A Single-chip W-band Transceiver with Front-end Switching Receiver for FMCW Radar Applications

D. C. W. Lo, K. W. Chang, R. Lin, E. W. Lin, H. Wang,
M. Biedenbender, G. S. Dow, and B. R. Allen

TRW
Electronic System and Technology Division
M5/1027, One Space Park, Redondo Beach, CA 90278

ABSTRACT

We have demonstrated the first monolithic W-band transceiver with front-end switching receiver for FMCW radar application. The switching receiver utilizes a novel balanced switching low noise amplifier for switching function and has achieved a conversion gain of 5.4 dB and 10 dB isolation. By operating the MMIC as a heterodyne receiver, we achieved a noise figure at 1MHz IF of 8 dB which is lower than that of the previous reported single-chip W-band homodyne transceivers.

INTRODUCTION

The frequency modulation continuous wave (FMCW) radar has been widely used in determining the range and velocity of a moving target [1]. In comparison with pulsed Doppler radar, FMCW radar shows the advantages of substantially lower transmitter power, significantly less signal processing complexity, and lower cost. The FMCW operating at millimeter-wave (MMW) frequencies, W-band in particular, offers many advantages over the microwave, optical, or infrared approaches. These advantages include better range resolution due to large RF bandwidth, smaller antenna/hardware sizes, lower probability of intercept, less ground clutter, and the ability to operate in adverse weather and harsh combat environments .

Owing to the rapid advance of monolithic microwave/millimeter-wave integrated circuit (MMIC) technologies in the past years, we have implemented a W-band homodyne transceiver on a single MMIC chip [2]. The mixer in the homodyne transceiver MMIC employed Schottky diodes from HEMT devices with source and drain connected together and thus were fully compatible with the fabrication process of the active devices. However, these diodes show high 1/f noise, resulting in high receiver noise figure and low system sensitivity when IF is operating below diode 1/f noise corner frequency. To solve the 1/f noise problem, the mixer diodes can be fabricated in a optimal device profile for low 1/f noise. However, it increases the complexity of either monolithic or hybrid integration of the mixer to the rest of the transceiver elements. The other approach is to use a heterodyne architecture with a high first IF which is higher than the 1/f noise corner frequency to improve the overall system noise figure [3]. However, this approach requires a single-sideband upconverter and thus makes MMIC complicated [3]. Another alternative approach is using recently proposed FMCW architecture [4], where a switch was used in front of the receiver. In comparison with the former two approaches, this approach offer simpler design and lower cost with comparable system sensitivity In this paper, we demonstrate a single-chip transceiver with front-end switching receiver at W-band by utilizing a novel balanced switching low noise amplifier (BSLNA) where switching element is placed after the front-end low noise amplifier (LNA), therefore, its loss will not degrade system noise significantly [5].

OPERATING PRINCIPLE AND CIRCUIT DESIGN

Figure 1 shows the block diagram of a FMCW radar with front-end switching receiver [4]. The front-end switching element is used to modulate receiving signal and generate two sidebands. One of the two sidebands, after first down conversion, is mixed with a signal coupled

CH3577-4/95/0000-0873$01.00 © 1995 IEEE

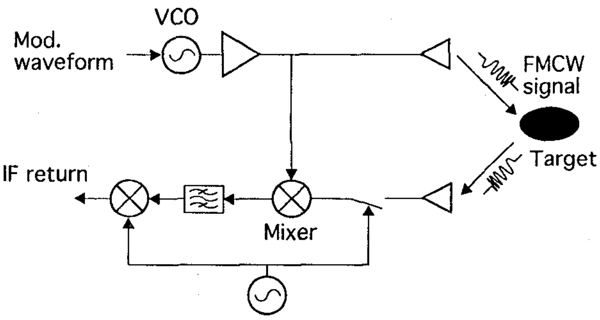
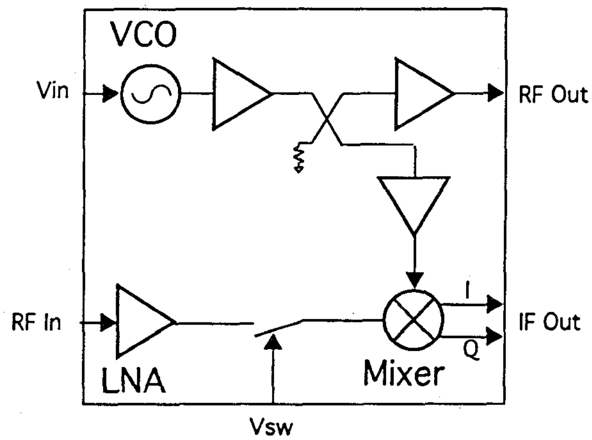


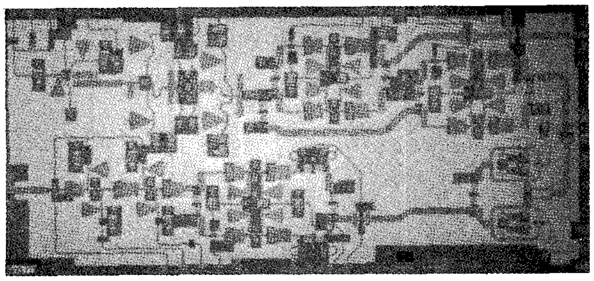
Fig.1 Block diagram of a FMCW radar with front-end switching receiver.

from the transmitting channel as a LO to generate a high IF. After a band pass filter, the IF signal is then down converted to base band for signal data processing. A low frequency source (100 MHz) can be used to control the switching elements as well as a second LO to downcovert the first IF signal. Since the first IF can be much higher than the diode 1/f noise corner frequency, the receiver noise figure is improved. It is noted that the low frequency source can be constructed easily with low cost and good phase noise performance.

Figure 2 shows the MMIC block diagram and the completely fabricated transceiver chip with a chip size of 6.5 mm x3 mm. The MMIC is fabricated using TRW 0.1 μm T-gate pseudomorphic AlGaAs/InGaAs/GaAs HEMT production line process [6]. To implement the switching function at W-band, a novel one-stage BSLNA is utilized. The architecture and operating principle of the BSLNA has been described elsewhere [5]. The one-stage BSLNA has a capability of ~4 dB gain and 10-20 dB isolation. In addition to the BSLNA, the MMIC transceiver consists of a W-band VCO, VCO buffer amplifier, a low noise amplifier (LNA), transmit amplifier, LO amplifier and image rejection mixer (IRM). The free running VCO is a common gate design similar to that in the previous reported homodyne transceiver [2]. Both transmit and LO amplifiers are the same balanced design consisting of two 40 μm HEMT devices with a capability of delivering more than 10 dBm power at 90-94 GHz. A 3-dB Lange coupler is employed to couple the FMCW signal generated from the VCO to the receiving channel as a LO source for the IRM. The IRM consists of a Lange coupler, a Wilkinson power divider and two identical single-balanced mixers with a 180^{o} rat-race ring hybrid and a matched pair



(a)



(b)

Fig.2 (a) Block diagram and (b) photomicrograph of the single-chip W-band transceiver with front-end switching receiver.

of 16-μm HEMT Schottky diodes for the mixing elements [7].

MEASURED RESULTS

The MMIC chip was mounted in a WR-10 wave guide test fixture for functional test. Figure 3 shows the transmitting frequency and corresponding output power of the transmitter as a function of the VCO tuning voltage. The transmitter shows a output power of 6 dBm and a tuning range of 1 GHz. Figure 4. shows the receiver frequency response with switch on and off by measuring from one IF port of IRM and terminating another IF port with a 50-Ω resistor. The receiver shows a conversion gain of 2 dB and an isolation of 10 dB for IF from 150 to 950 MHz. By configuring two IF ports through a hybrid, we achieve a conversion gain of 5 dB which is 3 dB higher than the data

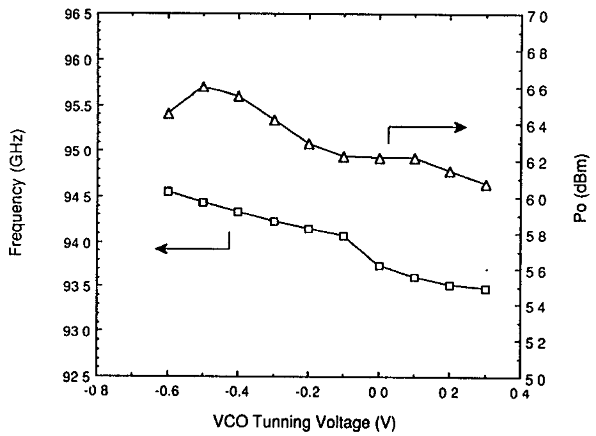


Fig.3 Measured transmitting frequency and corresponding output power of the transmitter as a function of the VCO tuning voltage.

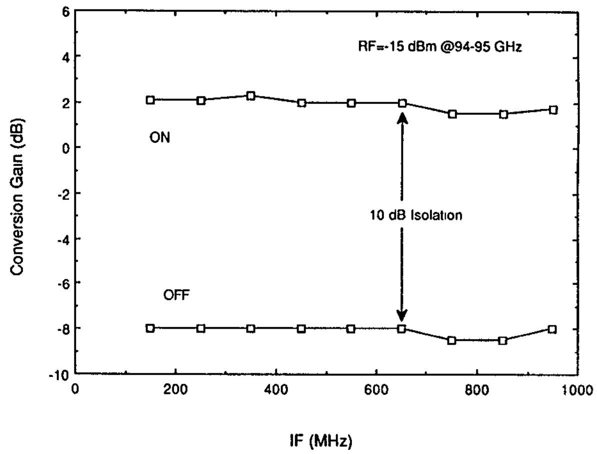


Fig.4 The receiver frequency response with switch on and off by measuring from one IF port of IRM and terminating another IF port with a 50-Ω resistor.

shown in Fig. 4 as expected and an image rejection of 18 dB when the switch is on. The receiver noise figure is characterized by Y-factor measurement. Figure 5 shows the measured receiver noise figure as a function of receiving frequency for the MMIC transceiver with the BSLNA controlled by a 100 MHz sine wave and a fixed bias (without switching). This figure illustrates that by using the simple front-end switching architecture, the receiver noise figure is significantly improved at low IF range. The receiver has achieved a noise figure of 8 dB which is much better than that of the previous reported single-chip homodyne transceiver (~30 dB) or heterodyne transceiver (11 dB) for IF in a few MHz range [2,3]. The MMIC has been inserted into existing FMCW radar system. The measured results will be presented in the conference.

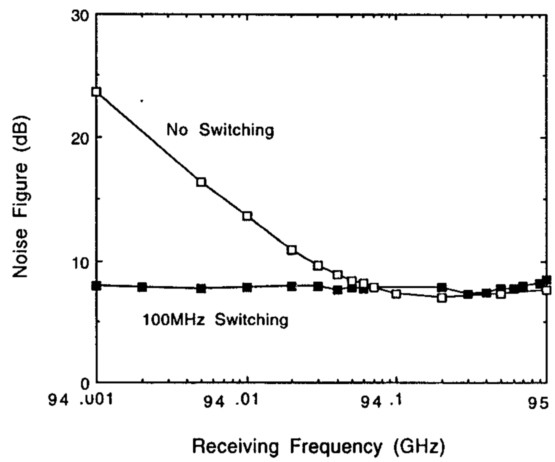


Fig.5 Measured receiver noise figure as a function of receiving frequency for the MMIC transceiver for the BSLNA with 100 MHz switching and without switching

CONCLUSIONS

We have demonstrated a single-chip W-band transceiver with front-end switching receiver. A novel BSLNA is used to implement the switching function at W-band. This MMIC enables a simple FMCW radar system to achieve high system sensitivity with minimum cost. The MMIC is ideal for application in automotive radar where high performance and low cost are important.

ACKNOWLEDGMENTS

The work is supported by MIMIC Phase 2 Program (Contract No. DAAL01-91-C-0156) from ARPA and Army Research Laboratory. The authors would like to thank Dr. D. Streit, P.H. Liu and K. L. Tan for MMIC fabrication efforts and E. Barnachea, P. Yocum for MMIC testing and members of the RF Product Center for their excellent technical support.

REFERENCES

[1] M. I. Sknolnik, Introduction to Radar Systems, McGraw-Hill, New York, 1980.

[2] K. W. Chang, G. S. Dow, H. Wang, T. H.Chen, K. Tan, B. Allen and J. Berenz," A W-band single-chip tranceiver for FMCW radar," IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium, p. 41, 1993.
[3] K. W. Chang, H. Wang, G. S. Dow, M. Biedenbender, T. H. Chen, D. C. W. Lo, and B.R. Allen," W-band monolithic signle sideband tranceiver for automotive radar applications," IEEE GaAs IC Symposium, p. 251, 1994.
[4] T. Saito, N. Okubo, Y. Kawasaki, O. Isaji, and H. Suzuki," An FM-CW radar module with front-end switching heterodyne receiver," IEEE MTT-S International Microwave Symposium Digest, p. 713, 1992.
[5] D. C. W. Lo, H. Wang, B. R. Allen, G. S. Dow, S. Chen and M. Biedenbender," A novel monolithic balanced switching low noise amplifier," IEEE MTT-S International Microwave Symposium Digest, p. 1199, 1994.
[6] K. L. Tan et al., " A high performance 0.1 mm pseudomorphic AlGaAs/InGaAs HEMT process for W-band MMICs," IEEE GaAs IC Symposium, p. 251, 1992.
[7] K. W. Chang et al., " A W-band image rejection downconverter," IEEE Trans. on Microwave Theory Tech., vol. 40, p. 2332, 1992.