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W-Band MMIC Direct Detection Receiver For Passive Imaging System

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ABSTRACT

We have demonstrated for the first time W-band MMIC direct detection receivers for passive millimeter-wave imaging applications. These receivers were developed using InGaAs HEMT based W-band LNA and preamplified detector MMICs. The first receiver uses a 50 dB gain, 6 dB noise figure amplifier and a Schottky barrier diode waveguide detector. The amplifier uses four W-band MMIC LNAs. The second receiver consists of two 3-stage MMIC LNAs and a MMIC preamplified /detector chip. Individual receiver was integrated with a millimeter-wave camera system. Field imaging acquisition runs were performed using the camera in stepping pushbroom image acquisition mode with excellent results.

I. INTRODUCTION

Passive millimeter-wave radiometer imaging systems, utilizing the propagation windows of 35, 94, 140 and 220 GHz, have been developed for imaging thermal radiation from objects in space and on earth [1]. Up to now, these imaging systems employed heterodyne receivers made of RF mixers and IF amplifiers. These systems suffer high system temperature and require complex LO signal distribution network. They are bulky and difficult to manufacture. An alternative imaging system is to employ a direct detection receiver architecture which requires a high gain low noise amplifier and a detector circuit. The advantages of this approach are, 1) low system temperature, 2) requires no LO, 3) low dc power consumption, 4) fewer parts, 5) high yield and low cost. These become even more pronounced in focal plan staring array systems.

However, until recently despite of its many advantages, the direct detection receiver approach was less popular than its heterodyne counterpart due to the lacking of enabling circuit components, specifically the high gain, low noise amplifier at millimeter-wave frequencies. In 1991, a two-stage W-band MMIC LNA was first reported [2], then in 1992, a 49 dB gain, 6 dB noise figure amplifier using four MMIC LNAs was reported [3]. In this paper, we report for the first time the design of two W-band direct detection receivers. The first receiver uses the 48 dB gain amplifier and a Schottky barrier diode waveguide detector. The second unit uses two 17 dB gain MMIC LNAs and a MMIC preamplified detector [4]. By integrating these receivers with TRW's passive millimeter-wave camera system, outdoor imaging acquisition runs were performed using stepping pushbroom image acquisition mode with outstanding results.

II. MMIC LNA/Waveguide Detector Direct Detection Receiver

The first W-band direct detection receiver is based on a high gain, low noise amplifier and a Schottky barrier diode waveguide detector. The amplifier [2] uses four 2-stage MMIC LNAs [3]. This MMIC LNA was fabricated using pseudomorphic InGaAs HEMTs with a 0.1 μm gate length. It has achieved a gain of 13 dB and noise figure of 5.5 dB at 94 GHz. Besides the four MMIC LNAs, the complete amplifier contains four interconnecting substrates and two waveguide-to-microstrip transitions. Figure 1 shows a photograph of the complete amplifier. Amplifier gain and noise figure performances are shown in Figure 2. It has achieved a gain of 40-49 dB and noise figure of 5.5 - 6.0 dB from 90 - 95 GHz. The total dc power consumption is 560 mW. The overall amplifier measured 1.068"x0.281"x0.72".

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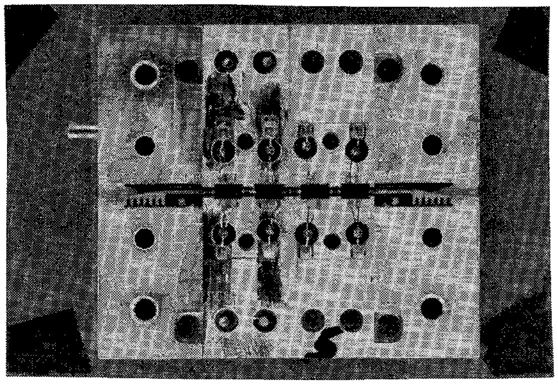

Figure 1 Photograph of a W-band 8-stage amplifier with waveguide-to-microstrip transitions

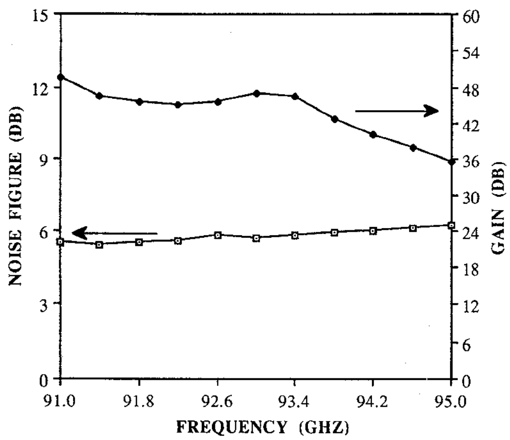

Figure 2 W-band 8-stage amplifier gain and noise figure performances

The detector used here is a commercial W-band zero-biased Schottky barrier diode detector with a Tss of -43 dBm. This detector is connected directly to the high gain amplifier to form a direct detection receiver system. Figures 3 and 4 show the measured output voltage and the responsivity (voltage sensitivity) of this receiver system. The optimum responsivity is about 540 V/μW which occurs at an input power around -60 dBm.

III. MMIC Preamplified Diode Detector

We have developed a W-band MMIC preamplified diode detector [4] to replace the bulky waveguide detector. The design uses the same 0.1 μm InGaAs HEMT device technology used in the MMIC design. The circuit consists of a 2-stage W-band LNA in front of a W-band Schottky barrier detector. Figure 5 shows the photograph of the MMIC preamplified diode detector circuit. The size of the chip is 3.2 mm x 1.2 mm. The LNA is a 2-stage single-ended design. Each stage uses a 40 μm HEMT with four gate fingers. The detector employed a two finger 16 μm Schottky barrier diode. The diode is constructed by connecting the source and drain metal of a HEMT device as the cathod of the diode and the gate is used as the anode so that the diode process is totally compatible with the HEMT process. The measured responsivity of this preamplified detector is 300 V/mW at 94 GHz and a Tss of -62 dBm.

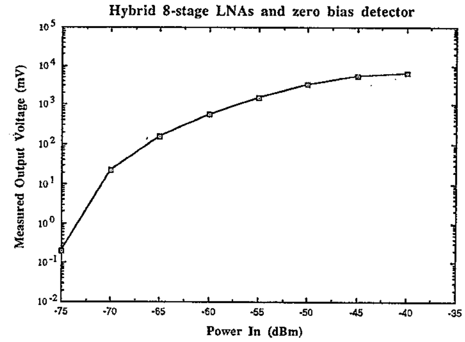

Figure 3 Measured output voltage vs. input power performance of the MMIC LNA/ waveguide detector receiver

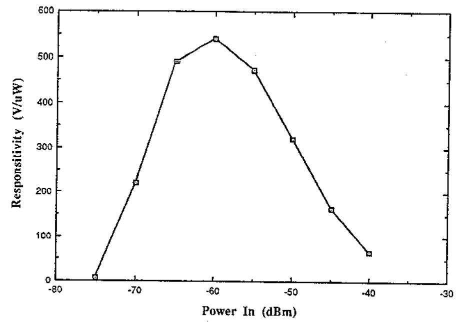

Figure 4 Measured MMIC LNA/ waveguide detector receiver responsivity

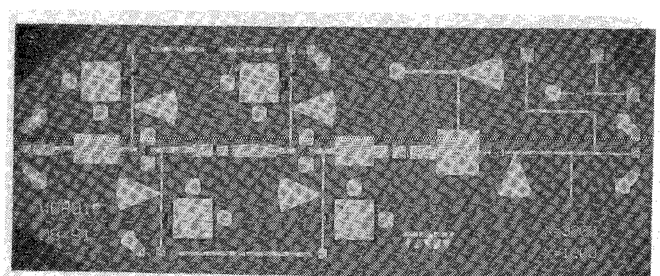

Figure 5 Photograph of the preamplified diode detector

IV. MMIC LNA/MMIC Detector Direct Detection Receiver

We have developed a second W-band direct detection receiver using all MMIC components. The MMIC LNA used here is a 3-stage single-ended design. This MMIC LNA was fabricated using pseudomorphic InGaAs HEMTs with a 0.1 μm gate length. Figure 6 shows a photograph of the chip. The size of the chip is 3.5 mm x 1.5 mm. This LNA has achieved a gain of 17-19 dB and a noise figure of 5.0 - 5.5 dB from 90 - 95 GHz. The MMIC detector uses the preamplified detector discussed in the previous section.

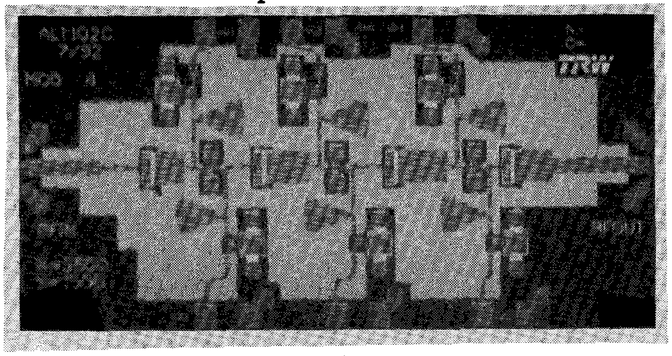

Figure 6 Photograph of the 3-stage MMIC LNA

This receiver employed two MMIC LNAs and one MMIC preamplified detector and, therefore, form a high gain 8-stage amplifier. To simplify the circuit operation, all drain and gate bias supplies to the HEMT devices are tied together. All receiver components - including MMICs, interconnecting substrates, bypass capacitors and bias networks are mounted on a aluminum carrier with a size of 0.15"x0.57"x0.25". The total dc power consumption of this receiver is 160 mW.

Figures 7 and 8 show the measured output voltage and the responsivity of this receiver. The test was done at 94 GHz with an input power variation from -103 to -63 dBm. The best responsivity is about 2000 V/μW which occurs at an input power around -90 dBm.

V. Passive Millimeter-Wave Imaging System

The waveguide mounted W-band direct detection receiver subassembly was connected to the waveguide feed of a 2' diameter dish antenna. Mounted next to the antenna feed is a rotary solenoid which, on command, swings a piece of microwave absorber in front of the feed horn opening. This provides a blackbody at ambient temperatures which can be periodically measured by the radiometer during image acquisition. The signal from this target is used to correct the data for any dc

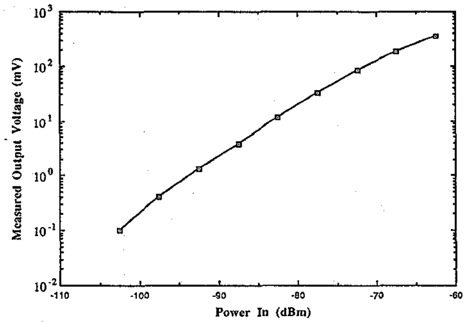

Figure 7 Measured output voltage vs. input power performance of the MMIC LNA/ MMIC detector receiver

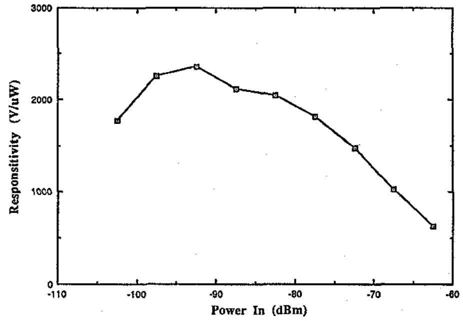

Figure 8 Measured MMIC LNA/ MMIC detector receiver responsivity

drifts that occur during the image acquisition run. The imaging radiometer is mounted on an azimuth-elevation (az-el) drive system. This mount allows computer controlled vertical and horizontal scanning of the 2' dish antenna. A Zenith AT is used as the image data acquisition system. It also activates the az-el drive system to position the antenna to selected position. The imaging acquisition cycle starts by commanding the antenna to swing up by a used defined angular increment. At the end of upward swing, the reference absorber is rotated in and out for temperature referencing. The computer then commands the turnable to rotate to the next azimuth value.

Several successful imaging acquisition runs were conducted. Figure 9 shows a radiometric image of a parking lot scene using the first direct detection receiver. The average distance is 80 feet. The horizontal coverage is 15° and the vertical coverage is 13°. The receiver was set to preferentially receive horizontal polarized radiation. Figure 10 shows a photo of the same scene. Figure 11 shows a radiometric image of another parking lot scene using the second direct detection receiver. Vertical polarization is used in this case. Fine details of the car are clearly distinguishable. Figure 12 is the corresponding photo of the same scene.

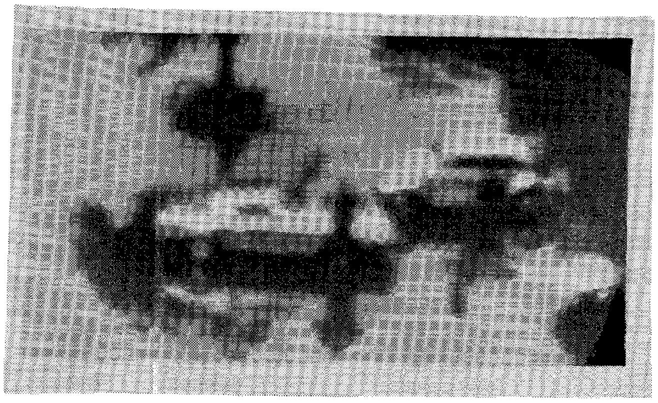

Figure 9 W-band radiometric image of a parking lot scene. The picture was taken using MMIC LNA/waveguide detector receiver

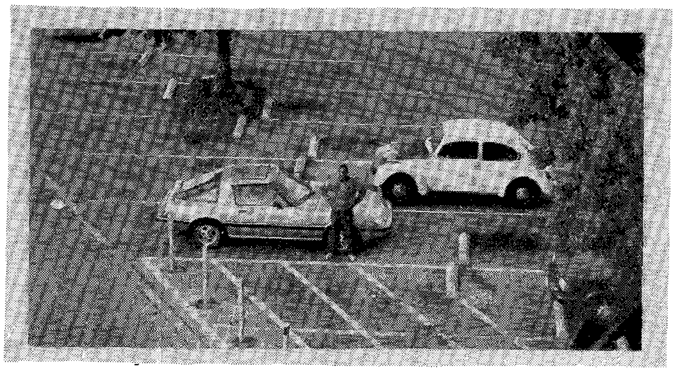

Figure 10 A photo of the same scene

Figure 11 W-band radiometric image of a parking lot scene. The picture was taken using MMIC LNA/ MMIC preamplified detector receiver

Figure 12 A photo of the same scene

VI. SUMMARY

We have made significant progress in the passive millimeter-wave imaging area. For the first time, W-band direct detection receivers were successfully demonstrated. MMIC LNA and preamplified detector using 0.1 μm InGaAs HEMT are the enabling circuit components. The receivers have exhibited excellent responsivity. Outdoor parking lot imaging acquisition runs using these receivers were conducted and have yielded excellent image quality.

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