FM-CW RADAR ON A SINGLE GaAs/AlGaAs HBT MMIC CHIP

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ABSTRACT

A novel low power FM-CW radar on a single chip has been implemented for the first time using GaAs/AlGaAs HBT technology developed at TRW. An innovative electronic circulator allows operation with a single antenna at C band. In addition, the chip contains a VCO, transmitter amplifier, and receiver mixer with proper filtering. The chip measures 1 x 2 x 0.25 mm and operates from a single +5 Volt supply. In order to minimize cost we used a process featuring a relaxed 3 µm emitter size, achieving f_t of 24 GHz. We also did not use via holes. Potential applications for the chip include range and velocity discriminating fuzes, sensors and altimeter functions.

INTRODUCTION

In a previous paper [1] we described an FM-CW radar on a singe chip using GaAs MESFET technology. The HBT chip is almost identical in function, size, block diagram, bonding pads location and power supply requirements. Lower transmitter and receiver noise has been achieved due to superior low frequency HBT characteristics. The sensitivity improvement results in up to 10 times decrease in target cross section in some applications. The improvement has been achieved while maintaining all the other features of the MESFET chip described in [1]. A discussion on the principles of FM-CW radar operation may be found in [2] and [3]. FM-CW technique allows the extraction of the range and doppler information at relatively high IF frequencies. This is important considering that active devices available for monolithic integration are not always optimized for low noise operation at low frequencies.

CIRCUIT DESCRIPTION

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

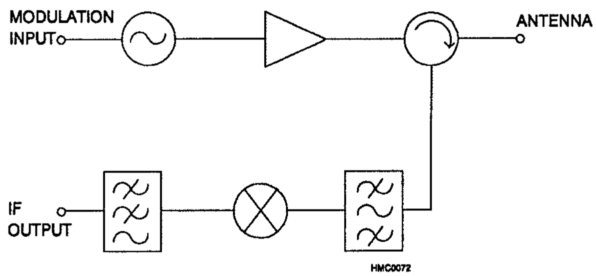

Figure 1. Block diagram of the FM-CW radar circuit.

As in the case of the MESFET chip [1], the transmitter chain starts with the VCO followed by a buffer amplifier. A novel electronic circulator, fabricated for the first time using HBT, follows the amplifier and on its output is the antenna. Signals returning from the target are channeled to the mixer where they mix with signal reflected from the antenna to produce the beat frequency IF signal. This signal is subsequently filtered to remove the high frequency components and is fed to a video frequency signal processor which extracts the target range and velocity.

HBT DEVICE AND TECHNOLOGY

The chips were fabricated in the MIMIC qualified TRW HBT line. The process is characterized by 3 µm emitter size with self aligned base metal and mesa isolation, f_t of 24 GHz and f_{max} of 35 GHz [4]. Figure 2 shows the schematic structure of an HBT device.

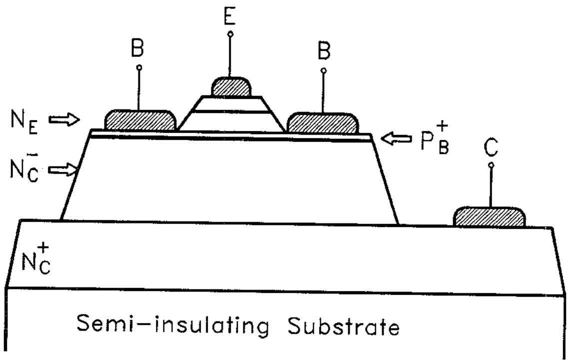

Figure 2. Schematic structure of an HBT device.

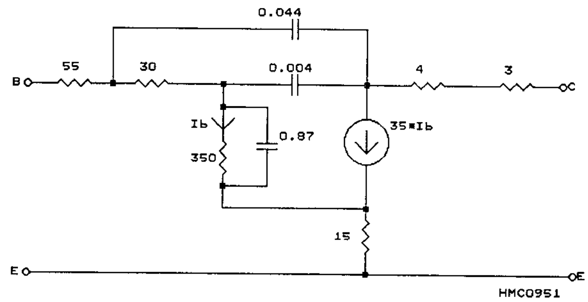

Figure 3. Small signal lumped element model of a 3 x 10 μm single emitter HBT.

At the time of fabrication, the process allowed two level metallization with dielectric bridges, and did not allow via holes to the back side of the wafer. Silicon nitride MIM capacitors and NiCr thin film resistors are also available with relatively tight tolerances (+/-10%). The 3-Inch wafers are thinned to 0.010 Inch.

Most of the active devices in such a circuit operate in their non-linear mode. Non-linear models therefore were important to the first time success of the program. We used the Gummel-Poon model [6] implemented in "Spice" and its commercial derivatives. In addition to available and measured dc data, the large signal models were derived from S-Parameter measurements of the devices under different bias conditions followed by fitting a small signal hybrid π model to the measured data. From this set of small signal equivalent circuits each at a different bias point we generated the element values for the Gummel-Poon model. Figure 3 describes the small signal hybrid π model of a device featuring a single 3 x 10 μm emitter. Table I delineates the element values for the Gummel-Poon model of the same device.

I_S=4.8E-22 (A)	N_C=2	M_{JE}=0.48
I_{SE}=2.4E-19 (A)	R_E=6Ω	M_{JC}=0.5
I_{SC}=5.9E-19 (A)	R_C=5Ω	X_{CJC}=0.5
N_F=1.13	R_B=25Ω	τ_F=6pS
N_R=1	C_{JE}=65fF	β_F=35
N_E=1.8	C_{JC}=16fF	β_R=0.2

Table I: Gummel-Poon model element values for a 3 x 10 μm Emitter HBT device.

A photomicrograph of the chip is shown in Figure 4. The chip measures 1 by 2 by 0.25 millimeter and includes 18 transistors, 33 resistors, 34 capacitors and 23 spiral inductors.

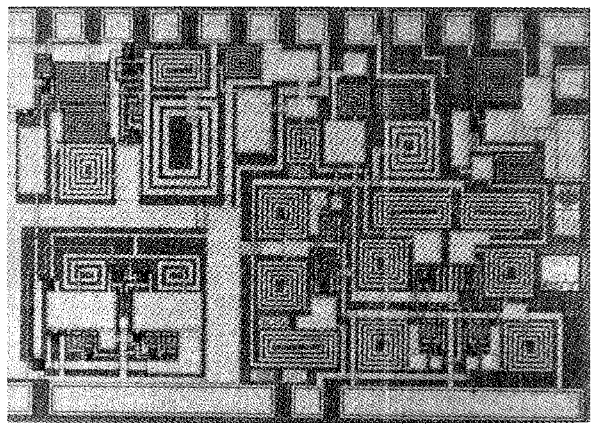

Figure 4. Photomicrograph of the HBT radar chip. Chip size is 1 x 2 x 0.25 mm.

MEASURED PERFORMANCE

GaAs/AlGaAs HBT's feature lower noise than GaAs MESFETS at low frequencies (below 1 MHz) because their 1/f corner frequency is much lower. Therefore, using the same design approach, an HBT oscillator will show less FM noise than a MESFET oscillator at frequencies that are close to the carrier. Electronic tuning was achieved by reverse biasing base-emitter junctions since they offered a greater capacitance ratio than schottky diodes in this process. The oscillator is designed using active feedback to couple the power from the collector of the oscillating transistor back to its input. The power is coupled out of the loop through the feedback device and a buffer amplifier, thus minimizing the loading. Figure 5 describes the frequency and output power of the radar chip.

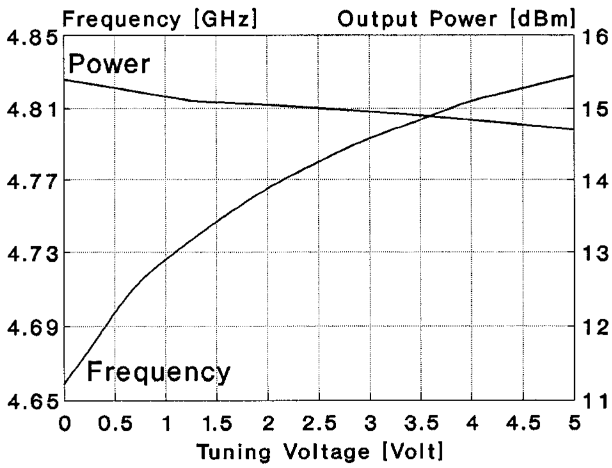

Figure 5. Frequency and output power of the radar chip as a function of tuning voltage.

The HBT circulator shares the design of our previous circulator, the concept and GaAs MESFET implementations of which are described in [5]. The HBT circulator features measured insertion gain of 1 dB, return loss of -13 dB and isolation better than 12 dB over 750 MHz at C-Band.

The mixer is based on a biased, single ended diode detector approach. Its features are minimum noise, voltage gain of 3 dB and insensitivity to LO power level. The voltage conversion gain of the receiver mixer as a function of the LO power is plotted in Figure 6.

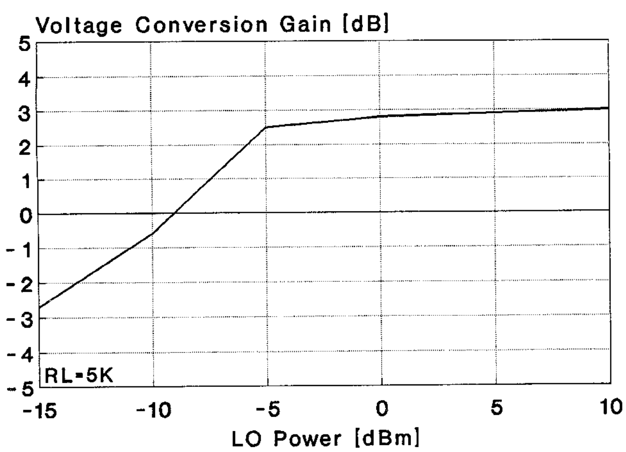

Figure 6. Voltage conversion gain of the radar chip as a function of LO power.

Improving sensitivity by reducing the output noise was the declared goal of this program. Indeed, the output noise of this chip is lower than the one measured at the output of the GaAs MESFET chip. Figure 7 shows the output noise in the range DC to 1 MHz. The noise level at 500 KHz is less than $40\text{nV}/\sqrt{Hz}$. In comparison, the noise measured at the output of the GaAs MESFET radar chip is about $300\text{nV}/\sqrt{Hz}$. Using HBT, the minimum target decreased by ten times for some applications.

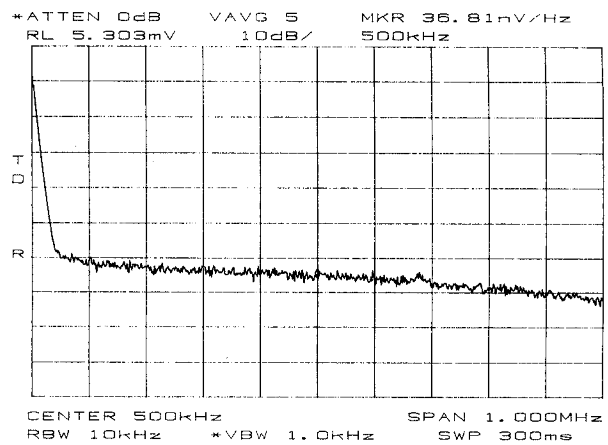

Figure 7. Noise power measured at the output of the mixer receiver of the HBT radar chip.

CONCLUSION

An single chip FM-CW radar has been implemented using GaAs/AlGaAs HBT devices for the first time. Success on first pass has been achieved using the TRW MIMIC qualified pilot line. The performance of the chip is similar to that of its "older brother" the GaAs MESFET chip reported in [1] with improved sensitivity due to superior noise characteristics of the HBT. The fabrication of the new chip in a foundry confirms that HBT technology is indeed reaching maturity.

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