A HIGHLY INTEGRATED MMIC K-BAND TRANSMIT/RECEIVE CHIP

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ABSTRACT

A highly integrated wide-band MMIC Transmit/Receive (T/R) chip was designed for both commercial and military FM CW applications. The MMIC circuit was designed using 0.25 μm pseudomorphic HEMT technology. The T/R chip has three 3-stage amplifiers, an active power divider, a diode double-balanced mixer, and a voltage controlled oscillator (VCO) all integrated on a single chip 96 X 71 mils (2.4 X 1.8 mm) in size.

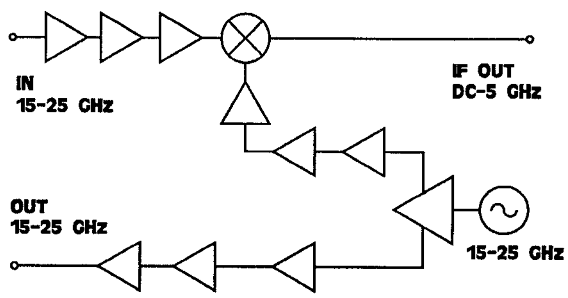

FIGURE 1. BLOCK DIAGRAM OF T/R CHIP

INTRODUCTION

Transmit/Receive (T/R) circuits are required for many commercial and military applications. The application frequencies start as low as 1 GHz extending to 60 GHz and even to 94 GHz in some cases. The transceiver MMIC described here has military applications in FM CW radar, and smart munitions systems. The chip also has commercial applications in data communication, collision avoidance, and industry liquid level sensors. Small chip size and high yield are important features to ensure low cost.

Transmit/Receive MMIC chips have been designed previously for FM CW radar applications at C band frequencies. Transceiver subsystems using MMIC chips have been recently developed for commercial data communication applications. The multiple MMIC chip assembly results in greater assembly and tuning time resulting in higher cost.

Presented here is a highly integrated MMIC K-Band transmit receive chip operating in the 15 to 25 GHz frequency range. The chip block diagram is shown in figure 1. An on chip a VCO generates a signal which is divided with an active power divider. Half the signal goes to a transmit amplifier and half the signal goes to a LO buffer amplifier. Since the VCO is constantly being swept in frequency, when the reflected signal returns into the receive input it is a different frequency than the LO signal. The input signal is amplified and mixed with the LO generating a low frequency IF which can then be processed.

CIRCUIT DESCRIPTION: MIXER DESIGN

The mixer used in the T/R chip is a double-balanced diode mixer. The double-balanced configuration gives the lowest dc offset voltage at the IF port. The diodes used in the mixer are pseudomorphic high electron mobility transistors (P-HEMT) with the source and drain connected together. A gate length of 0.25 μm used in the diodes is the same length used for active FET circuits. The diodes were characterized for modeling the mixer performance. Figure 2 is a plot of the I-V curve of the HEMT based diode (H-diode) compared to a typical MMIC N+ diode. The N+ diode measured has a gate length of 0.5 μm. Both the N+ and the H-diode have a total gate width of 40 μm. The capacitance variation of the H-diode versus voltage is also an important parameter for

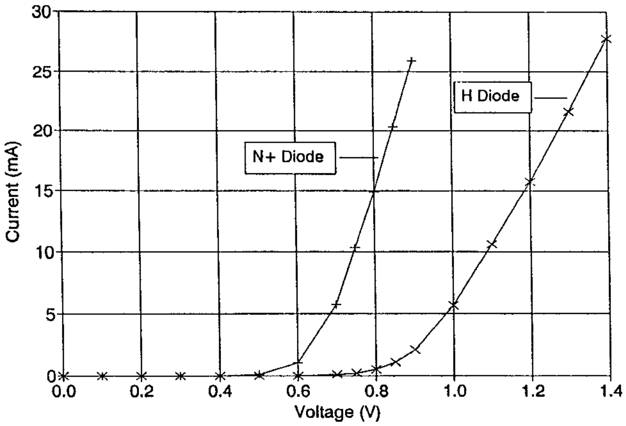

FIGURE 2. DIODE CURRENT VERSUS VOLTAGE

modeling. The data in figure 3 shows a comparison between the H-diode and a N+ diode capacitance variation versus voltage.

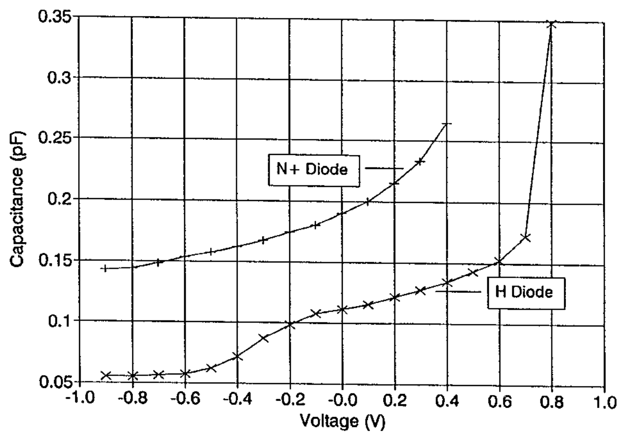

FIGURE 3. DIODE CAPACITANCE VERSUS VOLTAGE

The mixer uses two on chip baluns designed to cover 15 to 40 GHz. The typical loss of the balun at 20 GHz is 1 dB. Figures 4 and 5 show the conversion loss of the mixer with a constant IF frequency, and a constant LO frequency, respectively. Figure 6 shows the mixer conversion loss versus LO drive level for the H-diode mixer and for a N+ diode mixer. Both mixers are double-balanced. The H-diode mixer is more LO power dependent at the low end of the LO drive range due to its higher turn on voltage.

AMPLIFIER DESIGN

The RF amplifier is a 3-stage amplifier incorporating reactive and lossy match. The amplifier uses a 360 μm HEMT at the output and 120 μm and 240 μm HEMTs for the first and second stage. The measured gain of the active power divider and the amplifier is the top curve of figure 7. The active power divider consists of two 180 μm HEMTs with their gates connected together and their sources tied to the same substrate ground via hole. The output 1 dB compression point of the power divider and the amplifier is +12 dBm (figure 8). The measured noise figure in the 20 to 24 GHz range is approximately 7.0 dB. The amplifier requires 7 Volts DC bias and draws 50 ma current.

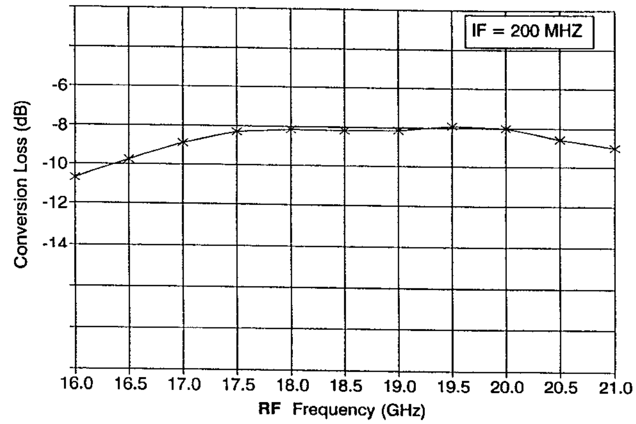

FIGURE 4. MIXER CONVERSION LOSS (CONSTANT IF)

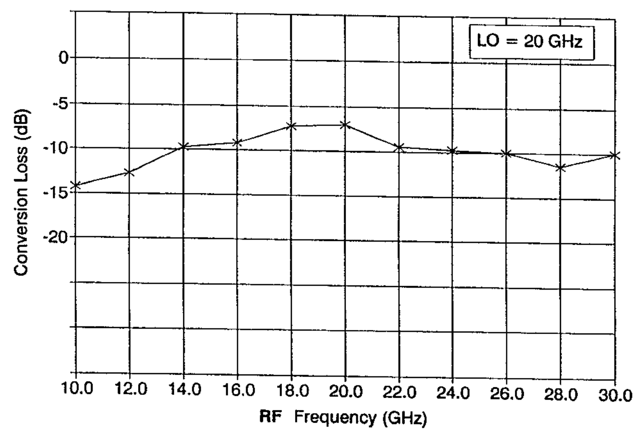

FIGURE 5. MIXER CONVERSION LOSS (CONSTANT LO)

VOLTAGE CONTROLLED OSCILLATOR

The voltage controlled oscillator (VCO) consists of a 150 μm HEMT. The source is capacitively coupled to ground providing positive feedback. The output is taken from the drain and the varactor tank circuit is connected to the gate. This configuration gives good isolation between the tuning network and the output load.

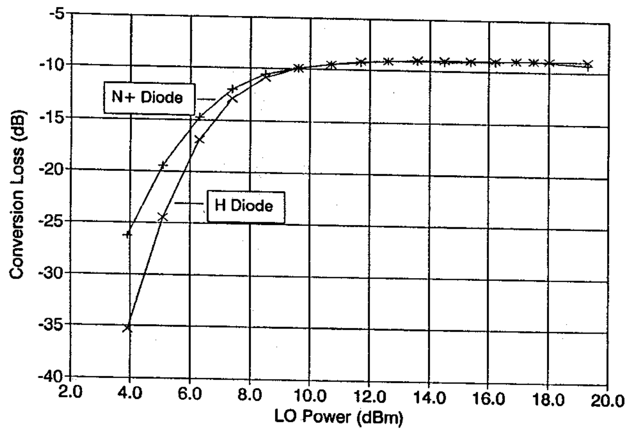

FIGURE 6. MIXER CONVERSION LOSS VERSUS LO DRIVE

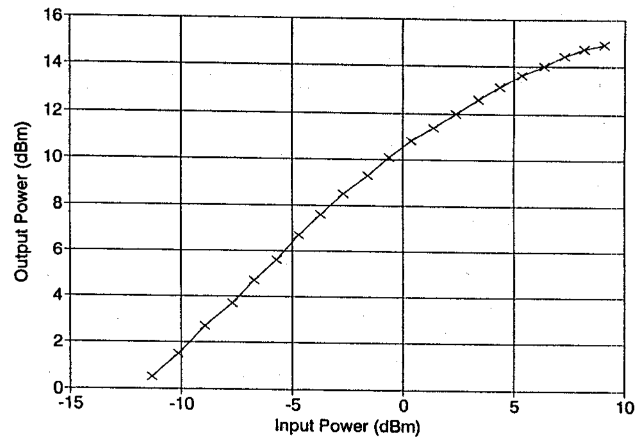

FIGURE 8. AMPLIFIER OUTPUT POWER COMPRESSION

COMPLETE T/R DESIGN

A photograph of the converter chip is shown in figure 9. The measured receive side conversion gain is the bottom curve shown in figure 7 (the top curve is the chip transmit gain). The on chip VCO oscillation frequency was too high for proper operation due to a wiring error. Therefore a similar design VCO chip was used externally until a second iteration of the T/R chip can correct the wiring error in the on chip VCO. Figure 10 shows the T/R chip output power over the selected tuning range of the external VCO.

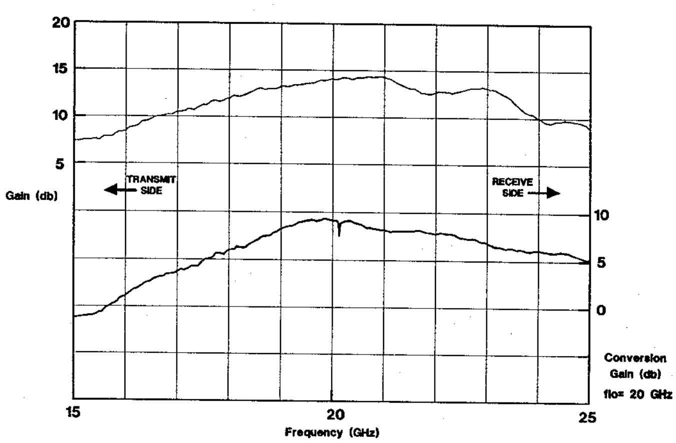

FIGURE 7. T/R CHIP TRANSMIT GAIN AND RECEIVE CONVERSION GAIN

A typical application for a T/R chip is FM CW radars. Figure 11 shows a schematic of one such application. An antenna is connected to a circulator and the T/R chip transmit and receive ports are connected to the remaining circulator ports. The T/R chip generates a Frequency Modulated signal by applying a saw-tooth wave form into the VCO control line. This signal is transmitted out of the antenna. The signal returns after being reflected from some distant object is received through the antenna amplified and downconverted the IF output. The received FM signal differs from the FM signal being transmitted due to the delay caused by the distance of the reflected signal. To simulate this concept a delay line can be connected between the transmit and receive ports of the T/R chip. The resulting IF signal will vary in frequency depending on the length of the delay between the transmit and receive ports.

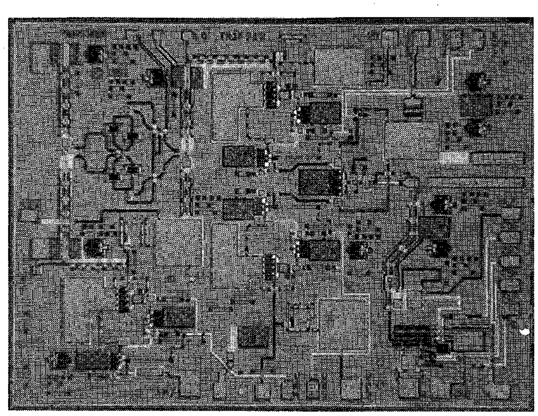

FIGURE 9. PHOTOGRAPH OF T/R CHIP

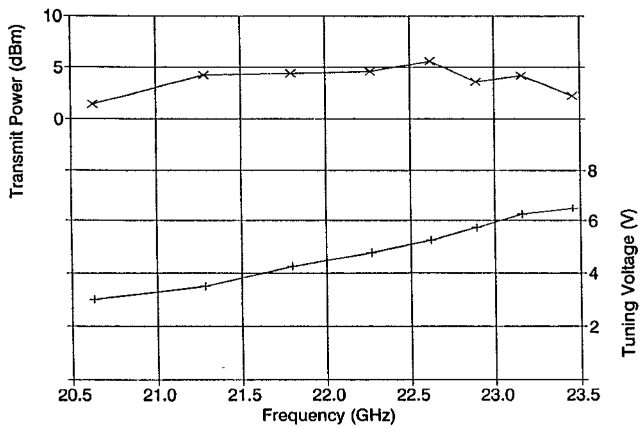

FIGURE 10. T/R CHIP OUTPUT POWER VERSUS FREQUENCY

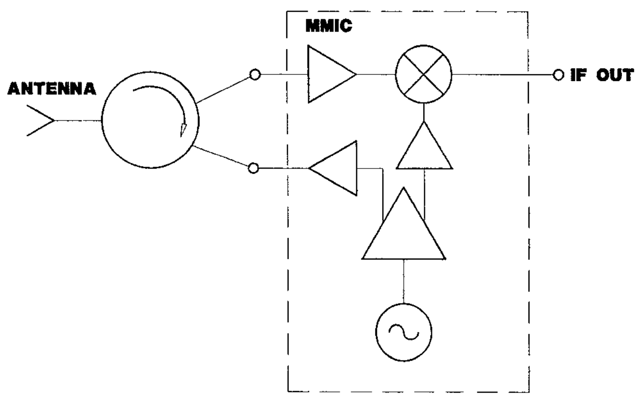

FIGURE 11. BLOCK DIAGRAM OF FM CW RADAR

CONCLUSION

A wide-band MMIC Transmit/Receive chip which covers a 15 to 25 GHz frequency range was designed and tested. The MMIC chip was fabricated using 0.25 μm P-HEMT technology. The chip incorporates three amplifiers, an active power divider, a VCO, and a double-balanced diode mixer all on the 71x96 mil chip. Use of high density layout techniques help to keep the chip size small thereby assuring high yield. These results were achieved on the first design cycle proving the modeling techniques employed were accurate.

ACKNOWLEDGMENTS

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