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Design of Lens Antenna and Detector Circuit for Layer Structured Imaging Module

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1. Introduction

Simple configuration and broadband characteristic are expected to RF module for passive millimeter-wave imaging [1]. We have already proposed a layer structured imaging RF module for low loss, low-profile and easy manufacturing [2]. This module is composed of four parts of microwave lens, horn antenna, microstrip-to-waveguide (MS-WG) transition and detector circuit as shown in Fig. 1. Radiated power from objects is received by the horn array through the microwave lens. Received power is transmitted to the detector circuit via MS-WG transition. A substrate printed a detector circuit with diode chip is fixed between two metal plates; one includes a number of the horn antennas and another one includes backed short structures of the transitions and shielding covers over the detector circuits. Consequently, the module forms a layer structure, which contributes to low-profile and easy manufacturing. Broadband feature is required in all the components for high S/N ratio. Horn antenna is advantageous at the point of broadband. A MS-WG transition is indispensable to connect a planar detector circuit to a waveguide horn antenna. We have already developed a transition which has quite wide operation frequency bandwidth [3]. The superior feature of the developed transition allows our original layer configuration of the broadband module for passive imaging. The measured and designed results of the components for the RF module are reported in this paper.

2. Design and Performance of 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. The microwave lens is designed by using the refraction law so that the all the incident waves are focused at the focal point in which F-number is equal to one [4], where the F-number is the ratio of focal length to diameter of lens. In order to illuminate the lens efficiently, the horn antenna is designed to match -10 dB beamwidth of the horn antenna with the width of the lens in both E- and H-plane. The horn antenna is designed by using electromagnetic simulator to obtain the symmetrical radiation pattern in broad frequency bandwidth.

Figure 2 shows the radiation patterns of the center horn antenna in 5×5 element arrangement with intervals of 14.3 mm in both E- and H-plane at the design frequency 76.5 GHz. Measured beamwidth almost agrees with design in both E- and H-plane. The symmetrical radiation pattern is obtained in ±30 degrees. On the other hand, the sidelobe level grows high in E-plane. It is confirmed by electromagnetic simulation that the cause of growing sidelobe level is influence of adjacent elements. Figure 3 shows the frequency dependency of -10 dB beamwidth of the horn antenna. The measured beamwidth almost agrees with design at the higher frequency region, however in the E-plane, it is wider than the design around the lower frequency by the influence of adjacent elements as mentioned in Fig. 2

Figure 4 shows the measured radiation pattern of the lens antenna in E-plane at the design frequency. A sharp main beam in which -3 dB beamwidth is 1.6° is obtained toward the broadside direction. Equivalent characteristic is obtained in H-plane. Figure 5 shows the frequency dependency of measured gain

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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. The bandwidth of gain over 40 dBi is wider than 30 GHz from 60 GHz to 90 GHz. High gain and high antenna efficiency are achieved.

3. Design and Performance of Detector Circuit

The photograph and the block diagram of the developed detector circuit are shown in Figs. 6 and 7, respectively. Alumina substrate is used (thickness : 0.1 mm, relative dielectric constant ε_r : 10.0). RF signal from the input port is rectified by diode on the substrate. The schottky diode is HSCH9161 of Avago technology. Since it operates without bias, no bias circuit is necessary in the detector circuit. The diode is mounted on the substrate and connects to RF signal line via beam lead terminal. Low-pass filters are designed so that DC probing terminals do not affect to the RF characteristics. Two low-pass filters are necessary to obtain high DC output voltage between the both sides of the diode. The input impedance of the low-pass filters are designed by using electromagnetic simulator as open circuit for an input side and short circuit for a diode end. In order to transmit the received power into the diode efficiently, matching circuit is necessary between input port and diode. The matching circuit is designed with taking ideal filter characteristics into account. Stub length and spacing between stub and diode are optimized by circuit simulator to operate low reflection over wide frequency bandwidth. Figure 8 shows the frequency dependency of measured sensitivity and reflection coefficient $|S_{11}|$. The bandwidth of $|S_{11}|$ below -3 dB is 6.0 GHz. The peak sensitivity is 1752 V/W at 74.5 GHz. The bandwidth of the sensitivity above 1000 V/W is 5.0 GHz. The sensitivity is high where the reflection is low.

The above-mentioned planar detector circuit and waveguide horn antenna are connected via broadband MS-WG transition. The design technique has already been developed [3] and is applied to an alumina substrate. Figure 9 shows the simulated frequency dependency of S-parameteres. Two resonances are observed in characteristic of $|S_{11}|$. The insertion loss is 0.52 dB at the 76.5 GHz. The bandwidth of reflection below -20 dB is 15 GHz. It is confirmed in the simulation that this transition works well over wide frequency bandwidth.

4. Conclusion

Simple configuration of RF module was proposed for passive millimeter-wave imaging systems. Broadband lens antenna is developed. With regard to the detector circuit, peak sensitivity is high. However, bandwidth is still narrow compared with other components. The future study is extending bandwidth of detector circuit and fabrication of RF module composed of developed components.

References

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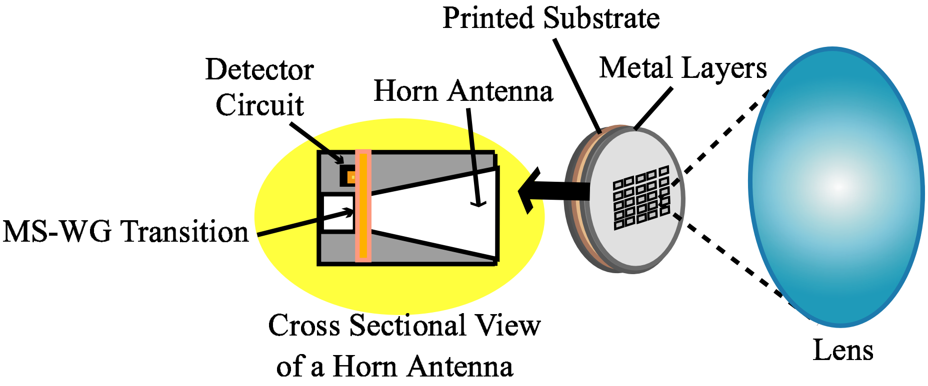

Figure 1: Layer structured passive imaging module

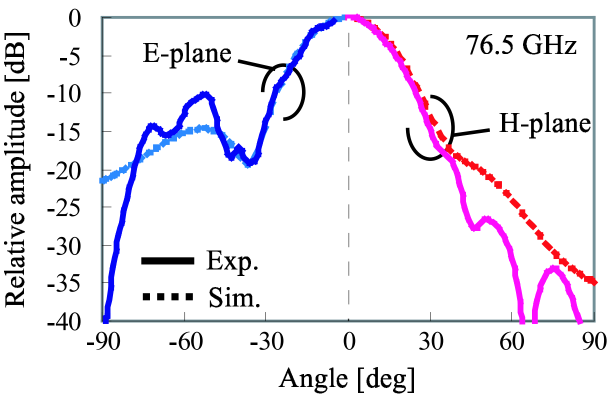

Figure 2: Radiation pattern of the horn antenna

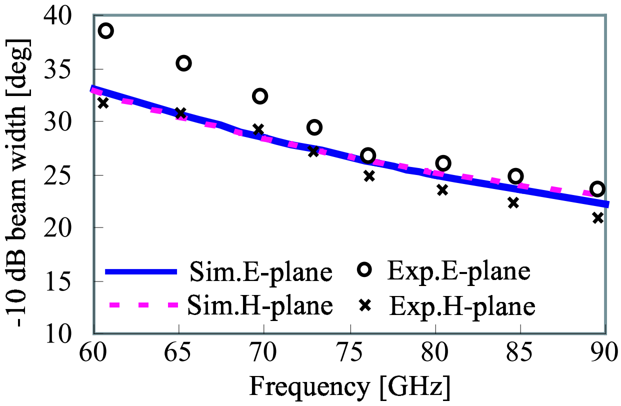

Figure 3: Frequency dependency of -10 dB beamwidth of the horn antenna

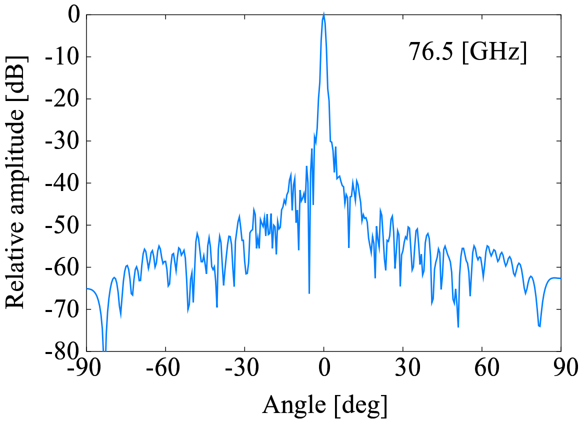

Figure 4: Measured radiation pattern of the lens antenna in E-plane

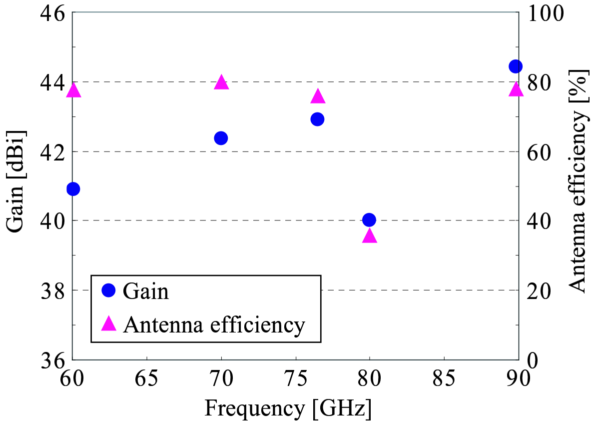

Figure 5: Measured gain and antenna efficiency of the lens antenna

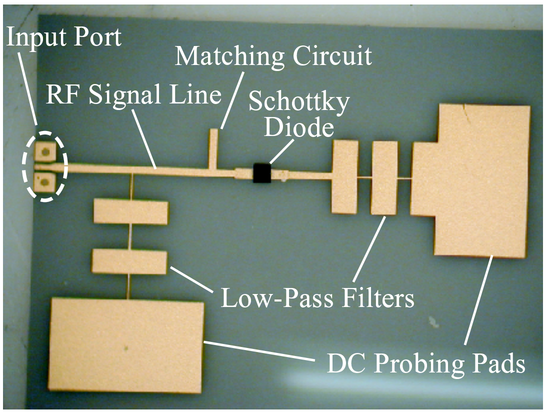

Figure 6: Photograph of the detector circuit

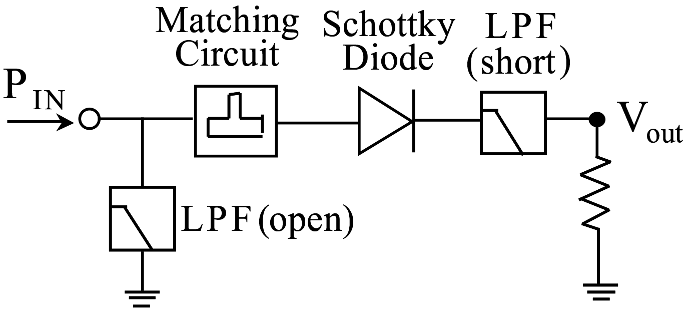

Figure 7: Block diagram of the detector circuit

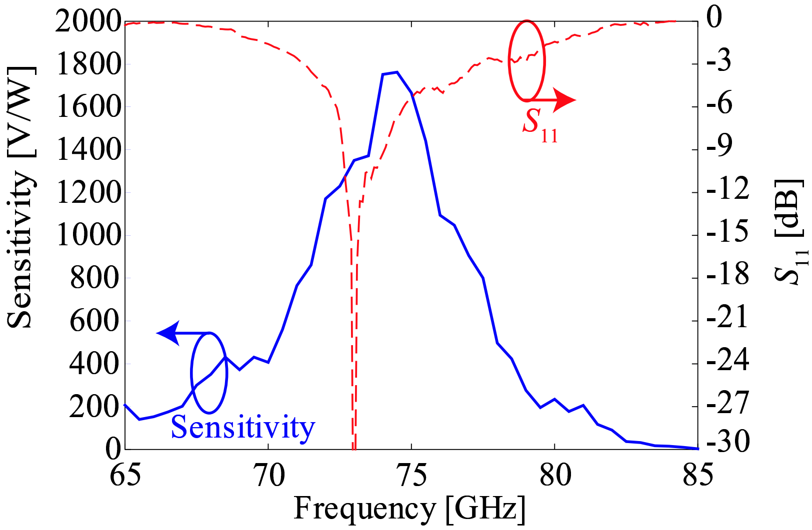

Figure 8: Measured sensitivity and reflectin of the detector circuit

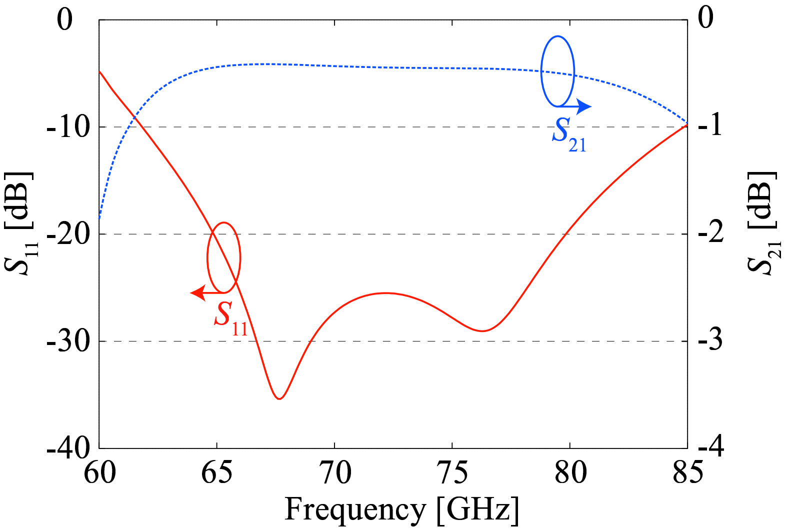

Figure 9: S-parameter of the MS-WG transition