitivity in measurement and S_{11} in simulation and measurement of detector circuit.

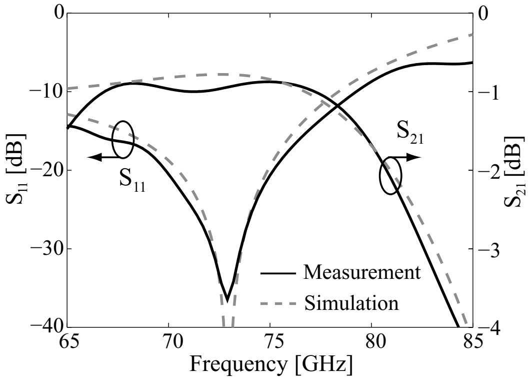

Figure 8: Simulated and measured S-parameters of WG-MS transition.

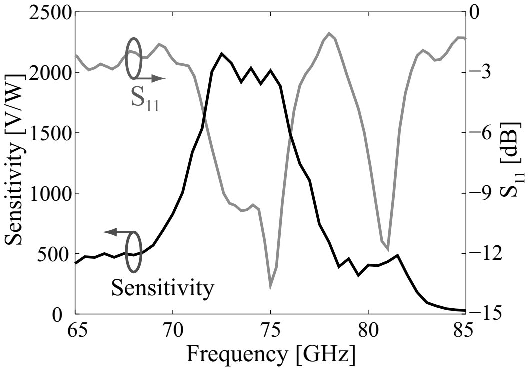

Figure 9: Measured S_{11} and sensitivity of detector module.