A Novel Common Gate Mixer for Wireless Applications

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Abstract — **In this paper, a balanced common gate mixer is presented. The common gate configuration allows 0.8 μm MESFETs to be used at frequencies in excess of their f_t by eliminating the Miller effect. Measurements on the mixer indicate a conversion loss of 10.7 dB, with a third order intercept at 0 dBm output power. This performance is in the range of reported mixers at this frequency, even though most mixers use higher-tolerance and more expensive processes.**

I. INTRODUCTION

The successful design and manufacture of a receiver for wireless applications requires that the circuit be not only reliable and have the appropriate features, but also that it be priced low enough to sell. While designing a receiver may be simple enough if any technology may be used, the design is more complicated if the process is constrained to be a simple, inexpensive one.

This paper presents a mixer that was designed using a simple 0.8 μm MESFET process, working at frequencies in excess of its f_t=20 GHz. The purpose of this work was to demonstrate the feasibility of developing a millimeter wave mixer using a simple 0.8 μm MESFET process, rather than the more expensive processes normally used at this frequency band.

The mixer in this paper was developed as part of an integrated receiver for the local multipoint distribution service (LMDS). LMDS is an integrated wireless broadband service offering bundled telephony, data, voice, and video.

In order to optimize the circuit for eventual production, we would like to select a process that would maximize the yield and minimize costs during the production run. To achieve this, the circuit must use a simple topology that is relatively compact and has a high tolerance for processing variations. The process used must then be a mature low cost technology. For this circuit the Self Aligned Gate Radio Frequency (SAGRF) 0.8 μm MESFET process was chosen. The relatively long channel length eases the tolerances in processing, so the masks required to fabricate the circuits are cheaper to produce, and the hardware required is less expensive.

The processed is intended for radio frequency designs, and the common source configuration has a unity short circuit current gain at f_t = 20 GHz, which is significantly less than the frequency of operation of this circuit. The common gate configuration, which was used for this circuit, has a unity current gain frequency significantly larger than this. Despite the fact that this process is not intended for millimeter wave circuits, it has already been demonstrated that it is suitable under certain conditions [2].

Since the cost of a circuit is closely related to its size, the circuit must be as compact as possible. By decreasing the circuit size, more circuits may be placed on a single die, decreasing the cost per unit of production. Additionally, a smaller device means reduced ohmic losses and greater efficiency.

II. MIXER DESIGN

The mixer was designed using a standard computer aided circuit design tool. The model used for the 0.8 μm MESFETs was extrapolated from a standard model intended for use up to 18 GHz. A block diagram of the mixer is shown in Figure 1.

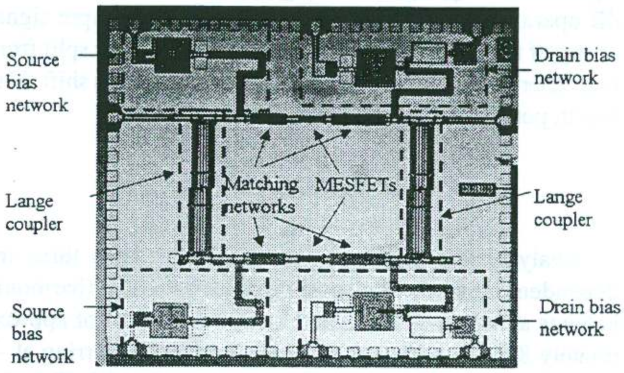

Figure 1: Mixer block diagram

Most FET mixers (and amplifiers) use transistors in a common source (CS) configuration because of their large low frequency gain and stability. However, the CS configuration suffers a large conversion loss at high frequencies due to Miller effect, whereby the parasitic capacitance C_{dg} between the drain and gate produces feedback at high frequencies. The common gate (CG) configuration does not suffer from this problem, but does have stability concerns. For this mixer, a common gate configuration was used in a balanced structure, negating the Miller effect and minimizing the conversion loss of the structure while providing isolation between the local oscillator (LO) and radio frequency (RF) ports, and also maintaining stability.

Although the common gate configuration has large gain at high frequencies, it requires that an external network be used to stabilize the mixer cells. Since the CG configuration is conditionally stable, it may be seen to have a negative real impedance by certain source and load impedances. If such a condition occurs, the structure will oscillate. As a result, it is necessary to ensure that all source and loads looking into the mixer will see reflection coefficients with a magnitude less than one.

A. Matching networks

Matching networks used a combination of distributed and lumped elements. Due to large parasitics associated with spiral inductors, high impedance coplanar waveguide transmission lines were used as inductors; these were combined with standard MIM capacitors to form LC matching networks.

B. Quadrature hybrids

In order to realize a balanced structure, some type of quadrature hybrids are needed. For this circuit, Lange couplers were chosen for their large bandwidth (an octave), very precise phase shift, and good power split. A Lange coupler is a symmetric four-port passive 3 dB quadrature coupler, commonly used for equal power splitting and power combining. It consists of four parallel fingers connected such that they may be treated as a two-wire coupled line circuit. The close spacing between four fingers allows for significant coupling between ports, and makes possible 3 dB operation over an octave of frequency. An input signal at any of the four ports will produce a 3 dB power split from two other ports, one of which will have a 90 phase shift. The fourth port is isolated from the first.

III. SIMULATION

Analysis was performed on the mixer using three independent methods, the most rigorous of which (harmonic balance simulation) estimated a conversion loss of approximately 8.5 dB, with a third order intercept occurring at -7 dB output power. It predicted approximately 16.5 dB isolation between the LO and IF ports, 23 dB isolation between the RF and IF ports, and 27 dB isolation between the LO and RF ports.

IV. MIXER LAYOUT

The mixer was laid out as shown in Figure 1. The circuit is approximately 2 mm by 2 mm.

The SAGRF process used for this mixer uses unthinned 625 μm GaAs with a thick metal sub-process for making spiral inductors, and with thin film capacitors. It was designed for use up to 20 GHz (its f_t=20 GHz when V_{gs}=0 V and V_{ds}=3 V), primarily for microwave and fiber optic applications.

Coplanar waveguide (CPW) transmission lines were used throughout the circuit, due to their simplicity and degree of freedom. Since the impedance of a CPW transmission line is set by two parameters (the central conductor width and the gap size), a specific impedance line may be fabricated using either a narrow central conductor and narrow gap (to minimize space requirements), or using a wide central conductor and large gap (to minimize ohmic losses).

V. MEASUREMENT

After fabrication, the mixer was characterized by its conversion gain, third order intercept, isolation, and match at the three ports. Further information on the measurement of this circuit is available in [1].

A. Conversion Loss

The conversion gain was measured by applying appropriate bias voltages to the drain and source networks, and a large signal LO signal and a small signal RF to the respective inputs.

The conversion gain was measured at various bias voltages, and RF and LO frequencies, in order to examine the accuracy of the matching networks. Since the mixer was designed to operate with an RF input at 30 GHz and an LO of 28 GHz, if the optimum frequencies were shifted from these values, it would indicate that the matching networks were not matched to the transistors.

Several chips were measured, to get an indication of the amount of variability in the process. The minimum conversion loss was measured to be 8.5 dB when the RF was at 27 GHz and the LO was at 25.5 GHz. Since the mixer was designed to be used at an RF of 28 GHz and an LO of 26 GHz, the matching networks around the transistors seem to be slightly mismatched. This was attributed to the transistor model used in the design; the only model available was designed for use up to 18 GHz only. It is not surprising that it is somewhat inaccurate when extrapolated to 30 GHz.

B. Port Match

Figure 2 below shows the return loss at the LO port, Figure 3 shows the return loss at the RF port, and Figure 4 shows the return loss at the IF port. From these plots it can be seen that the match at the RF and LO ports are acceptable, but the RF match is very poor.

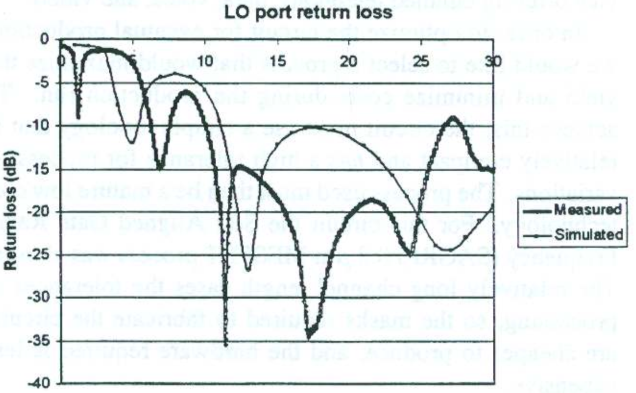

Figure 2: Return loss at LO port

C. Third Order Intercept

The third order intercept was measured using two closely space signals at the RF port. The measurement was done

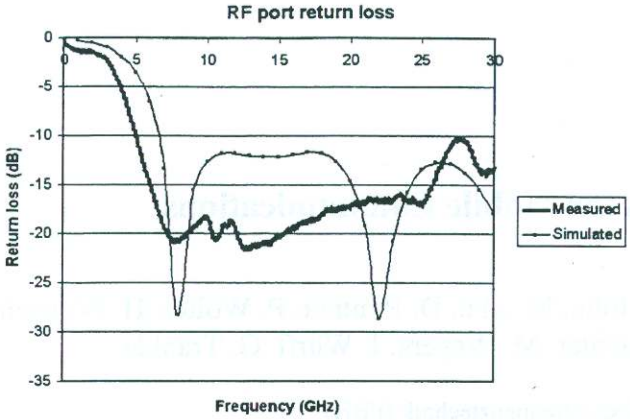

Figure 3: Return loss at RF port

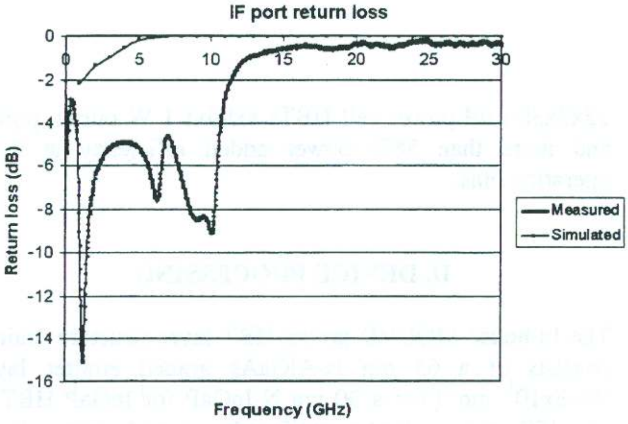

Figure 4: Return loss at RF and IF ports

under the conditions that provided maximum conversion gain. They are summarized in Table 1

Table 1: Conditions for IP_3 measurement.

RF		LO	
Freq. (GHz)	Power (dBm)	Freq. (GHz)	Power (dBm)
Source 1: 27.07	-10	25.57	11
Source 2: 27.063			

From Figure 5 below, it can be seen that the third order intercept occurs at an output power of approximately 0 dBm, corresponding to an input power of 16 dBm. It was only possible to make the measurement at three values of input power due to the losses presented by the RF probes, and the output power limitations of the RF sources. The third order harmonic shown in Figure 5 is the upper frequency harmonic - the lower frequency third order harmonic was lower, just as was predicted in the harmonic balance simulation, though the measured difference (about 3 dB) is much less than the simulated difference.

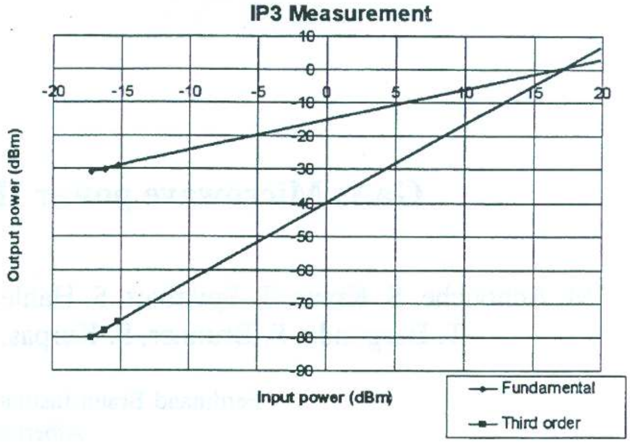

Figure 5: Mixer third order intercept

D. Isolation

The isolation between the ports with mixer at the designed bias condition was measured using a spectrum analyzer and a 10 dB directional coupler. The LO-RF isolation was measured to be 49 dB, the RF-IF isolation was 52 dB, and the LO-IF isolation was 33 dB.

VI. CONCLUSIONS

This paper has presented a MESFET downconvert mixer that uses the common gate configuration. The common gate configuration allows a simpler process to be used that would be possible with a common source configuration. Measurements on the mixer indicate a conversion loss of 8.5 dB, with a third order intercept at 0 dBm output power.

A survey of published mixer results showed that the performance of this mixer is similar to that of other mixers in this frequency band. However, most mixers designed in the Ka band use more expensive, higher performance processes. This work suggests that circuits may be designed using common gate transistors in a balanced configuration to achieve performance comparable to circuits designed using more expensive processes.

VII. ACKNOWLEDGEMENTS

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VIII. REFERENCES

[1] Frank, B.M. *A Novel Common Gate Mixer for Wireless Applications*, M.Sc.Thesis, Queen's University, Kingston, Ontario, 1999

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