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Tapered Slot Antennas with MMIC for 94 GHz Band Passive Millimeter-wave Imager

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1. Introduction

Passive millimeter-wave (PMMW) imaging systems are now spreading to various applications [1] such as security, intelligent transport systems (ITS), and military uses, giving a key advantage. In particular, 94 GHz band PMMW imaging systems have already been developed for detecting concealed weapons and for providing heightened visibility under low-visibility conditions during landing approach [2]-[4]. However, conventional systems are very large because they require large antennas in an arrayed configuration [4]. In order to realize commercially usable imaging array systems, miniaturizing antennas are essential.

The tapered slot antenna with its slot profile defined by the Fermi-Dirac function (Fermi antenna), is one of the practical candidates for PMMW imaging systems because of its compactness and its broadband characteristics. In addition, it has a circular radiation pattern, which means almost the same E-plane and H-plane radiation patterns. This circular radiation pattern is well suited to our lens-coupled PMMW imaging system. We have already developed 35 GHz band Fermi antenna [5], which provides a circular radiation pattern with low side lobe levels. We also have proposed a parabolic tapered slot antenna with a center-cut metal (PTSA) [6]. The advantage of this antenna is its compactness; antenna length of it is less than a wavelength.

In this paper, we demonstrate our developed Fermi antenna and PTSA for 94 GHz band PMMW imaging. When measuring the radiation patterns of these antennas, we used MMICs with a low noise amplifier (LNA) and a square-law detector (DET) on the antenna substrate to increase receiver sensitivity. The sensitivity of these MMICs is as high as 450,000 V/W with the noise figure of 3.5 dB.

2. Design of tapered slot antennas for circular radiation patterns

2.1 Fermi antenna

Fig.1 shows the structure of the Fermi antenna with the corrugation on both sides of the metal edge. As the parameters of the Fermi-Dirac function influence antenna characteristics, the beam widths of the antenna's E-plane and the H-plane are mainly controlled by the aperture width (*a* in Fig. 1) and the inflection point, position *c* [5]. Fig.2 shows simulated results for the 10 dB beam width at the frequency of the 94 GHz as a function of the inflection point (c/λ_0), where, λ_0 is the wavelength in vacuum at the center frequency. By choosing c/λ_0 of 1.2, almost the same 10 dB beam width of 48 degree can be obtained. We fabricated a Fermi antenna using these parameters.

Next, I'll explain the external interface of the Fermi antenna. Fig.1 also illustrates a coplanar-to-slot transition. Since the transmission lines used in MMIC circuits are designed using coplanar waveguides, a compact and low-loss transition is essential. The transition consists of a quarter - wavelength short stub. Although the circuitry is simple, the measured transmission losses is about

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0.5 dB at 90-100 GHz. Using this coplanar-to-slot balun, we developed the Fermi antenna with a coplanar waveguide interface.

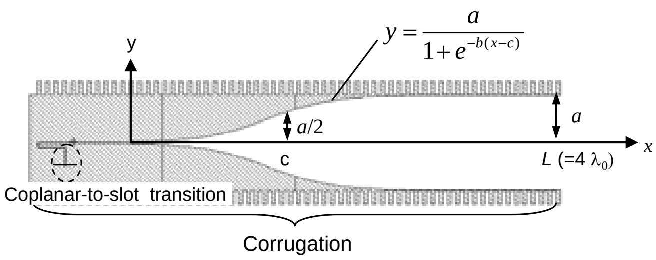


Fig.1 Geometry of the Fermi antenna.

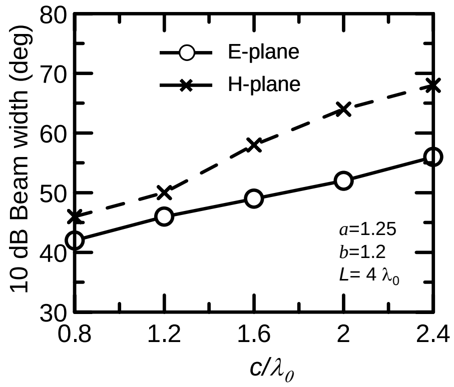


Fig.2 10dB beam width of Fermi antenna as a function of the position of inflection point c.

2.2 PTSA

Fig.3 is a structure of the PTSA. It consists of three functional parts: a tapered slot antenna with a parabolic shaped aperture, a center-cut metal (M1 in Fig.3) placed at a $\lambda_0/4$ distance from the parabolic shaped aperture, and a coplanar-to-slot transition, which is also used in the Fermi antenna. The radiation patterns of E-plane and H-plane of the PTSA are controlled by the substrate thickness and the space in M1. Fig. 4 shows a simulated result for 10 dB beam width as a function of the space in the M1 at the frequency of 94 GHz. In this simulation, we used a quartz substrate (ε_r=3.8) of 100 μm thickness. We chose 50 μm for the space to obtain almost the same beam patterns of 80 deg. in the E- and H-planes.

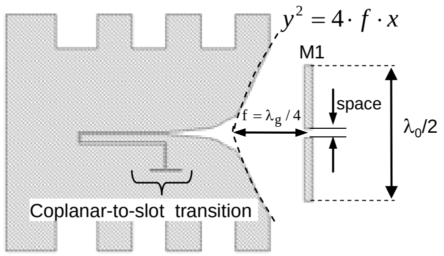


Fig.3 Geometry of the parabolic tapered slot antenna

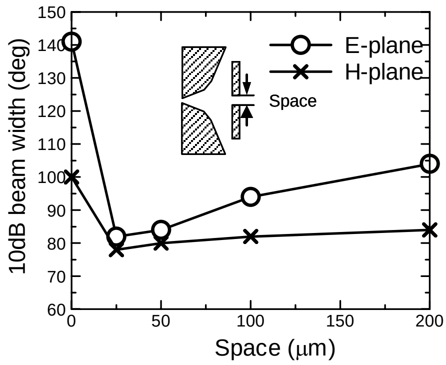


Fig.4 10dB beam width of PTSA as a function of space in M1.

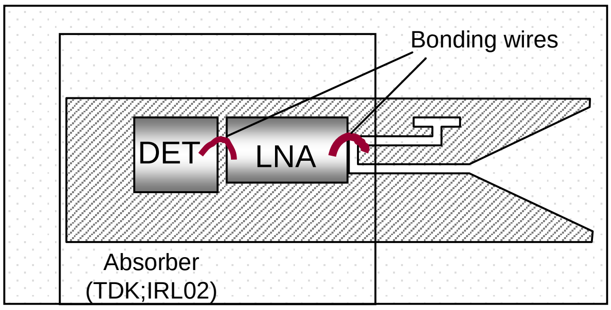
3. Radiation pattern measurement system and results of measurements

Because the transmitted power from the millimeter-wave (such as W-band) power source is low compared to that of the microwave region, the received power with an antenna is often buried in the noise level of a spectrum analyzer. Therefore, the sensitivity for the receiver must be improved to measure the radiation pattern accurately. We used MMICs to boost receiver sensitivity for detection of low level power of the millimeter-wave signal. The MMICs consist of an LNA and a DET. The LNA has the role of amplifying the received millimeter-wave power, and the DET converts the amplified millimeter-wave power into DC voltages. We have already presented a state-of-the-art, high-gain LNA [7]. The noise figure and the gain of the LNA are 3.5 dB and 33 dB respectively, and the sensitivity of the DET is 120 V/W. Bonding wires are used to connect the antenna with the LNA, and the LNA with the DET. The total sensitivity of the receiver is as high as 450,000 V/W.

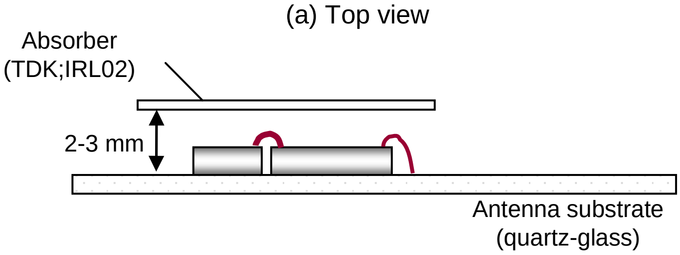
By using these MMICs, very low power around -70 dBm can be detected, so the radiation pattern can be measured even if the output power from the TX antenna is low. In addition, since the output signal is converted to DC voltage, the receiver system can be compact compared to conventional measuring systems using waveguide components.

Although this measuring system has a high sensitivity, it is possible for the DET to detect unwanted millimeter-wave power that is received by the LNA, or by the bonding wires or other parasitic elements. Since this LNA has a high gain in particular, such received power would disturb the radiation pattern. We therefore covered the MMIC with the absorption sheets (TDK; IRL02) about 2 to 3 mm apart from the MMICs as shown in Fig. 5. Using these assembled antennas, we measured the radiation patterns.

Fig.6 and Fig.7 shows the measured radiation patterns of the Fermi antenna and PTSA. We can see that very low level power can be detected, so this system is useful for measuring antenna radiation patterns in the millimeter-wave region. In addition, both results indicate that these antennas have circular radiation patterns.



(a) Top view



(b) Side view

Fig.5 PMMW imaging receiver.

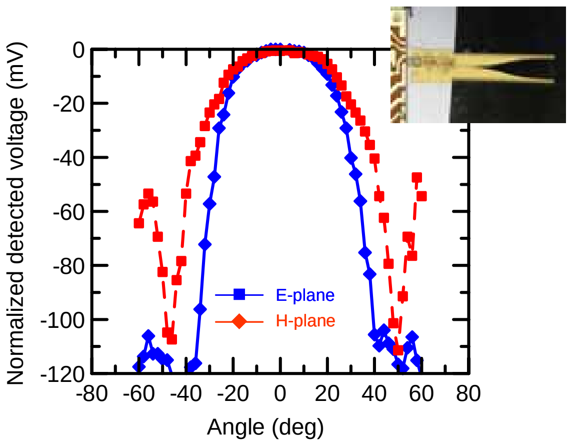


Fig.6 Measured radiation pattern of the Fermi antenna.

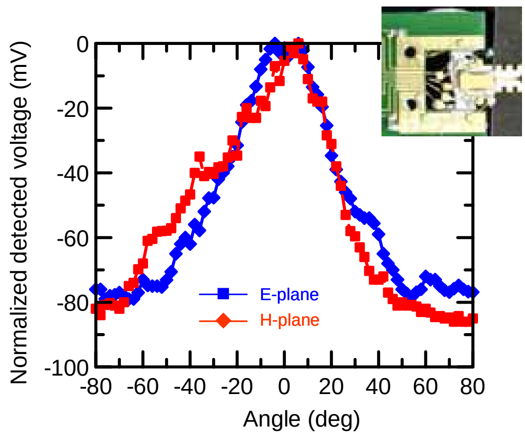


Fig.7 Measured radiation pattern of the PTSA.

4. Conclusion

We have designed and fabricated a Fermi antenna and PTSA for a 94 GHz band PMMW imaging system. To evaluate the radiation patterns of these antennas and increase the sensitivity of the receiver, we assembled an MMIC that is also used for the PMMW imager. In addition, we have shown how to avoid receiving the unwanted power from parasitic elements. Using this measuring system, we measured the radiation patterns of the Fermi antenna and the PTSA. The results of the measurements show that circular radiation patterns can successfully be obtained for these antennas.

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