A 60GHz Imaging Array Using CPW-Fed Twin-Slots on Multilayered Substrates

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ABSTRACT

We report optimal design and experiments of a novel 60GHz imaging array using CPW-fed twin-slots on multilayered dielectric substrates. This is an all-planar structure without having to use accompanying superhemispherical substrate lenses. It has nearly symmetric radiation patterns, low surface wave losses, as well as controllable beamwidths to match the f-number of the quasi-optic system. Optimal design of the antenna/detector circuitry has been realized using FDTD analysis results of the CPW-fed slot. A 6-element array has been fabricated and tested, with results revealing excellent capabilities of this newly proposed imaging array structure.

INTRODUCTION

Millimeter-wave focal plane imaging array has been a topic of intensive study in recent years, because of its unique capability to penetrate through fog, rain and clothes, as well as its high spatial resolution in comparison with microwave systems. Several recent reports have shown exciting results with such imaging arrays and their potential applications in automobile collision avoidance, all-weather landing systems, as well as airport security systems[1, 2, 3]. However, further efforts are required in order to realize the full capabilities of these imaging systems. Among all others, finding a proper antenna element is the greatest challenge, because in a fully developed two-dimensional imaging array, each antenna should be considerably smaller than one wavelength, yet retaining all the performances such as symmetric narrow beams, high efficiency and good compatibility with the detecting circuitry. The twin-slot antenna, initially proposed by Kerr *et al*[4], has proved to be one of the most promising candidates, and has been adopted in a number of quasi-optic applications. Among them, the

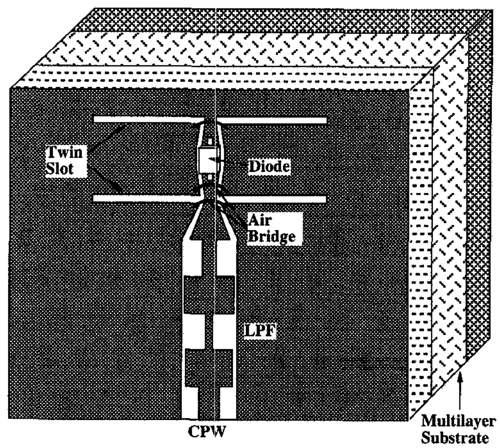

Figure 1: Proposed imaging array element based on CPW-fed twin-slot antennas on multilayered dielectric substrates.

CPW-fed double-slot structure in combination with a superhemispherical dielectric lens is a very successful design, which has resulted in similar performances in comparison with conventional waveguide systems at millimeter and submillimeter wavelengths[5, 6].

The motivation of this work is to realize a 60GHz imaging array based on twin-slot antennas, but without having to use hemispherical lenses, because for a two-dimensional imaging array such lenses would be undesirably large in dimensions. As an alternative, we employed the multilayered substrate approach as proposed by Rogers *et al*[7]. The new contributions include rigorous analysis of the CPW-fed slot antenna using the FDTD method, making it possible to realize optimal design of the antenna/detector circuitry. The 6-element array reported here, to the author's knowledge, is the first of its kind ever fabricated and tested at millimeter wavelengths.

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ANTENNA DESIGN AND TEST

Fig. 1 shows the proposed imaging element, which consists of a twin-slot antenna connected by CPW lines. A

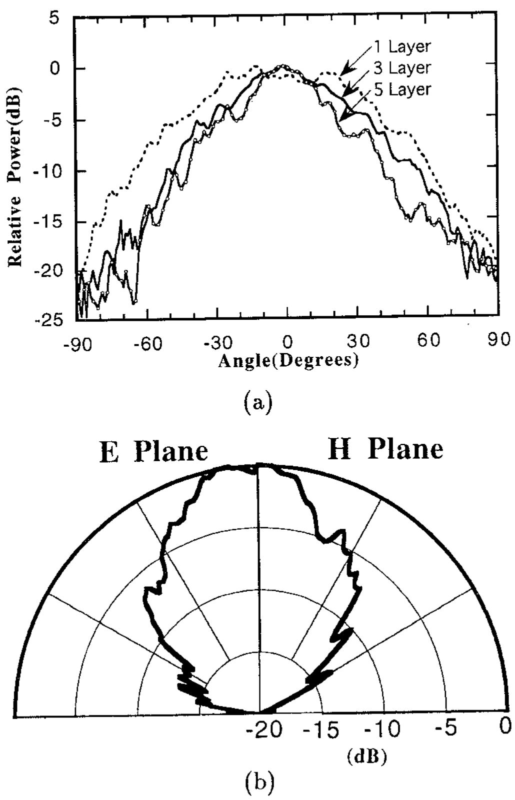

Figure 2: (a)Measured H-plane pattern for various number of layers and (b)E and H-plane pattern for a 5-layer structure.

Shottcky beam-lead diode is utilized to result in sum-mode video detection of the incoming RF signal. The detected video signal is extracted through a low-pass filter. This structure is similar to that in Ref. [5]. However, there are some differences in the design philosophy. Since the present twin-slot antenna is on top of multilayered structure, the radiation pattern is mostly determined by the substrates, rather than the dimensions of the twin-slot itself. The slot length is chosen so that the antenna works at second resonance to realize a broadband, low input impedance to match the detecting diode. Meanwhile, the thickness of the substrate has been chosen to be $\lambda_d/4$, so that only the TM_0 mode contributes significantly to surface waves. The separation between the two slots is thus chosen to be $\lambda_{TM_0}/2$ to suppress surface wave losses to the minimum. Fig. 2 shows the measured radiation patterns at 60GHz. The beam becomes narrower with increased substrate layers. For a 5-layer structure consisting of alternative Alumina(0.4mm) and Quartz(0.64mm) substrates, the E and H plane beamwidths are 40° and 30°, respectively, which

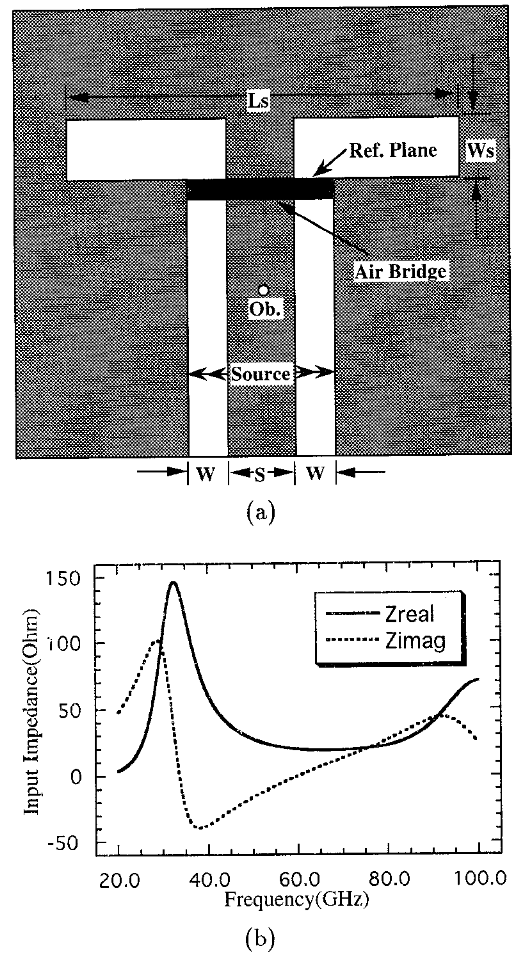

Figure 3: (a)FDTD analysis model of the CPW-fed slot and (b)Calculated results of the input impedance of a single slot.

matches favorably to an objective lens with f-number=1.5. The signal level in the direction of the substrate is below -20dB, revealing low surface wave losses and crosstalk into neighboring elements in an array environment.

For optimal design of the detector, it is important to know the input impedance of the slot antenna. For this purpose we use the FDTD method, with which we have obtained similar results for a CPW-fed slot antenna as by the method of moments[8]. Fig. 3(a) shows the FDTD model of the CPW-fed slot, where the bonding wire effect has also been included. Details of the FDTD analysis has been reported in a recent paper[9]. Fig. 3(b) shows the calculated input impedance for a single slot with L_s = 2mm and w_s = 60μm. The complex input impedance is found to be 19.5-j0.2Ω at 60GHz. The input impedances of the two slots are tranformed by the feeding CPW to the terminal of the Schottky diode(HP HSCH-9101), resulting in an estimated

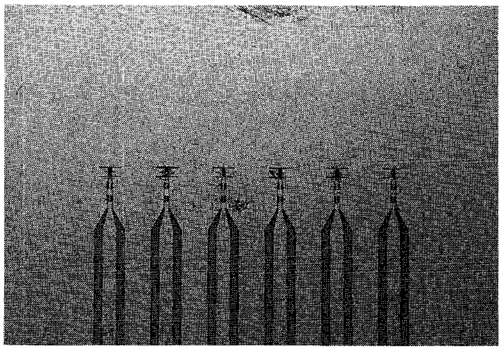

Figure 4: Photograph of the fabricated 6-element array.

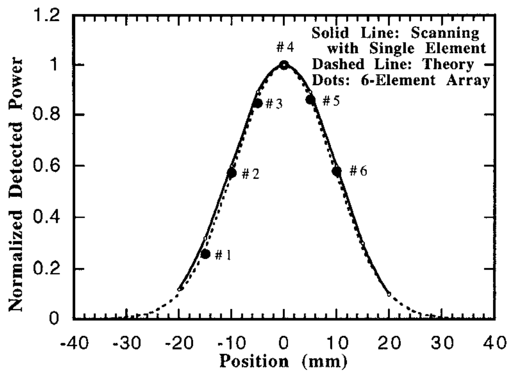

Figure 5: Video response of the 6-element array for the transformed Gaussian beam from a horn antenna.

impedance mismatch loss of 1.8dB. This mismatch loss can be reduced by optimizing the feeding CPW, or adding a proper impedance matching stub.

EXPERIMENT WITH SIX-ELEMENT IMAGING ARRAY

Fig. 4 shows the fabricated 6-element imaging array, each separated by one wavelength(5mm) at 60GHz. The twin-slot, CPW and low-pass filter are made by photolithography, the beam-lead diodes are soldered, and gold wires are bonded finally to make a complete array. To test the focusing capability of the quasi-optic system, as well as the response of the 6-element array, we first measured the focused image of a standard gain horn(Millitech SGH-15), whose radiation can been approximated by a Gaussian beam with a waist size w_{01}=11.7mm[10]. The horn antenna is located 90cm from the objective Teflon lens(D=30cm, $f\#$=1.5). The array is placed at the focal plane, and the six elements have shown almost identical scanned profiles for the transformed Gaussian beam except for some discrepancies in peak amplitudes due to the unequal responsitivities from diode to diode. After compensation of this deviation factor, we obtain the non-scanned response of the 6-element array as shown in Fig. 5, which is in good agreement with the scanned result using a single element, as well as that predicted by the Gaussian beam transform theory[10].

Imaging of several simple targets with the 6-element array has also been tried. The experiment system is shown in Fig. 6. In a first experiment, two rectangular acryl plates(7cm×3.5cm in size, 3cm in separation) has been resolved succeefully. Imaging of metallic targets is, however, more difficult because of the specular reflections associated with coherent illumination of the target. Fig. 7 shows the original target and imaging results for a triangular metal plate. With the present 6-element array, 72 scannings were required to obtained the total 432 pixels. Since only one horn antenna has been used in our experiment, the image obtained was found to depend strongly on the angle of illumination. Some "speckles" in the image are also noticed in the image because of the single-source illumination with a coherent source. However, the 60° angle in the target has been succeefully resolved, and we believe much improved image should be obtainable if a multiple source illumination approach is used[11].

CONCLUSION

In conclusion, a novel 60GHz focal plane imaging array has been developed and tested. The elementary antenna is small in size(less than $\lambda/2$), and matches well with both the quasi-optic system and the detecting circuitry. Furthermore, since it does not need accompanying hemispherical lenses, this novel all-planar imaging array making it possible to realize millimeter-wave imaging systems at greatly reduced cost.

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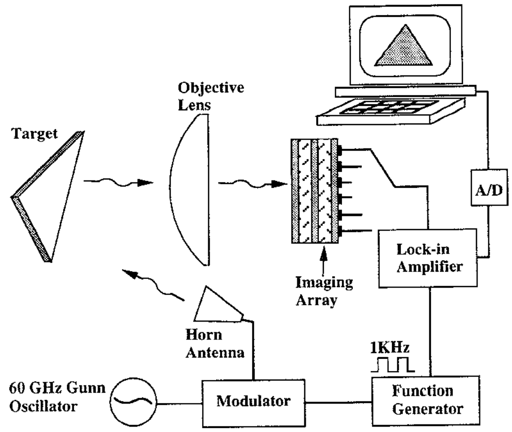
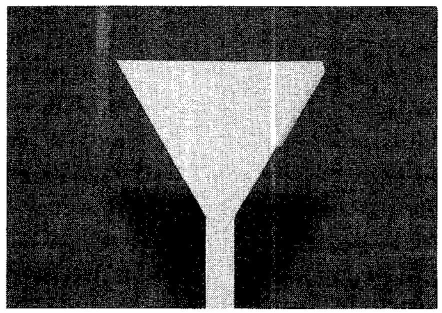
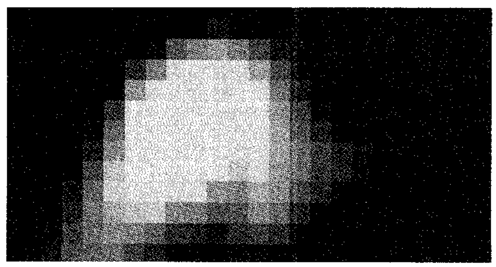


Figure 6: Experimental setup of the 60GHz imaging system.



(a)



(b)

Figure 7: Imaging results of a triangular metal plate. (a)Photograph of the target and (b)Image of the target obtained with half-wavelength(2.5mm) scannings.