A GaAs MESFET BALANCED MIXER WITH VERY LOW INTERMODULATION

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ABSTRACT

A new type of balanced resistive mixer has been realized by using the unbiased channel of a GaAs MESFET as the mixing element. Because this resistance is only very weakly nonlinear, very low intermodulation results. State-of-the-art second- and third-order output intercept points of 34 and 21 dBm are achieved, with 7 dB conversion loss at X band.

INTRODUCTION

The Schottky-barrier diode used in most microwave mixers is one of the most strongly nonlinear devices found in microwave components. As such, it is not surprising that diode mixers have relatively poor intermodulation (IM) and spurious response properties. Methods to improve diode mixer IM performance have been proposed periodically [1-4], but because of practical limitations, none have been widely accepted. However, it is not necessary to use a nonlinear device for a mixer; it is theoretically possible to realize an intermodulation-free mixer with a time-varying linear resistor. The mixer described here approximates a time-varying linear resistor, and achieves IM performance which far exceeds the state of the art for diode mixers. It uses the very weakly nonlinear resistive channel of a GaAs MESFET as the mixing element, with the LO applied to the gate. Additionally, it is a highly practical circuit, simple and easy to design, with good conversion loss and port impedances.

CIRCUIT DESIGN AND DESCRIPTION

Figure 1 shows the equivalent circuit of a MESFET with no bias applied to the drain. $g(V_g)$ is the channel conductance, which is weakly nonlinear and is directly controlled by V_g, the internal gate/source voltage. The gate depletion capacitance is divided equally between C_{gs} and C_{gd} as long as the drain bias voltage is zero. R_g, R_d, and R_s, the gate, drain, and source resistances, are the same as in the biased device. To realize a mixer, the LO and a dc bias are applied to the gate, and the RF is applied to the drain. The IF output is filtered from the drain. The large value of C_{gd} is a potential problem: first, because it reduces RF/LO isolation, and second, because it couples LO voltage to the drain and RF voltage to the gate. The LO voltage coupled to the drain swings the drain voltages over a more strongly nonlinear range, exacerbating IM generation, and the RF coupled to the gate may also increase IM due to transconductance nonlinearities. Hence to optimize IM performance, the LO is short-circuited at the drain, and the RF is shorted at the gate. This short can be realized with filters or via a balanced structure.

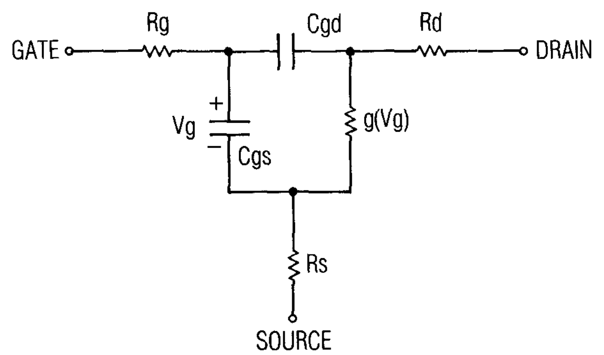

Figure 1. Equivalent circuit of a GaAs MESFET with no bias applied to the drain.

The mixer circuit is shown in Figure 2. It was designed to operate at 10 GHz with an IF of 10-100 MHz. The two FETs (packaged Avantek type AT10650) were chosen from the same processing lot of devices, and checked to ascertain that their I/V characteristics were well matched. The FET gates must be driven with a 180 degree LO phase difference; this phase split is achieved by a loop

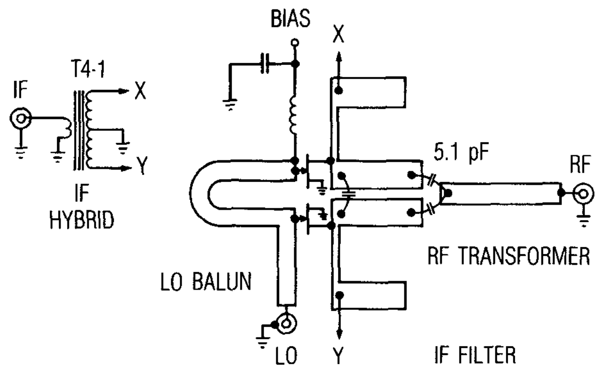

Figure 2. Circuit of the balanced mixer. All capacitors are 5.1 pF.

of transmission line 180 degrees long. The drains are in parallel at the RF, and are fed through a quarter-wave transformer which matches the 50 ohm RF input to the 25-ohm input impedance of the parallel channels. The small reactive part of the input impedance due to C_{gd} is tuned out empirically. The IF currents in the channels are 180 degrees out of phase, and are therefore combined with a miniature RF transformer, Mini-Circuits type T4-1. The IF transformer also applies a near-optimum IF load impedance of 100 ohms to each FET; its loss is approximately 1 dB at 100 MHz.

The geometry of the circuit supplies the desired RF and LO short circuits to the gate and drain. Because of the 180 degree phase difference of the LO currents through C_{gd} in the two FETs, the drain node is a virtual ground to the LO. Similarly, the LO balun presents a short-circuit to even-mode inputs such as the RF leakage. Many commonly used baluns, such as the Marchand balun used in doubly-balanced diode mixers, may not be suitable here because they present an open circuit to even-mode inputs.

PERFORMANCE

Figures 3a and 3b show the passband of the mixer for fixed IF and fixed LO. At a fixed IF frequency, conversion loss averages 7.0 dB over a 1-GHz band, including the 1-dB loss of the IF hybrid. The shape of the IF passband is determined primarily by the IF transformer. This performance is as good as most commercially-available balanced diode mixers.

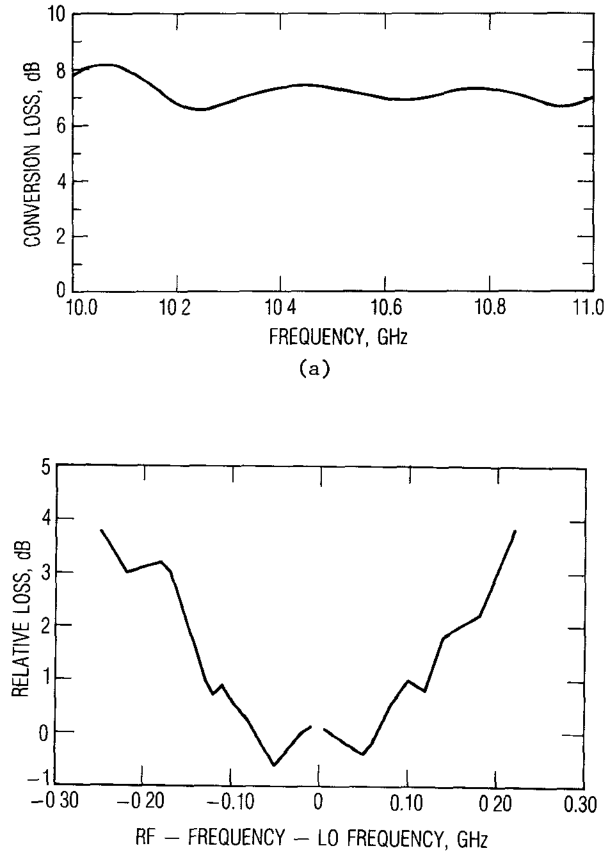

Figure 3. Mixer passband with a fixed IF frequency (a); with fixed LO frequency (b).

Figure 4 shows the conversion loss as a function of LO power and gate bias, and Figure 5 shows the corresponding IM levels. Higher gate bias gives better optimum IM performance, although at lower LO power levels it is better to use somewhat lower bias. Lower bias also reduces the sensitivity of conversion loss to LO power. The sensitivity of

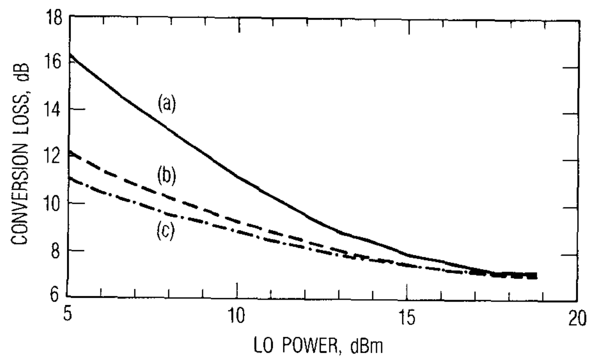

Figure 4. Conversion loss as a function of LO power and gate bias. (a) V_{gs}=-1.10; (b) V_{gs}=-0.84; (c) V_{gs}=-0.63.

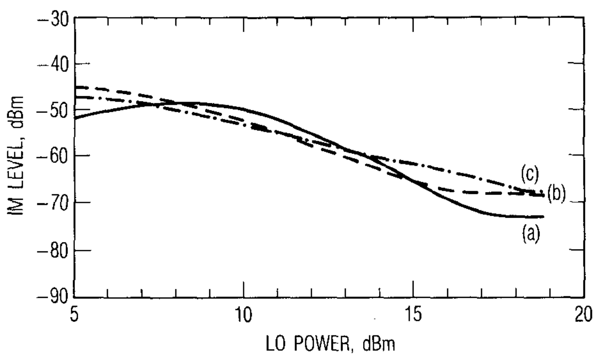

Figure 5. IM level as a function of LO power and gate bias; RF level is -3 dBm. (a) V_{gs}=-1.10; (b) V_{gs}=-0.84; (c) V_{gs}=-0.63.

both conversion loss and IM level to LO level is significantly lower than that of most diode mixers.

Figure 6 shows the second- and third-order IM levels as a function of RF level (the second-order component shown is the IF output at the difference between the two input frequencies). The second-order component exhibits the expected 2 dB/dB slope, but the third-order output has a slope of 2.6 dB/dB at low RF levels, and rises monotonically at high input levels. This result is not unusual, and indicates that nonlinearities of degree higher than three contribute significantly to third-order IM generation. Under these circumstances it is difficult to define an intermodulation intercept point, but over this range of power levels the IM level is lower than that which would be indicated by a 21 dBm output third-order intercept point. The second-order output intercept point from Figure 6 is 34 dBm.

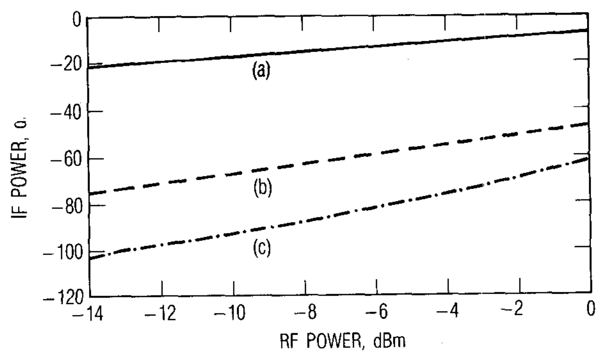

Figure 6. (a) linear, (b) second-order, and (c) third-order IM levels vs. RF level.

CONCLUSIONS

A simple balanced mixer circuit using the resistive channel of a GaAs MESFET exhibits intermodulation performance which exceeds the state of the art for diode mixers. Other performance parameters--conversion loss, port impedances, and LO sensitivity--are equal to or better than those of a diode mixer.

ACKNOWLEDGEMENTS

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