A W-band Single-chip Transceiver for FMCW Radar

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ABSTRACT

This paper reports a W-band transceiver implemented on a single-chip MMIC. The MMIC chip contains a W-band VCO, transmit amplifiers, a receiver low noise amplifier and a mixer. It is used as the front-end of a homodyne FMCW radar for target range and range rate sensing applications. The 6.9 X 3.6 mm^2 monolithic chip was fabricated using 0.1 µm pseudomorphic InGaAs/AlGaAs/GaAs HEMT process technology. The transmitter output power is more than 10 dBm for frequencies between 90-94 GHz and maximum tuning bandwidth is 500 MHz for the VCO. The receiver channel has 6 dB conversion gain when the output transmitting power is 10 dBm. A complete radar system has been tested based on the single-chip MMIC front-end. The calculated range and range rate are in good agreement with the measurement data.

INTRODUCTION

The frequency modulation continuous wave (FMCW) radar provides a simple and lower cost means of determining the range and velocity of a moving target [1]. Single-chip monolithic FMCW radars using GaAs MESFETs and AlGaAs HBTs were developed at microwave frequencies [2,3] for sensor applications. Compared with the microwave (λ > 10 mm) and infrared (λ < 1 mm) regions, the millimeter wave frequency range has three advantageous characteristics that are very useful for radar system applications. These include less susceptibility to the weather condition, a relatively large RF bandwidth (better range resolution), and smaller circuit/hardware sizes. For frequencies below 100 GHz, 35 GHz and 94 GHz are the two main windows for millimeter wave transmission. Although the attenuation loss at 35 GHz is lower than that at 94 GHz, the later still has the advantage of smaller circuit/antenna sizes and better range resolution, which are important considerations for systems having size and weight limitations.

The key W-band monolithic circuit elements have been successfully developed over the past two years [4-8]. In this paper, we report the first W-band single-chip transceiver used as the front-end of a homodyne FMCW radar for target range and range rate sensing applications. The MMIC chip was fabricated using 0.1 µm T-gate pseudomorphic InGaAs power HEMT technology.

CIRCUIT DESIGN

A block diagram of the FMCW radar is shown in Figure 1.

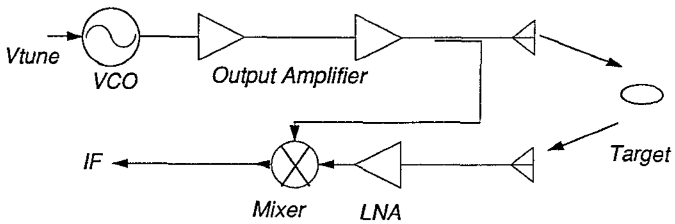

Figure 1. Block diagram of the FMCW radar.

The transmit and receiver channels use two different antennas for isolation purposes. A frequency modulated CW is generated from the VCO and fed to the transmit amplifiers. A portion of the transmit power was coupled back to the receiving channel and used as LO source for the mixer.

The VCO is a common gate design which uses gate bias voltage to adjust the oscillation frequency, and the output power is coupled out of drain terminal through the microstrip edge-coupled lines.

The transmit amplifier consists of two identical

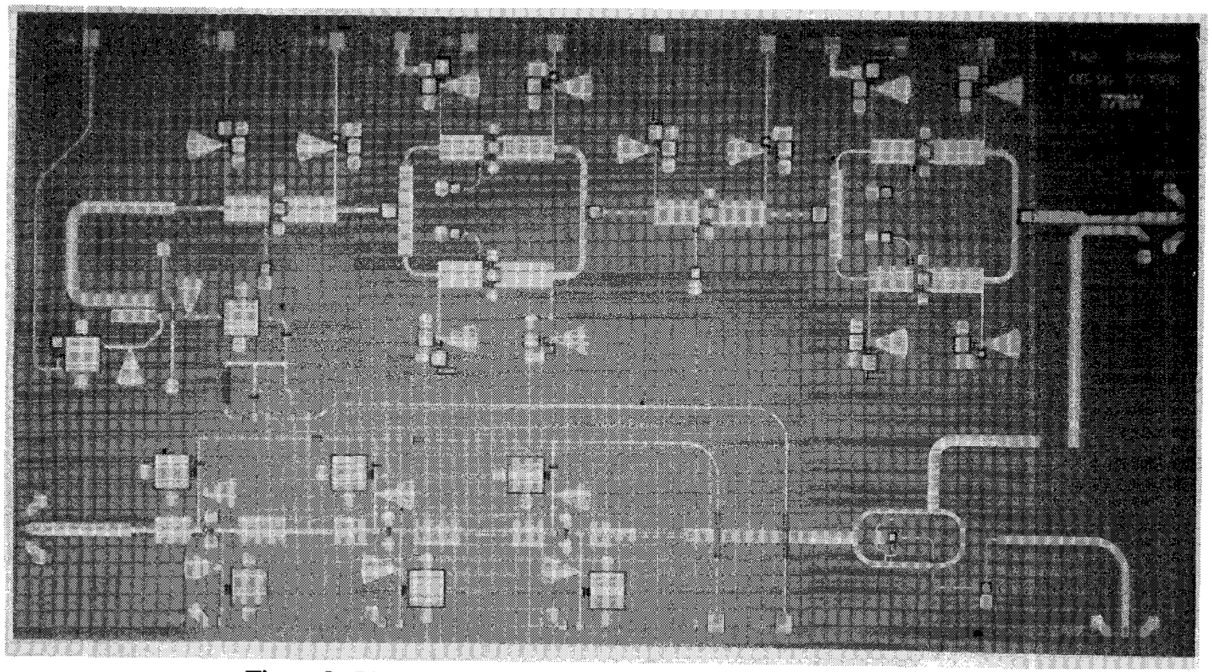

Figure 2. Photograph of the W-band FMCW radar MMIC chip.

two-stage amplifiers which are capable of delivering more than 10 mW power at 90-94 GHz. To ensure circuit stability at the out-of-band frequencies, a lossy series resonator was used at the gate of each HEMT device. The dc biases can be provided on both sides of the circuit for ease of system integration.

The receiver has a three-stage LNA at the front and is followed by a single-balanced diode mixer. The LNA was designed for low noise figure based on reactive matching technique while the mixer was designed using a 180^{o} rat-race hybrid and a pair of 16 µm diodes. In addition, the three gate biases for the LNA were connected together to simplify the test fixture design. The diodes were fabricated using the gate-to-channel junction of a HEMT device and thus are fully compatible with the fabrication process of the active devices. Furthermore, in order to minimize the mixer circuit size, the diodes were positioned inside the rat-race hybrid. Figure 2 is a photo of the transceiver chip.

DEVICE FABRICATION

The power HEMT device was fabricated on an MBE-grown wafer with an AlGaAs/InGaAs/GaAs heterostructure. Figure 3 illustrates the device structure. The InGaAs channel layer grown on top of the superlattice buffer is 150 Å thick. A 300 Å AlGaAs donor layer and a 400 Å of $6x10^{18}$ cm^{-2} GaAs contact layer are then followed in sequence. The device current handling capability is increased by inserting a silicon planar doping of $1x10^{12}$ cm^{-2} in the center of the InGaAs channel in addition to the AlGaAs donor layer doping of $5x10^{12}$ cm^{-2}. Hall measurement indicated an electron sheet charge density of $3.2x10^{12}$ cm^{-2} and a mobility of 3770 cm^2/V-sec at 300K. The maximum transconductance is around 778 mS/mm and the average cut-off frequency f_T was 120 GHz.

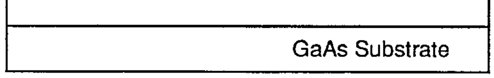

Figure 3. Cross section of 0.1 µm T-gate AlGaAs/InGaAs/GaAs power HEMT.

MEASURED PERFORMANCES

Figures 4(a)-(d) are the measurement results of each individual microcell. The VCO and LNA were

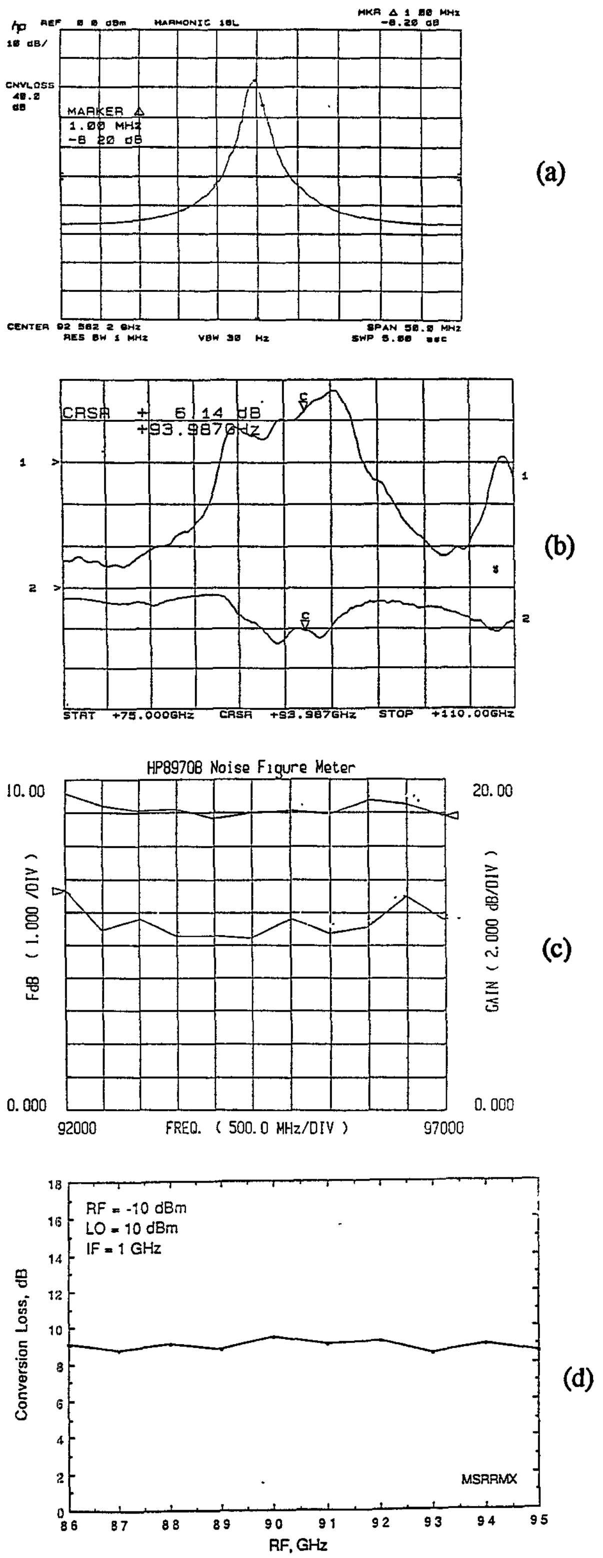

Figure 4. Measured data of (a) VCO output spectrum at zero gate bias, (b) frequency response of a transmitter amplifier, (c) gain and noise figure of LNA, and (d) SB mixer conversion loss.

biased at peak transconductance and V_{ds}=3V. The transmit amplifier was operating at the same gate bias and V_{ds}=4V. The VCO oscillated around 92.5 GHz at the zero gate bias and can be tuned over 500 MHz The transmit amplifier has 6 dB gain and more than 10 dBm output power around 94 GHz. At 94 GHz the three-stage LNA demonstrated 5.2 dB noise figure and associated gain of 18 dB. The conversion loss of the SB mixer is 9 dB for 86-95 GHz RF frequency with an LO power of 10 dBm at 94 GHz.

A complete radar system has been tested based on the W-band single-chip front end described above. The MMIC chip was integrated with two dc voltage regulators and a pair of transmit/receive lens antennas for detecting both stationary and moving targets. A PC-based signal processor was used to control the FMCW waveform and to do real time range and range rate measurements from the target return signal. Figure 5(a) shows a typical transmit output spectrum when the VCO was modulated with a sawtooth waveform. The FMCW radar was used to detect a corner reflector located at different ranges. Figure 5(b) shows the typical target return signal measured on a spectrum analyzer while Figure 5(c) indicates the real time FFT power spectrum of an approaching car (Pontiac Sunbird). The calculated range and speed of the car are 33 meters and 41 Km/hr, respectively. In both cases the computed range and range rate are in good agreement with measurement data.

SUMMARY

We have reported a W-band FMCW radar front-end implemented on a single-chip MMIC. The MMIC chip contains a W-band VCO, transmit amplifiers, a receiver low noise amplifier and mixer. A complete radar system has been tested based on the W-band single-chip front end. The computed range and range rate are in good agreement with measurement data.

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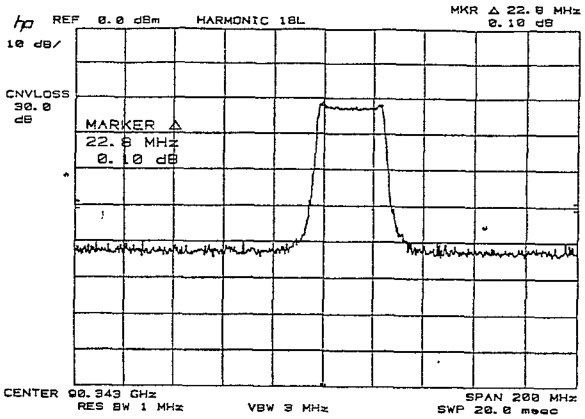
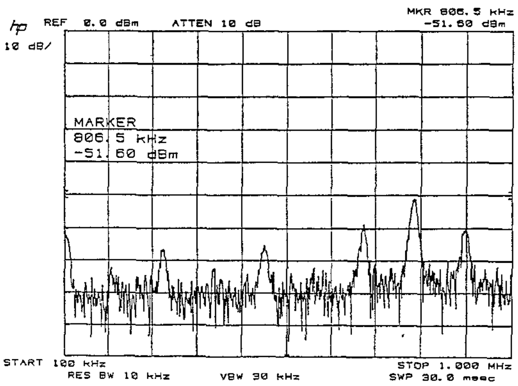


(a)



(b)

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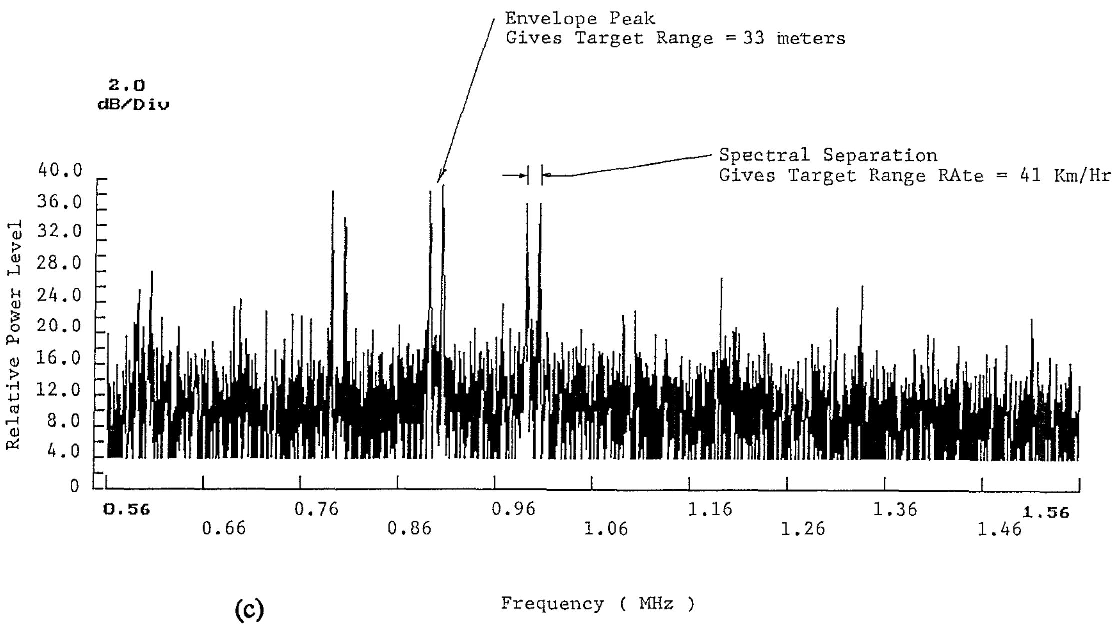

(c)

Figure 5. Measured power spectrum of (a) FMCW signal, (b) output spectrum of a corner reflector at 27 meters, and (c) FFT of a car approaching FMCW radar.