Design of Millimeter-wave Detector Module Composed of Detector Circuit and Waveguide-to Microstrip Transition

[#]Wataru Maeda, Kunio Sakakibara
Nobuyoshi Kikuma, 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

Millimeter-wave penetrates various materials like clothes, fire and fog [1]-[3]. Millimeter-wave imaging is applied to detection of weapons under clothes, discovery of victims in afflicted area, and monitoring of driving environment. High sensitivity and wideband are demanded in millimeter-wave detector module, because the weak thermal radiation from object is received to obtain image in passive imaging. We propose a millimeter-wave detector module for simple structure, low profile and easy manufacturing [4]. We designed a millimeter-wave detector module at two frequency bands around 70 GHz and around 90GHz for imaging test in these frequency bands. Miniaturization of detector module and improving of resolution is expected at higher design frequency. Configuration of the detector module is presented and performances of these components are reported in this paper.

2. Configuration of detector module

Detector module is composed of detector circuit and waveguide-to-microstrip (WG-MS) transition to connect the waveguide and a detector circuit printed on the substrate as shown in Fig. 1. In this section, configurations of detector circuit and WG-MS transition are indicated to show the feature of the proposed module.

2.1 Detector circuit

The photograph of the developed detector circuit is shown in Fig. 2. The input RF power is rectified by diode and DC voltage is detected by eliminating RF signal component from terminal voltage via LPF whose input impedance is short circuit. LPF whose input impedance is open circuit suppresses the influence of DC terminal parallel connected to the RF signal line. Matching circuit is implemented to transmit power efficiently to the diode. There are three items in the design of detector circuit extracting equivalent circuit of diode, designs of matching circuit and LPF.

The Schottky barrier diode, HSCH9161 of Avago Technology, is used for detector. Since HSCH9161 is zero-bias diode, bias circuit is not necessary. The accuracy of the equivalent circuit affects a design of matching circuit. In order to extract the equivalent circuit of the diode in circuit simulator, S-parameters of the diode is measured in the setup shown in Fig. 3. The diode is mounted on a gap of the microstrip line on the substrate. Since the microstrip line is fed by coplanar probes, input and output ports are composed of coplanar-to-microstrip transitions. Scattering parameters of the diode are measured by vector network analyzer. Equivalent circuit of diode is extracted by optimization of the circuit parameters in the circuit simulator as simulated S-parameters fit to measured ones.Matching circuit is designed to match the impedance of signal line and equivalent circuit of diode. We adopted line stub for matching circuit. Stub length and spacing between stub and diode are optimized by using circuit simulator to minimize low reflection. A microstrip line LPF is composed of series connections of wide and narrow lines [5]. Since wide line works as shunt capacitance and narrow line works as series inductance, this circuit operates as LPF. Line width and length of LPFs are optimized by using electromagnetic simulator for two LPFs to be open circuit for

branch DC terminal and to be short circuit for end DC terminal.

2.2 WG-MS transition

WG-MS transition is designed to connect waveguide and planar detector circuit. The WG-MS transition is composed of printed substrate with conductor patterns on both planes located on the open-ended waveguide as is shown in Fig. 4. Back-short waveguide is set on the printed substrate. Height of the back-short waveguide is approximately $\lambda_g/4$ (λ_g: guided wavelength of the waveguide) [6]. A microstrip line is inserted into the waveguide in order to couple electric current on the microstripline to the magnetic line of forth of waveguide TE_{10} mode. Therefore, important design parameters are height of the back-short waveguide and inserted length of the microstrip line. These parameters are optimized by using electromagnetic simulator.

3. Design and performance of detector module

Detector circuit and WG-MS transition are designed at 70 GHz band. Alumina Substrate (thickness: 0.1 mm, relative dielectric constant ε_r: 10.0) is used for detector circuit. Equivalent circuit of diode is obtained by fitting the simulated S-parameters to measured ones. Measured and simulated S-parameters of diode after fitting are shown in Fig. 5. Differences between simulation and measurement of S_{11} and S_{21} are 0.6 and 0.1 dB in amplitude and 2.5 and 5 degrees in phase at 73 GHz, respectively. Matching circuit is designed for detector circuit by using the equivalent circuit of diode. Simulated and measured S_{11} and measured sensitivity of the detector circuit are shown in Fig. 6. Bandwidth of reflection below -10 dB is 2.2 GHz in simulation and 1.4 GHz in measurement. Sensitivity is a ratio of output voltage divided by input power. In this case, input power is -30 dBm. As a result, the peak sensitivity is 8900 V/W. The bandwidth of sensitivity higher than 1000 V/W is 10 GHz. Measured sensitivity is high in the frequency band where reflection is low.

Measured and simulated S-parameters of the WG-MS transition are shown in Fig. 7. Resonant frequency of WG-MS transition is designed to be 73 GHz that is a resonant frequency of the detector circuit. Bandwidth for reflection lower than -20 dB is 4.8 GHz. S_{21} at 73 GHz is -0.94 dB in measurement.

The photograph of the developed detector module composed of the detector circuit and the WG-MS transition is shown in Fig. 8. Measured S_{11} and sensitivity of the detector module is shown in Fig. 9. Bandwidth of reflection below -10 dB is 4.9 GHz in measurement. In this case, input power is -30 dBm as well. Peak sensitivity is 8100 V/W at 73 GHz. Bandwidth of sensitivity higher than 1000 V/W is 10 GHz. This is almost the same level with the isolated detector circuit.

A detector circuit with similar configuration is designed at 90 GHz band. The dielectric material of the substrate is Fluorocarbon resin film (thickness: 0.08 mm, relative dielectric constant ε_r: 2.59). Miniaturization of detector module and improving of resolution is expected at higher design frequency. The accuracy of extracting equivalent circuit of the diode is evaluated. As shown in Fig. 10, differences between simulation and measurement of S_{11} and S_{21} are 0.8 and 0.5 dB in amplitude and 9 and 1.2 degrees in phase at 90 GHz, respectively. Matching circuit of detector circuit is designed by using equivalent circuit. Measured and simulated S_{11} of the detector circuit is shown in Fig. 11. Bandwidth of reflection below -10 dB is 1.0 GHz in simulation and 1.8 GHz in measurement.

4. Conclusion

We proposed millimeter-wave detector module. We designed components of detector module at 70GHz and 90GHz band. Detector module by using detector circuit will be developed at 90GHz band for future study. In order to improve sensitivity performance, detector module should be developed for wideband.

References

[1] K.Mizuno, K.Watanabe, J.Bae, T.Nozokido, and S.Sugawara, "Millimeter-wave imaging technologies," 1997 Topical Symposium on millimeter-waves(Invited), Hayama, Japan, July 1997.

[2] J. E. Bjarnason, T. L. J. Chan, A. W. M. Lee, M. A. Celis, and E.R. Brown, "Millimeter-wave, terahertz, and mid-infrared transmission through common clothing," Appl. Phys. Lett. 85, pp.519-522, 2004.

[3] L.Yujiri, M.Shoucri, P.Moffa, "Passive millimeter wave imaging," Microwave Magazine, vol.4, pp.39-50, 2003.

[4] 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.

[5] I.J Bahl and P. Bhartia, Microwave Solid State Circuit Design, Second Edition Wiley, Chap.6, 2003.

[6] Y.Deguchi, K.Sakakibara, N.Kikuma and H.Hirayama, "Millimeter-wave Microstrip-to-Waveguide Transition Operating over Broad FrequencyBandwidth," in IEEE MTT-S Int. Symp. Dig., 2005.
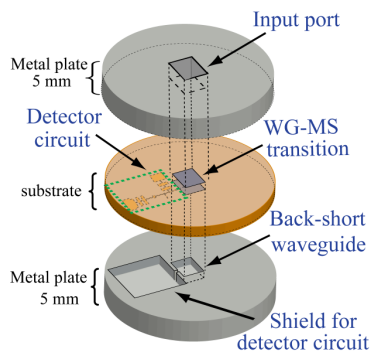
Fig.1 Configuration of layer-structured detector module
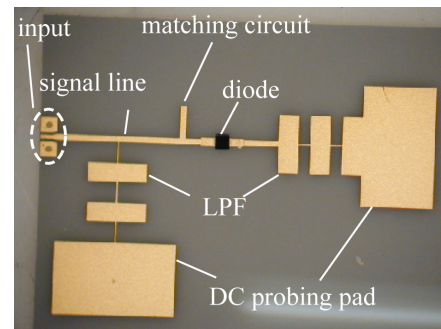
Fig.2 Photograph of detector circuit
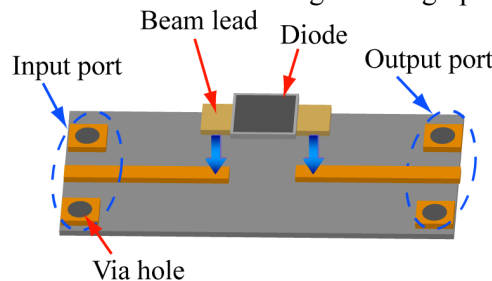
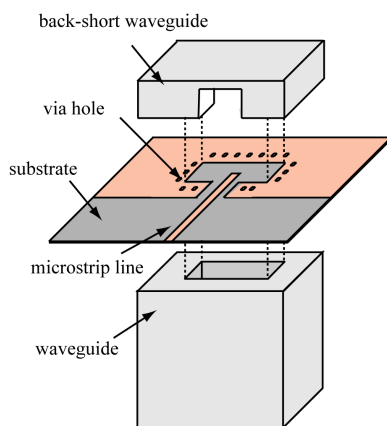Fig.3 Measured setup for extracting the equivalent circuit of diode

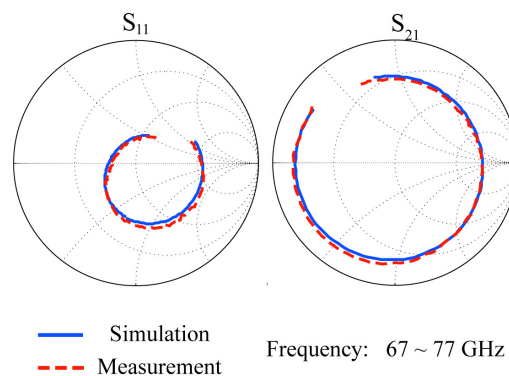Fig.4 Structure of waveguide-to-micristrip transition

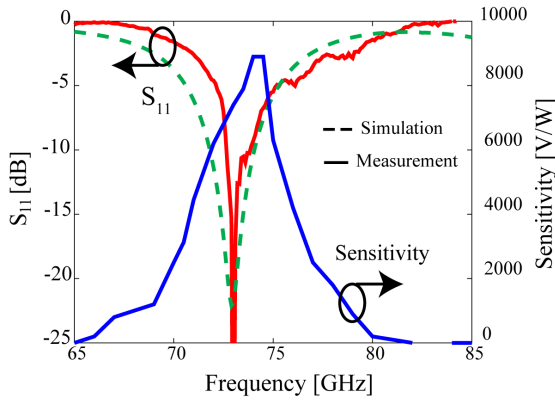Fig.5 Measured and simulation *S*-parameters of diode at 70GHz band

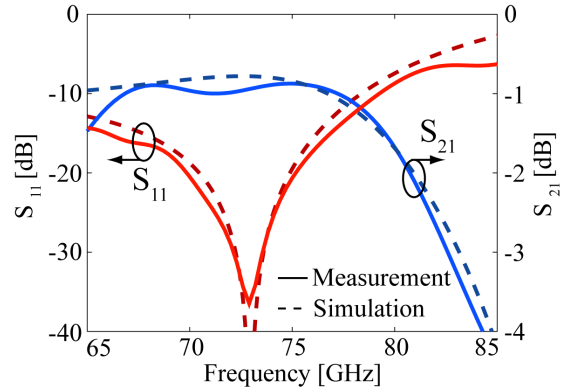Fig.6 S_{11} and sensitivity of the detector circuit at 70GHz band

Fig.7 *S*-parameters of waveguide-to-micristrip transition at 70GHz band
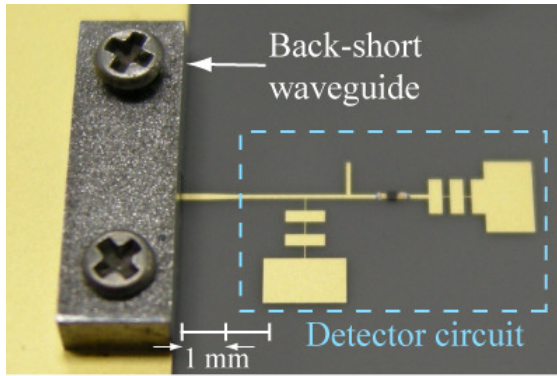

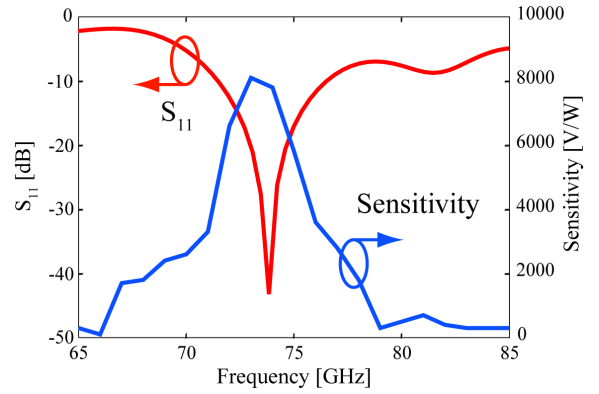Fig.8 Photograph of detector module at 70GHz band

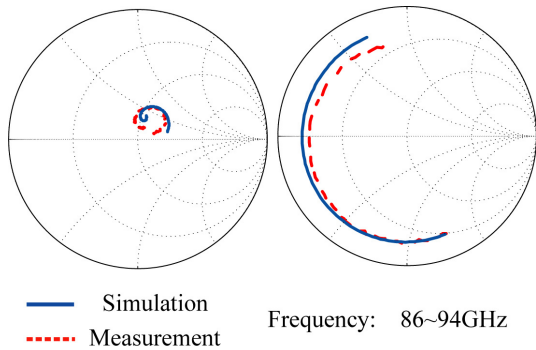Fig.9 S_{11} and sensitivity of the detector module at 70GHz band

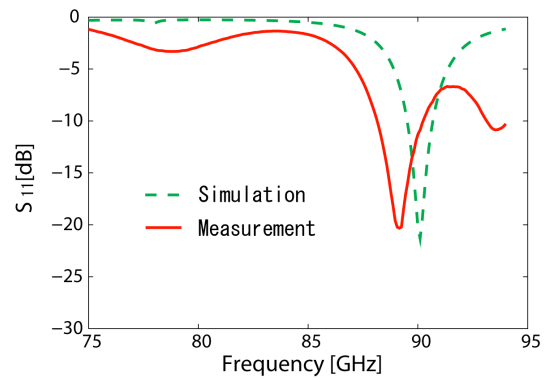Fig.10 Measured and simulation *S*-parameters of diode at 90GHz band

Fig.11 S_{11} of the detector circuit at 90GHz band