Design of Waveguide-Input Millimeter-wave Detector Module

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1. Introduction

A waveguide-input detector module is developed and the design technique is introduced in this paper. Detector circuits are commercially used for RF power meters and for passive millimeter-wave imaging systems. Millimeter-wave imaging systems have developed by many research institutions in recent decades [1], [2]. Broadband characteristics are often advantageous for wide tolerance in manufacturing of millimeter-wave circuits and for high-received power of passive millimeter-wave imaging systems. Waveguide-input detector module is proposed to connect with waveguide-based horn antenna which has broadband characteristic in general. We have already developed a broadband waveguide-to-microstrip (WG-MS) transition [3] which can connect the planar detector circuit on the substrate and waveguide output port for the developed module. As for the detector circuit, low-pass filters (LPF) and matching circuit are designed by extracting equivalent circuit of diode accurately. Furthermore, the design validity is confirmed by experiments.

2. Configuration and design of module

The proposed module is composed of a detector circuit and a WG-MS transition as shown in Fig.1. RF power from input waveguide port is transmitted to the detector circuit via WG-MS transition. Since a printed substrate with detector circuit is fixed between the two metal plates, the module forms a layer structure, which contributes to low profile and easy manufacturing.

2.1 Configuration of detector circuit

We designed detector circuit on the substrate which operates in the millimeter-wave band. Photograph of the developed detector circuit is shown in Fig.2. Teflon substrate (thickness: 0.08 mm, relative dielectric constant ε_r: 2.59) is used for low loss and broad frequency bandwidth. DC voltage is output from the detector circuit by rectifying RF signal using diode. Diode is placed between open-ended RF signal line and short terminal. In order to transmit RF signal to diode efficiently, matching circuit is placed at the input of the diode. To observe DC voltage, DC probing pads are necessary on both terminals of diode. One of the two pads is placed at the short terminal of the diode. LPF equivalent to short circuit for RF signal is connected between the diode and the probing pad. This LPF prevents to leak RF signal and only DC voltage appears to the DC terminals. The other pad is connected on the signal line between the input and the matching circuit via LPF with open input impedance which isolates the effect from RF characteristic. Consequently, there are three items in the design procedure for detector circuit. First is extracting equivalent circuit of diode. Next is design of matching circuit using the equivalent circuit. Finally, LPFs are designed for short and open circuits. Performance of detector circuit is confirmed by experiments.

2. 2 Extracting equivalent circuit of diode

The schottky barrier diode, which is HSCH9161 of Avago technology, is used for detector circuit. Since HSCH9161 is zero-bias diode, bias circuit is unnecessary. The accuracy of the equivalent circuit affects a performance of matching circuit. Equivalent circuit of diode is extracted by changing the parameters of the circuit in the simulation as simulated *S*-parameters fit to measured ones. Figure 3 shows simulated and measured *S*-parameters. Differences between simulation and measurement of S_{11} and S_{21} are quite small as 0.55 and 0.07 dB in amplitude and 6 and 1.3 degrees in phase at 76.5 GHz, respectively. Accurate equivalent circuit is obtained.

2. 3 Design of matching circuit and low pass filter

Matching circuit is designed to transmit the received power efficiently to diode. Line stub is used for matching shown in Fig.2. Length of line stub and spacing between the diode and the stub are optimized in electromagnetic field simulator to match impedance of extracted diode.

LPF is designed to achieve the required cut off characteristics with desired input impedance. Two radial stubs are used in LPF as shown in Fig.2. In order to achieve the cut off characteristics, length of radial stub is $\lambda_g/4$ (λ_g : guided wavelength of the microstrip line). Furthermore, in order to achieve the broadband characteristics for input impedance, one of the two radial stubs for the LPF with short input impedance is located on the microstrip line so that the distance from the diode to the stub end is $\lambda_g/4$. Figure 4 shows simulated S_{11} of LPFs with open and short input impedance, respectively. Phase variations of S_{11} are relatively small in the frequency range over 60 to 90 GHz. As for the LPF with short input impedance, this result is approximately two times as stable as standard LPF using line stubs.

3. Performance of detector circuit and WG-MS transition

Figure 5 shows measured sensitivity and $|S_{11}|$ of the detector circuit. Resonant frequencies of $|S_{11}|$ are observed at the 76.2 GHz in both simulation and measurement. Bandwidth of $|S_{11}|$ below -5 dB is 6.6 GHz in simulation and 6.4 GHz in measurement. Measured and Simulated results almost agree with each other. Bandwidth is not very wide and it is due to characteristic of matching circuit. The peak sensitivity is 1906 V/W at 76.0 GHz. The bandwidth of sensitivity above 1000 V/W is 8.0 GHz. The sensitivity is high at the frequency where the reflection is low.

The above-mentioned planar detector circuit and input waveguide port are connected via broadband WG-MS transition. The transition is designed by using the design technique of the developed transition [3]. Figure 6 shows the simulated frequency dependency of *S*-parameters. Two resonances are observed in characteristic of $|S_{11}|$. The insertion loss is 0.17 dB at 76.5 GHz. The bandwidth of reflection below -20 dB is 18.1 GHz. It is confirmed in the simulation that this transition works well over wide frequency bandwidth.

4. Conclusion

We proposed waveguide-input detector module which consists of detector circuit and WG-MS transition. LPF and matching circuit were designed by using the accurate equivalent circuit of diode. With regard to the detector circuit, peak sensitivity is high. However, bandwidth is still narrow compared with WG-MS transition. The future study is extending bandwidth of detector circuit and fabrication of entire module composed of developed components.

Acknowledgments

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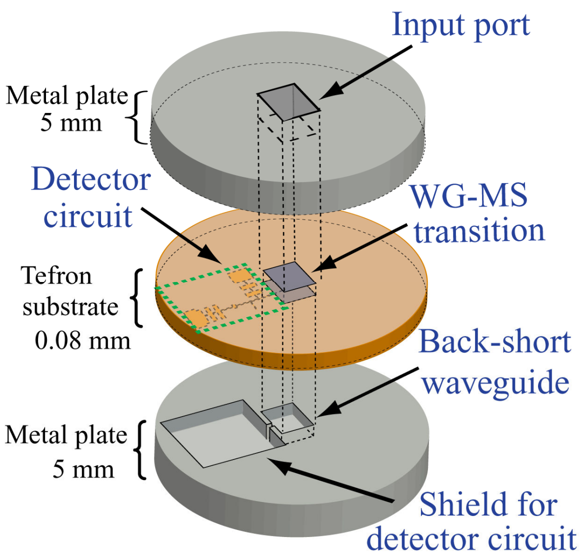

Figure 1: Configuration of waveguide-input detector module.

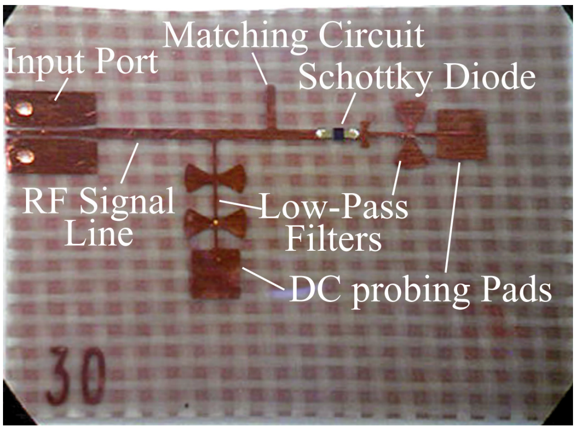

Figure 2: Photograph of detector circuit.

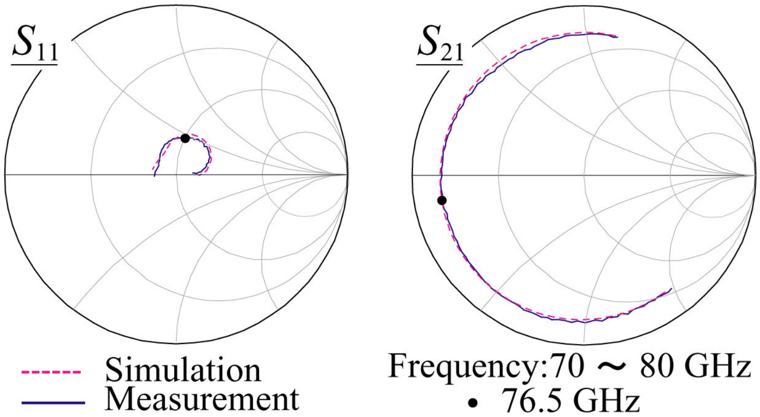

Figure 3: Measured and simulated *S*-parameters of diode.

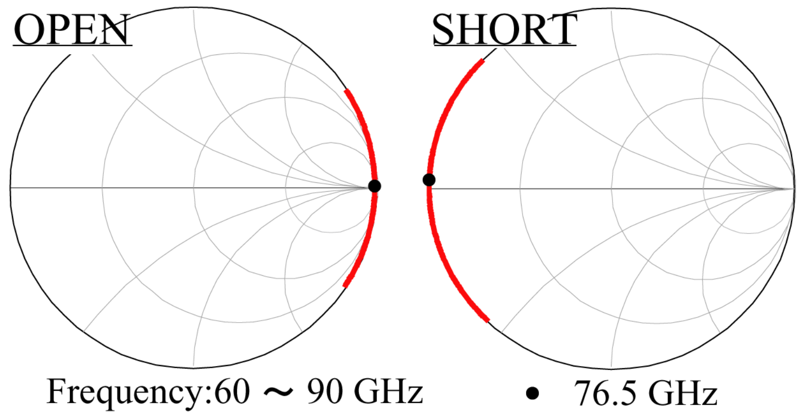

Figure 4: Simulated S_{11} of LPFs.

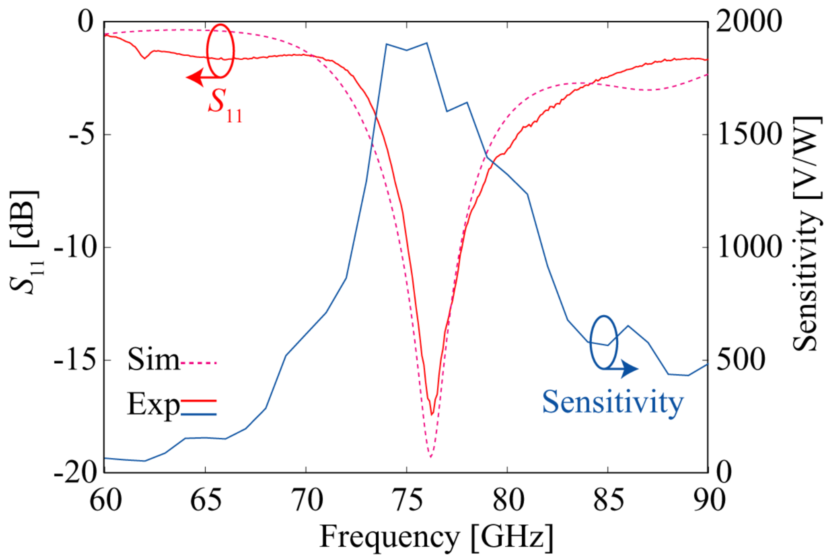

Figure 5: Measured sensitivity and reflection of the detector circuit.

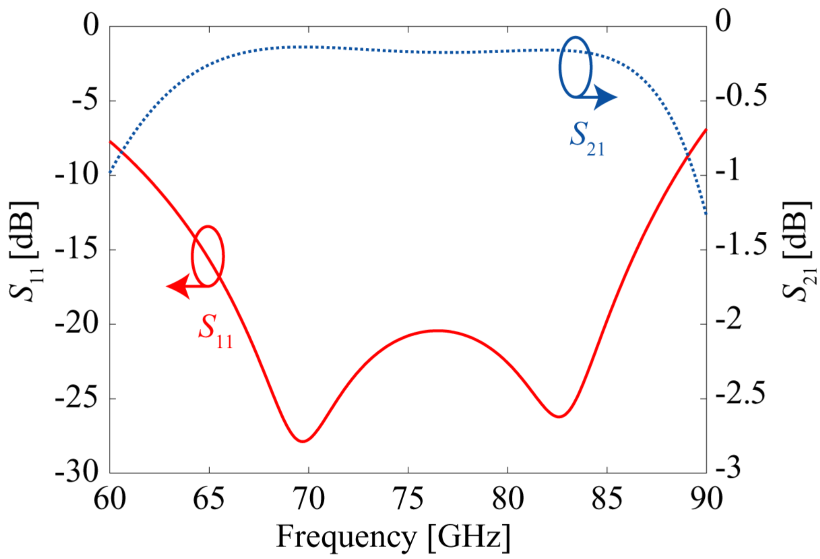

Figure 6: Simulated S-parameters of the WG-MS transition.