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Millimeter-Wave Imaging Using Preamplified Diode Detector

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***Abstract*— A 2-pixel imaging array was developed to demonstrate millimeter-wave imaging. Each pixel consists of a Q-band Vivaldi antenna and a preamplified diode detector, using InGaAs pseudomorphic HEMT MMIC low noise amplifiers (LNA) and beam-lead Schottky-diode detector. The approach does not require local oscillator (LO) power, is compatible with MMIC technology, and can reduce the complexity and manufacturing cost of millimeter-wave imaging arrays. The preamplified diode detector exhibited 17 V/uW responsivity at 44 GHz and −75 dBm tangential sensitivity at 1-MHz video bandwidth. The array demonstrated millimeter-wave imaging of three vehicles in a parking lot.**

I. Introduction

PASSIVE millimeter-wave focal-plane arrays containing up to 64 pixels have been successfully developed for imaging thermal radiations from objects in space and on the earth [1], [2]. These arrays utilized RF mixers and IF amplifiers. They are sensitive frequency selective, and capable of high-speed imaging. However, the approach requires LO power and signal distribution, which are either expensive, bulky, or difficult to manufacture due to the small cellular packaging requirement of the array. The video Schottky-diode detector offers many advantages including wide bandwidth, operational simplicity, and MMIC compatibility [3], [4]. The approach does not require LO power, and can reduce the array complexity and manufacturing cost. However, the detector sensitivity is low. The typical tangential sensitivity is about −50 dBm at 1-MHz video bandwidth. Higher sensitivity can be obtained by incorporating a low noise preamplifier in front of the detector. The InGaAs pseudomorphic HEMT MMIC LNA technology is developing rapidly and can be low cost for high-volume applications. High performance MMIC LNA's have been successfully developed up to W-band. Wang *et al.* [5] demonstrated a MMIC LNA with 3.5-dB noise figure and 21-dB gain at 94 GHz. Ton *et al.* [4] developed a W-band LNA with 6-dB noise figure and 50-dB gain. The increase in receiver sensitivity enables the array to image faster and farther. Potential applications include navigation, mapping, and surveillance. Weinreb [7] explored the approach of using preamplifier and diode detector for millimeter-wave focal-plane imaging arrays. This letter reports a 2-pixel imaging array using MMIC LNA's and beam-lead Schottky-diode detectors. The array was demonstrated at Q-band frequencies, since the components were available.

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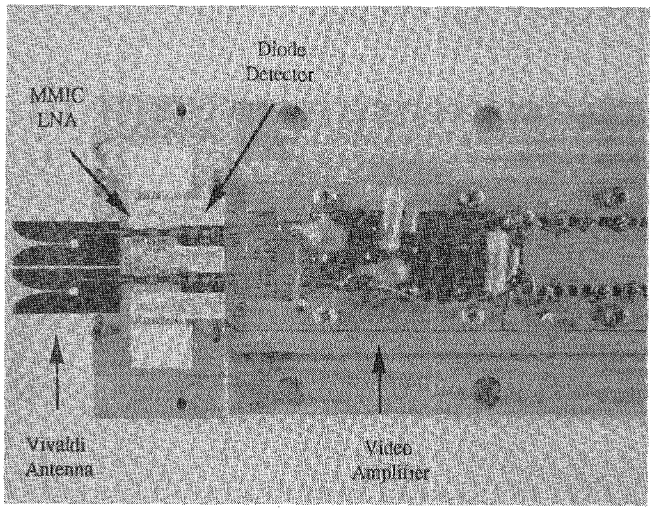


Fig. 1. 2-pixel imaging array using Q-band preamplified diode detector.

II. Design

Fig. 1 shows the 2-pixel imaging array. The array spacing is 320 mils, which is 1.2-freespace wavelengths at 44 GHz. Each pixel consists of a Vivaldi antenna, a video amplifier, and a preamplified diode detector, using two InGaAs pseudomorphic HEMT MMIC LNA's and a beam-lead Schottky-diode detector. The antenna receives the incident radiation, the LNA amplifies the received signal, and the diode detects the received power. The video amplifier enhances the output signal strength of the diode to a level suitable for electronic signal processing. The preamplified diode detector was developed on a subcarrier test-fixture and subsequently transferred onto a supercarrier test-fixture, which included the Vivaldi antenna and video amplifier.

III. Result

Fig. 2 shows the measured input–output transfer characteristic of the preamplified diode detector. The measured responsivity of the preamplified diode detector was 17 V/uW at 44 GHz and the tangential sensitivity was −75 dBm at 1-MHz video bandwidth. The preamplifier required 2 V and 60 mA of drain bias, and the measured gain was better than 30 dB from 42 to 47 GHz. The diode detector employed a beam-lead Schottky diode and required −3 V and 30 uA of dc bias. The measured responsivity of the diode detector was 25 V/mW at 44 GHz and the tangential sensitivity was −50 dBm at 1-MHz video bandwidth.

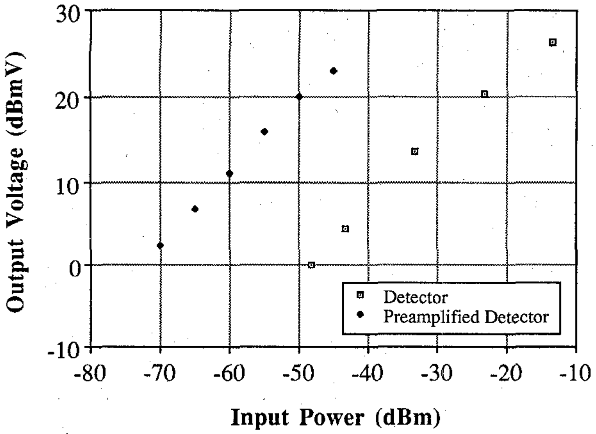
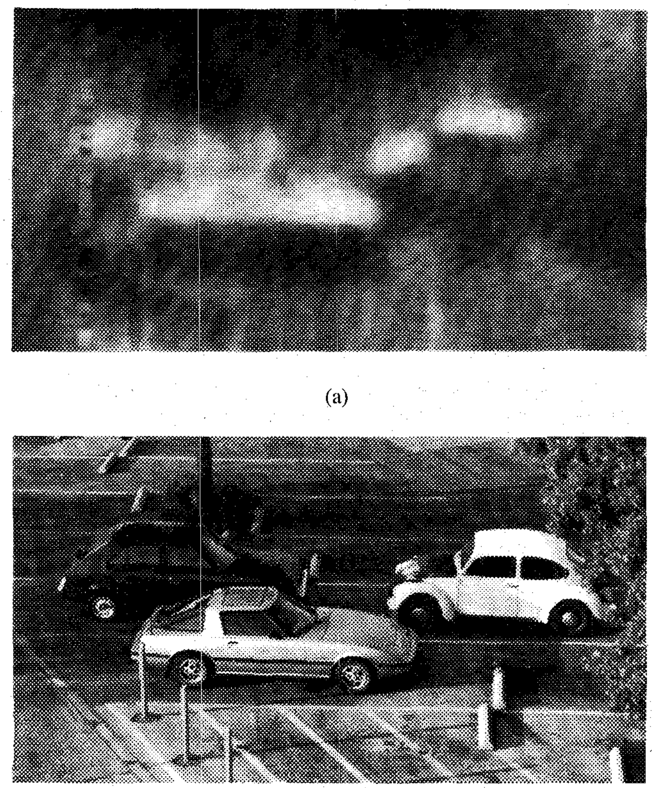


Fig. 2. Measured responsivity of the diode detector and the preamplified diode detector at 44 GHz.

The Vivaldi antenna utilized an exponentially tapered slotline and was fabricated on a quartz substrate. The measured return loss was better than 10 dB from 40 to 50 GHz. The 3-dB beamwidth in the E-plane is about 60 degree at 44 GHz. The video amplifier employed an operational amplifier and resistor-capacitor elements, and was integrated on a printed circuit board. The measured voltage gain was 10 and the 3-dB corner frequency was 1.4 kHz.

The completed pixel was evaluated with hot and cold loads (absorbers at room and liquid-nitrogen temperatures). The measured voltage (output voltage difference between the hot and cold loads) was 48 mV, which translated into a pixel responsivity of 0.23 mV/K. The measured root-mean-square voltage was 2.2 mV, which translated into a root-mean-square temperature of 10 K.

The imaging array was placed at the focal plane of a 2-foot diameter, f/1.1 Rexolite lens. The imaging system was then mechanically scanned under computer control to image a scene, which included 3 vehicles in a parking lot at TRW. The range to the vehicles was about 80 feet. Fig. 3(a) shows the resultant image, enclosing a field of view of 25 degrees in azimuth and 13 degrees in elevation and containing 252 horizontal and 261 vertical pixels. The lighter color represents the colder region, while the darker color represents the hotter region. Fig. 4(b) shows a photograph of the same scene to aid object identification.



(a)

(b)

Fig. 3. Q-band radiometric image (a) of 3 vehicles in a parking lot at TRW. Image consists of 252 horizontal and 261 vertical pixels using lighter colors for colder and darker colors for hotter regions. Momentary signal disruption during image acquisition generated the vertical striped pattern on the left side of the image. (b) Photograph of the same scene was also taken to aid object identification.

IV. Conclusion

A 2-pixel imaging array was developed using InGaAs HEMT MMIC LNA's and beam-lead Schottky-diode detectors. The LNA's provided a significant improvement in receiver sensitivity and enabled the array to demonstrate passive millimeter-wave imaging. The InGaAs pseudomorphic HEMT MMIC LNA technology is developing rapidly [5], [6], and higher receiver sensitivity and imaging quality can soon be obtained up to 94 GHz.

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