A Monolithic W-band Preamplified Diode Detector*

H. Wang, W. Lam**, T. N. Ton, D. C. W. Lo, K. L. Tan,
G. S. Dow, B. Allen and J. Berenz

TRW
Electronic Technology Division
M5/1085, One Space Park, Redondo Beach, CA 90278
TEL: (310) 812-8377 FAX: (310) 813-9623

ABSTRACT

A monolithic W-band preamplified diode detector was developed based on 0.1 μm pseudomorphic AlGaAs/InGaAs/GaAs HEMT technology. This chip consisted of a Schottky diode detector with a two-stage W-band low noise amplifier has a measured detector responsivity of 300 V/mW at 94 GHz and a tangential sensitivity of -62 dBm. This is the first reported monolithic preamplified diode detector at this frequency. A higher sensitivity preamplified detector which was built by cascade of two monolithic three-stage W-band LNA with the preamplified detector chip also shows a tangential sensitivity of -85 dBm. This monolithic chip is ideal for insertion into the W-band radiometer and passive imaging array systems.

INTRODUCTION

Passive millimeter wave (MMW) cameras have been developed at 94 GHz for imaging thermal radiation from objects in space and on the earth [1]-[2]. These cameras employed array antennas and heterodyne sensors constructed with RF mixers as well as IF amplifiers. They are highly sensitive and frequency selective, but require LO power and signal distributions, which are either expensive, bulky, or difficult to manufacture due to the small cellular packaging requirement. An alternate approach is the direct detection array camera using the video Schottky-diode detector [3]-[4], which has the advantages of wide bandwidth, operational simplicity, compatibility with MMIC process technology. The approach does not require LO power, and thus can reduce the array complexity and manufacturing cost. However, the Schottky-diode detector sensitivity is low. The typical tangential sensitivity is about -50 dBm at 1 MHz video bandwidth. Higher sensitivity can be obtained by incorporating low noise amplifier (LNA) in front of the detector. The increase in receiver sensitivity enhances the direct detection camera array resolution. This approach has been proposed by Weinreb [5] and successfully implemented by Lam *et al.* at 44 GHz [6].

Owing to the successful development of W-band monolithic high gain LNAs using the 0.1 μm pseudomorphic AlGaAs/InGaAs/GaAs HEMT technology [7]-[10], it is feasible to implement the same approach for the direct detection cameras at 94 GHz. In this paper, we will present a W-band monolithic preamplified detector constructed by a 2-stage W-band LNA in front of a 94 GHz Schottky-diode detector. More than one order-of-magnitude improvement is demonstrated. The tangential sensitivity is increased from -45 dBm for a single detector to -62 dBm at 94 GHz. The preamplified detector chip can be easily combined with more monolithic LNAs to obtain additional 2 to 3 order-of-magnitude improvement. A such unit has been built by cascade of two monolithic three-stage W-band LNAs. It demonstrates a tangential sensitivity of -85 dBm and enables passive MMW radiometry and imaging W-band. To our knowledge, this is the first reported monolithic preamplified diode detector at this frequency range.

OF1

DEVICE CHARACTERISTICS AND MODELING

The HEMT devices used in the LNA have been optimized for high gain operation at W-band. The 22% PM AlGaAs/InGaAs/GaAs HEMT uses planar doping to achieve high channel aspect ratio as well as higher electron transfer efficiency. The MMIC fabrication process used

*This work is supported in part by MIMIC Phase 2 Program (Contract No. DAAL01-91-C-0156) from the Department of Army's Electronics Technology & Device Laboratory.

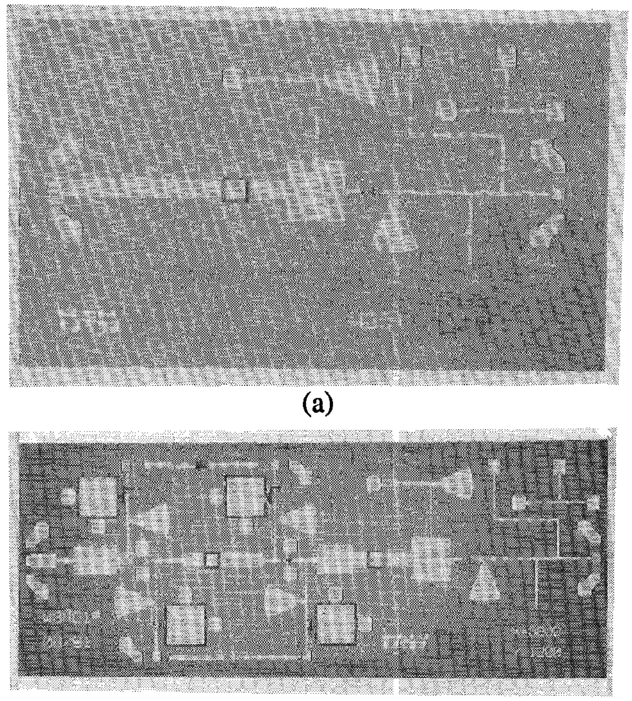
**W. Lam was formerly with Electronic Technology Division, TRW. He is now with Hughes Aircraft Company, Torrance, CA.

CH3277-1/93/0000-0365$01.00 © 1993 IEEE

for this work has been previously reported [11]. The 0.1 μm T-gate PM InGaAs HEMTs fabricated using this process typically have a transconductance of 670 mS/mm with a unit current gain f_T about 140 GHz.

The HEMT linear small signal equivalent circuit parameters are obtained from careful fit of the measured small signal S-parameters to 40 GHz. Noise model parameters used for simulation are obtained from fitting measured noise parameters to 26 GHz. These parameters are consistent with an estimation based on device physical dimensions and parameters. The details of this modeling procedure were documented in [7].

The Schottky diode is constructed by connecting the source and drain metal of a HEMT device as the cathode of the diode and the gate pad is used as the anode so that the diode process is 100% compatible with our W-band 0.1 μm PM AlGaAs/InGaAs/GaAs HEMT process. The series resistance, reverse leakage current and the ideality factor of the diode are calculated from the diode dc $I-V$ characteristics, while the junction capacitor and other parasitics are obtained from the measured S-parameters at various bias conditions. A cut-off frequency of 450 GHz for this diode is estimated from the model, and the diode modeling procedure can be found in [13].



(a)

(b)

Fig. 1. The photograph of the monolithic 94 GHz (a) Schottky diode detector, and (b) preamplified detector.

MONOLITHIC CIRCUIT DESIGN

Fig. 1(a) shows the photograph of the monolithic Schottky diode detector chip. The size of the chip is 2.0 × 1.2 mm^2. The detector employed a two finger 16 μm diode. The diode matching network is constructed by cascaded high-low impedance microstrip lines on 100 μm thick GaAs substrate. A quarter-wave high impedance line together with a radial stubs is used to lead the diode bias voltage. A low-pass-filter with a shunt microstrip line is placed at the diode output port for low frequency signal and dc return.

Fig. 1(b) shows the photograph of the monolithic preamplified detector chip. The chip size is 3.2 × 1.2 mm^2. It consists of a two-stage W-band LNA and the Schottky diode detector. The LNA is a two-stage single ended design. Each stage utilizes a 40 μm HEMT with four gate fingers. The input and interstage matching networks are designed for low noise figure and also realized by cascading high-low impedance microstrip lines. Metal-insulator-metal (MIM) capacitors are used for dc block and radial stubs are employed for RF bypass. N^+ bulk resistors and MIM capacitors are used to ensure bias network stability, and reactive ion etching (RIE) process is used to fabricate back side via holes for grounding. The overall circuit design is similar to the previously published W-band monolithic LNAs [7]-[9] except that the shunt resistors on the bias network were replaced by series RC network. This approach eliminates the dc power consumption in the bias network. Also, the gate and drain bias lines on the two stages were connected for ease of operation.

MEASUREMENT RESULTS

The Schottky-diode detector chip alone was tested first and then the complete monolithic preamplified detector chip was evaluated. The measured input-output transfer characteristics and frequency response of the Schottky-diode detector are shown in Fig. 2. The measured responsivity of a diode detector is 7.2 V/mW at 94 GHz and the tangential sensitivity is -45 dBm. Fig. 3 presents the results of a preamplified detector chip. The responsivity increased to 300 V/mW at 94 GHz and tangential sensitivity became -62 dBm owing to the two-stage preamplifier.

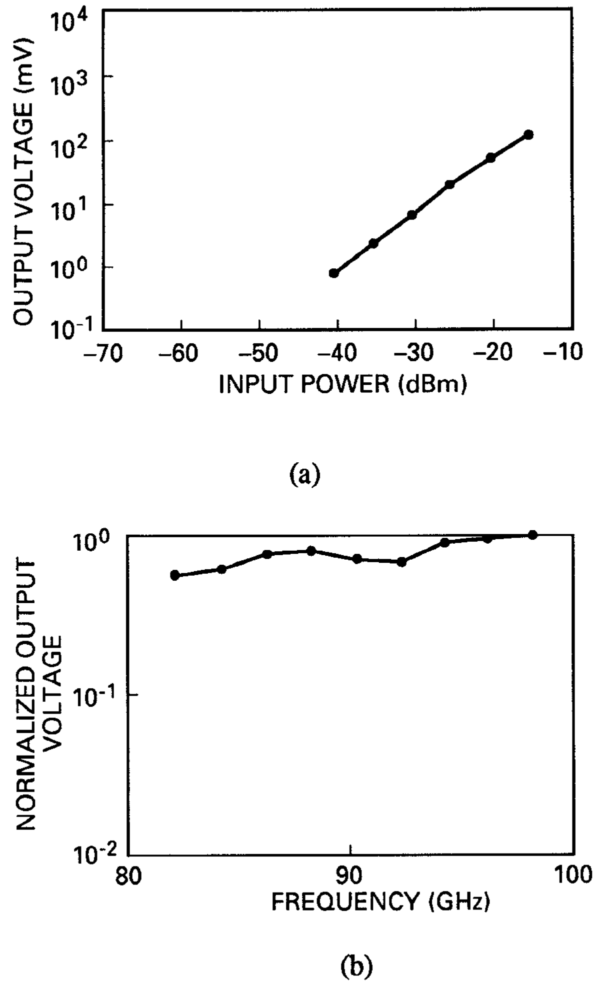


Fig. 2. Measured (a) responsivity, and (b) frequency response of the monolithic 94 GHz diode detector.

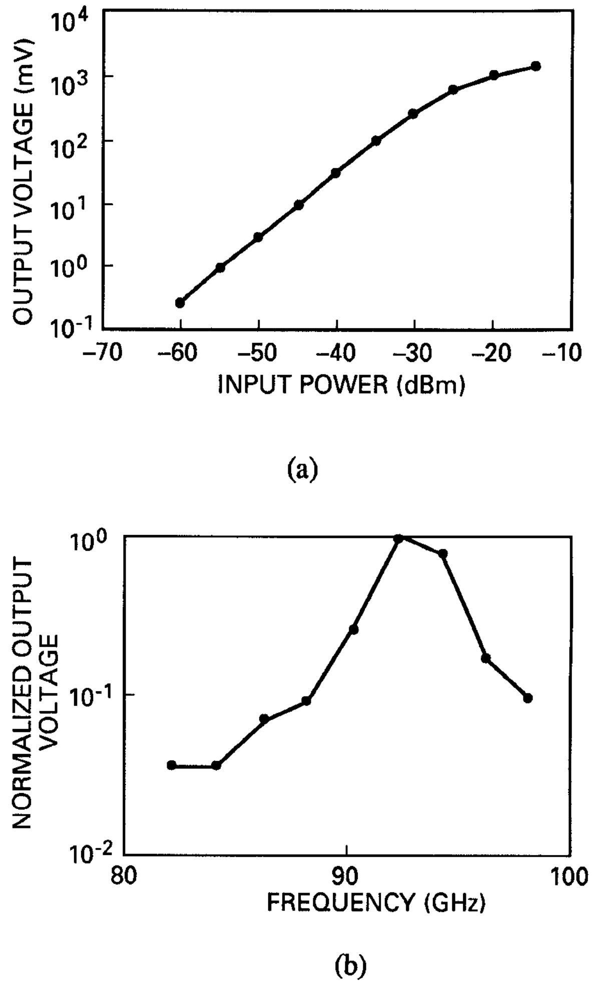


Fig. 3. Measured (a) responsivity, and (b) frequency response of the monolithic 94 GHz preamplified diode detector.

A higher sensitivity preamplified detector was built by cascade of two monolithic three-stage W-band LNAs with the preamplified detector chip. Edge coupled lines fabricated on a 5-mil thick quartz were placed between the monolithic chips for dc blocking. The block diagram of this unit is shown in Fig. 4(a). The three-stage LNA using the same design as reported in [9] but fabricated by passivated HEMT process and without re-optimization for better performance has a small signal gain about 13 dB. The transfer characteristics is plotted in Fig. 4(b). The measured tangential sensitivity is about -85 dBm, which is suitable for passive imaging application.

SUMMARY

We have presented a monolithic preamplified diode detector using on 0.1 μm pseudomorphic AlGaAs/InGaAs/GaAs HEMT technology. The measured detector responsivity was 300 V/mW at 94 GHz and tangential sensitivity was -62 dBm. This is the first reported monolithic preamplified diode detector at this frequency and ideal for passive imaging application. A higher sensitivity preamplified detector which was built by cascade of two monolithic three-stage W-band LNA with the preamplified detector chip also shows a tangential sensitivity of -85 dBm.

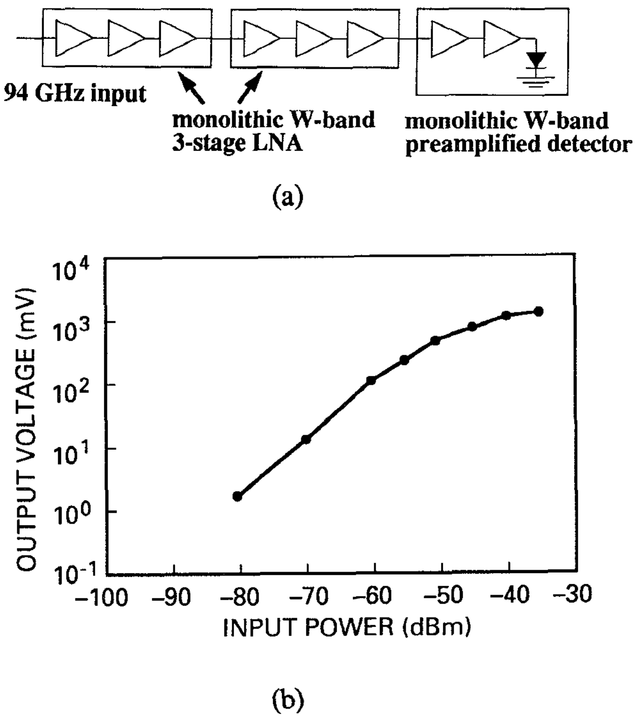


Fig. 4. (a) The block digram, and (b) the responsivity plot of the integrated high sensitivity preamplified detector unit.

ACKNOWLEDGMENT

The authors would like to thank Drs. T. H. Chen, K. W. Chang for their helpful technical discussions and suggestions, G. Coakley for his layout support, Dr. D. Streit for the MBE material growth, Dr. P. H. Liu for the EBL effort, R. Dia for wafer processing, the MBE and EBL groups in TRW for their excellent support, and E. Banachea for the testing support.

REFERENCES

[1] N. R Erickson et al., "A 15 element focal plane array for 100 GHz," *IEEE Trans. on Microwave Theory Tech,* vol. 40, no. 1, pp. 1-11, Jan, 1992.

[2] S. K. Young et al., "Passive millimeter-wave imaging," *TRW Quest Mag.,* vol. 13, no. 2, pp. 3-20, Winter, 1990/1991.

[3] S. Weinreb et al., "Monolithic integrated circuit imaging radiometers," *1991 IEEE MTT-S International Microwave Symposium Digest,* vol. 2, pp. 405-407, Boston, June, 1991.

[4] H. G. Henry et al., "A GaAs monolithic array of impedance matched antenna/detector pixels for a 94 GHz imaging system," *1989 IEEE International Electronic Device Meeting Digest,* pp. 181-184, Dec., 1989.

[5] C. E. Zah et al., "Progress in monolithic Schottky-diode imaging arrays," *9th Int. Conf. Infrared and Millimeter Waves,* Japan, 1984.

[6] W. Lam et al., "Millimeter-wave imaging using preamplified diode detector," *IEEE Microwave and Guided Wave Letters,* vol. 2, no. 7, pp. 276-277, July, 1992.

[7] H. Wang et al., "High performance W-band monolithic InGaAs pseudomorphic HEMT LNAs and design/analysis methodology," *IEEE Trans. on Microwave Theory and Tech.,* pp. 417-428, vol. MTT-40, No. 3, March, 1992.

[8] H. Wang et al., "State-of-the-art low noise performance of 94 GHz monolithic amplifiers using 0.1 μm InGaAs/GaAs pseudomorphic HEMT technology," *IEEE International Electronic Device Meeting Digest,* pp. 939-942, Washington D. C., Dec., 1991.

[9] H. Wang et al., "An ultra low noise monolithic three-stage amplifier using 0.1 μm InGaAs/GaAs pseudomorphic HEMT technology," *1992 IEEE MTT-S International Microwave Symposium Digest,* vol. 2, pp. 803-806, New Mexico, June, 1992.

[10] T. N. Ton et al., "A W-band high gain low noise amplifier using PHEMT MMIC," *IEEE Microwave and Guided Wave Letters,* vol. 2, no. 2, pp. 72-73, Feb., 1992.

[11] K. L. Tan et al, "94 GHz 0.1 μm T-gate low noise pseudomorphic InGaAs HEMTs," *IEEE Electronic Device Letters,* vol. 11, no. 12., pp. 585-587, Dec., 1990.

[12] J. C. Rautio and R. F. Harrington, "An electromagnetic time-harmonic analysis of shielded microstrip circuits," *IEEE Trans. Microwave Theory Tech.,* vol. MTT-35, no. 8, pp. 726-730, Aug., 1987.

[13] K. W. Chang et al., "A W-band monolithic downconverter," *IEEE Trans. on Microwave Theory and Tech.,* vol. MTT-39, no. 12, pp. 1972-1979, Dec., 1991.