A FET Transceiver Suitable for FMCW Radars

Klas Yhland and Christian Fager, *Student Member, IEEE*

***Abstract*—We present a new FET transceiver suitable for frequency modulated continuous wave (FMCW) radars. The circuit obviates the need for dual antennas, a circulator, or a coupler for the separation of the transmit and receive signal paths. A FET is used simultaneously as an amplifier for the transmitted signal and as a resistive mixer for the received signal. At the optimum bias point, the circuit has an output power of 7 dBm and a conversion loss of 9 dB. Also, the noise performance is investigated. The circuit performance is shown to be insensitive to bias voltage variations. Furthermore, the transceiver's simple topology makes it suitable for commercial high-volume applications.**

***Index Terms*—FMCW, radar, transreceiver.**

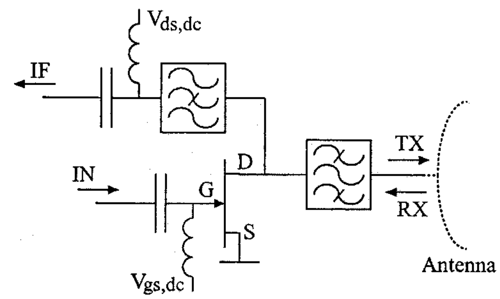

Fig. 1. Circuit diagram of the FET transceiver.

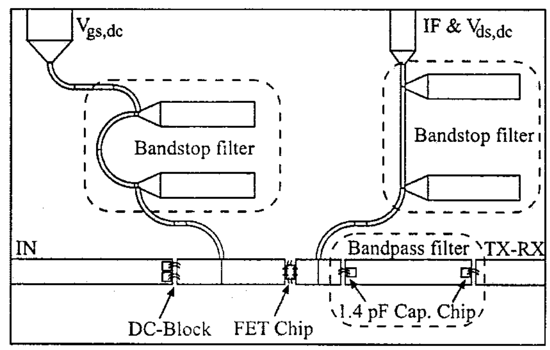

Fig. 2. Layout of the FET transceiver test circuit.

I. Introduction

In recent years, considerable efforts have been made to develop automotive anti-collision or cruise control radars. Demands for high volume, low cost, and small size make solutions based on microwave monolithic integrated circuits (MMICs) favorable. The most common choice of radar type has been the frequency modulated continuous wave (FMCW) radar.

As in any microwave transceiver front-end, the separation of the receive and transmit signal paths poses problems. There are several ways to facilitate this separation in FMCW radar front-ends. One is to keep the signal paths separated all the way through the antenna, using one transmit and one receive antenna [1], [2]. However, the need for dual antennas increases the size and cost of the radar. A second approach is to use the same antenna for transmission and reception and to separate the signals with a circulator connected to the antenna. The circulator can be a passive ferrite device [3] or an active semiconductor circuit [4]. However, a ferrite circulator has to be placed outside any MMIC circuitry and an active circulator increases the device count. Instead of a circulator, a power divider can be used [5], [6]. This method, however, wastes one half of both the transmitted and received power. It is also possible to use the same circuit for output power generation and for down conversion of the received signal [7]. This circuit has the lowest device count. However, since most MMIC semiconductor processes are optimized for FET's, the diodes necessary for this circuit may have poor quality if the circuit is built as an MMIC.

To avoid the difficulties when separating two signals closely spaced in frequency [1]–[6] and the disadvantages associated with diode circuits [7] we present a FET transceiver suitable for FMCW radars (Fig. 1). The transceiver is well suited for implementation in MMIC technology. A FET is used simultaneously to amplify the transmitted signal and as a resistive mixer to down-convert the received signal. For the sake of simplicity, the circuit is verified at 10 GHz with the HFET NE 32 400 from NEC.

Manuscript received May 24, 2000; revised July 20, 2000. This work was supported by the Chalmers Centre for High Speed Technology (CHACH), and by the Swedish National Board for Industrial and Technical Development (NUTEK).

The authors are with the Department of Microelectronics, Microwave Electronics Laboratory, Chalmers University of Technology, S-41296 Gothenburg, Sweden (e-mail: fager@ep.chalmers.se).

Publisher Item Identifier S 1051-8207(00)08448-8.

II. Circuit Operation

The circuit, shown in Fig. 1, is a combination of a common source amplifier and a resistive mixer [8]. If operated as a common source amplifier, the HFET would have been biased with a drain to source voltage (V_{ds}) of about 2 V and the gate to source voltage (V_{gs}) at half the drain to source saturation current in order to obtain maximum output power (P_{TX}) and gain. On the other hand, if operated as a resistive mixer, the HFET would have been biased at zero V_{ds} and V_{gs} close to pinch-off in order to minimize the conversion loss (CL). Our idea is to find an intermediate $V_{ds} - V_{gs}$ bias point where the HFET operates satisfactorily as both an amplifier and a resistive mixer. Obviously, the selection of $V_{ds} - V_{gs}$ bias point will be a compromise between minimum CL and maximum P_{TX}. Since the IF output power (P_{IF}) is maximized when $P_{\mathrm{TX}}/\mathrm{CL}$ is maximized we use $P_{\mathrm{TX}}/\mathrm{CL}$ as a figure of merit to facilitate this compromise.

1051–8207/00$10.00 © 2000 IEEE

III. VERIFICATION

A. Test Circuit

A test circuit was built using microstrip technique on a 0.38 mm thick teflon substrate with $\varepsilon_r = 2.33$. The circuit was built in a 50 Ω environment without any tuning of the circuit. The layout of the test circuit is shown in Fig. 2. A commercially available bias-T was placed outside the microstrip board to separate the IF and $V_{ds,\,dc}$.

B. Output Power and Conversion Loss

The input signal (IN) at 10.2 GHz was provided by an HP 83 620 signal generator. When measuring CL and P_{TX}, the received signal (RX) at 10 GHz was provided by an HP 8350 signal generator. A circulator at the transmit-receive (TX-RX) port was used to enable measurement of P_{TX} simultaneously as RX was applied. P_{TX} and P_{IF} were measured using the diode detectors HP 85025D and HP 85025E respectively.

Fig. 3 shows the measured $P_{\mathrm{TX}}/\mathrm{CL}$ plotted versus V_{gs} and V_{ds}. The optimum gate to source dc bias ($V_{gs,\,dc}$) is approximately 0 V and the optimum drain to source dc bias ($V_{ds,\,dc}$) is approximately 1.1 V. The optimum is flat and $P_{\mathrm{TX}}/\mathrm{CL}$ varies less than 3 dB for a V_{ds} variation of 1.5 V and a V_{gs} variation of 0.6 V.

Fig. 4 shows P_{TX}, CL, and $P_{\mathrm{TX}}/\mathrm{CL}$ versus input power (P_{IN}). As can be expected from [8], the circuit requires a P_{IN} of a few dBm to function properly.

C. Noise

The noise power density at the IF port was measured using an HP8565E spectrum analyzer with a preamplifier having 33 dB gain and approximately 2 dB noise figure. The TX-RX port was terminated with a 50 Ω load. Also here IN was provided by an HP 83 620 signal generator at 10.2 GHz. In this measurement the transceiver and the preamplifier were powered by batteries.

Fig. 5 shows the double sideband noise power density referred to the TX-RX port (P_{DSB}) versus f_{IF} at $P_{\mathrm{IN}} = 3$ dBm.

When sweeping P_{IN} from 6 to 2 dBm, P_{DSB} increases with approximately 2 dB over the whole f_{IF} range. This corresponds to the increase in CL. When further decreasing P_{IN}, from 2 to -4 dBm, P_{DSB} increases approximately 15 dB.

For the purpose of verification, the HP 83620 signal generator was equipped with a bandpass filter having 200 MHz bandwidth. This did not lower P_{DSB} for $f_{IF} > 100$ MHz. Thus, at least at high f_{IF}, the noise generated in the transceiver dominates over that supplied by the signal generator.

IV. DISCUSSION AND CONCLUSION

The width of the optimum in Fig. 3 has several causes. When increasing V_{ds}, P_{TX} will increase with about the same amount as CL. Thus, in the V_{ds} direction we can trade CL for P_{TX}. In the V_{gs} direction the dc level has little influence on P_{TX} and CL as long as the ac magnitude at the FET gate is high enough to swing the device from pinch-off to fully conducting. In both directions the width of the optimum increases with increasing P_{IN}. Also the noise performance improves with increasing P_{IN}

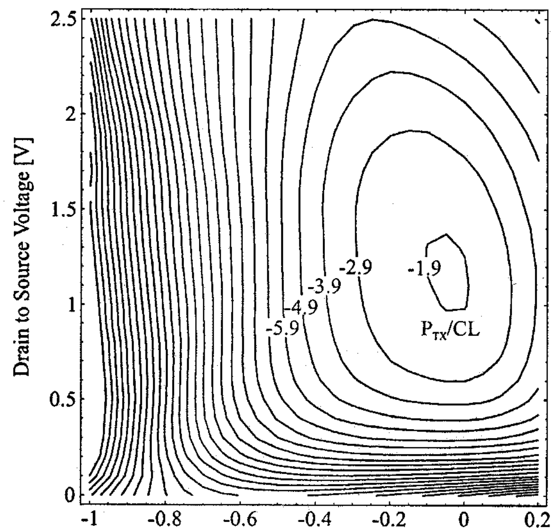

Fig. 3. Contour plot of measured $P_{\mathrm{TX}}/\mathrm{CL}$ at $P_{\mathrm{IN}} = 3$ dBm.

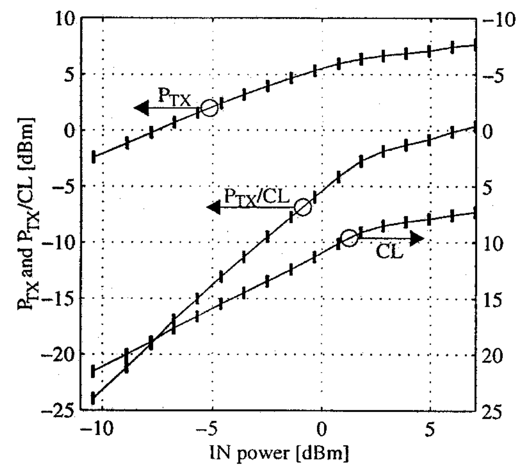

Fig. 4. Measured transmitted power (P_{TX}), conversion loss (CL), and the quotient $P_{\mathrm{TX}}/\mathrm{CL}$ versus input power (P_{IN}) at $V_{ds,\,dc} = 1.0$ V and $V_{gs,\,dc} = 0.0$ V.

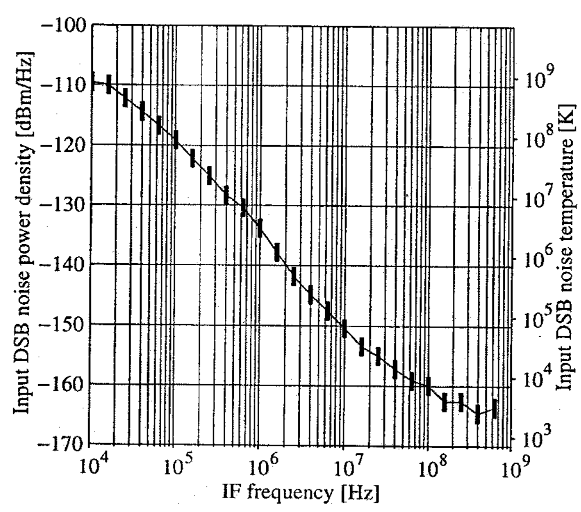

Fig. 5. Measured input DSB noise power density (P_{DSB}) and input DSB noise temperature versus IF frequency (f_{IF}) at $P_{\mathrm{IN}} = 3$ dBm, $V_{ds,\,dc} = 1.0$ V and $V_{gs,\,dc} = 0.0$ V.

and for a P_{IN} higher than 2 dBm it is insensitive to variations in P_{IN}.

The simple circuit topology and the insensitivity to bias variations make the presented transceiver suitable for commercial high-volume applications.

ACKNOWLEDGMENT

The authors thank Prof. L. Lundgren for stimulating discussions.

REFERENCES

[1] K. W. Chang, G. S. Dow, H. Wang, T. N. Chen, K. Tan, B. Allen, I. Berenz, J. Wehling, and R. Lin, "A W-band single-chip transceiver for FMCW radar," *Proc. 1993 IEEE Microwave and Millimeter-Wave Monolithic Circuits Symp. Dig.*, vol. 1, pp. 41–44, 1993.

[2] H. D. Griffiths, "New ideas in FM radar," *IEE Electronics and Communication Eng. J.*, vol. 2, pp. 185–194, Oct. 1990.

[3] D. D. Li, S. C. Luo, C. Pero, W. Xiaodong, and R. Knox, "Millimeter-wave FMCW/monopulse radar front-end for automotive applications," *Proc. 1999 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 1, pp. 13–19, 1999.

[4] L. Reynolds and Y. Ayasli, "Single chip FMCW radar for target velocity and range sensing applications," *Proc. 11th Annu.GaAs IC Symp. Dig.*, vol. 1, pp. 243–246, 1989.

[5] M. Nalezinski, M. Vossiek, and P. Heide, "Novel 24 GHz FMCW front-end with 2.45 GHz SAW reference path for high-precision distance measurements," *Proc. 1997 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 1, pp. 185–188, 1997.

[6] J. Kehrbeck, E. Heidrich, and W. Wiesbeck, "A novel and inexpensive short range FM-CW radar design," *Proc. IEE Int. Conf. Radar*, vol. 1, pp. 288–291, 1992.

[7] S. A. Maas, "FM-CW radar transceiver," U.S. Patent 5 596 325, Jan. 21, 1997.

[8] ——, "GaAs MESFET mixer with very low intermodulation," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-35, pp. 425–429, Apr. 1987.