A DOUBLE BALANCED 3-18 GHZ RESISTIVE HEMT MONOLITHIC MIXER

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ABSTRACT

A double balanced (DB) 3-18 GHz resistive HEMT monolithic mixer has been successfully developed. This mixer consists of a AlGaAs/InGaAs HEMT quad, an active LO balun and two passive baluns, RF and IF. At 16 dBm LO power, this mixer achieves the conversion losses of 7.5-9 dB for 4-14 GHz RF and 7.5-11 dB for 3-18 GHz RF. The simulated conversion loss is very much in agreement with the measured results. Also, a third order input intercept of +26 dBm is achieved for a 10-11 GHz RF and 1 GHz IF at a LO drive of 16 dBm. This design is believed to be the first DB resistive HEMT MMIC mixer covering up to 6:1 bandwidth.

INTRODUCTION

At the present time, Schottky diode mixers are the most commonly used mixers in microwave systems. However, they have relatively poor intermodulation and spurious response properties due to their strongly nonlinear characteristics. Although various circuit schemes have been proposed to improve the intermodulation performance of the diode mixers [1-4], they either are not practical for wide frequency band application or require a massive LO power. References [5-7] show that three-terminal devices, such as MESFETs and HEMTs, when used as mixing elements can achieve better performance and require less LO power than diode mixers. Both MESFETs and HEMTs can be used as mixing elements in either an active or a resistive mode. The resistive mixer has the advantages of low noise figure, high two-tone third-order intermodulation intercept point, and low dc power consumption when compared with a corresponding active mixer [8]. In addition to that, a resistive HEMT mixer requires lower LO power and can operate over a wider frequency range than a resistive MESFET mixer because it has a steeper transfer curve and a higher cutoff frequency, f_T. This paper describes a double balanced resistive HEMT mixer which downconverts a 3 to 18 GHz RF to a 0.75 to 1.25 GHz IF.

BALANCED MIXER DESIGN

Since a double balanced (DB) mixer configuration provides isolation between all ports, it does not require filters to seperate the RF, LO and IF signals. This configuration also has the advantages of LO noise and spurious signal rejection and even order spurious response rejection. Therefore, the DB mixer configuration is used in the design of the 3 to 18 GHz monolithic mixer. Figure 1 shows the circuit schematic of the double balanced mixer.

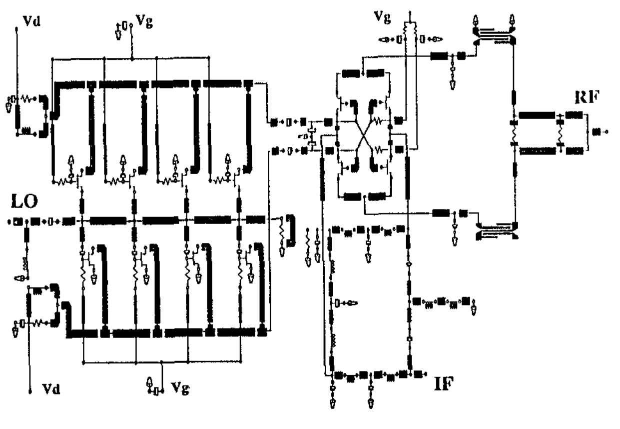

Fig. 1 Circuit schematic of DB resistive HEMT mixer.

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The mixer circuit consists of an AlGaAs/InGaAs HEMT quad, an active LO balun and two passive baluns, RF and IF. Four 160µm AlGaAs/InGaAs HEMTs with 0.25µm gate length are connected in a ring as the mixing devices. The HEMT acts as an variable resistor whose value is modulated by the LO signal voltage applied to the gate. The frequency conversion is achieved when a pair of balanced LO signals are used to switch ON and OFF in turn between two pairs of HEMTs of the quad while another pair of balanced RF signals are applied to two opposite nodes among the four of the quad. At the same time, two 180° out of phase IF signals appear at another two opposite nodes and are combined by the IF balun.

Due to its capability of insertion gain and very broad bandwidth, an active LO balun is used. The active LO balun is composed of two four-section distributive amplifiers with one in common gate and the other in common source configuration. The total device periphery is 504µm and the balun consumes about 100mA current at 4V drain voltage. To minimize the mixer's noise figure, the passive baluns are used at the RF and IF ports. The RF balun comprises a two-section Wilkinson power devider and a pair of Lange couplers. One of the Lange couplers is loaded with the open circuits while the other is loaded with the short circuits. This balun can operate over a bandwidth of up to 4:1. Since the IF frequency is low, a lumped element balun is preferable for the IF port. In this design, a lumped-element ratrace hybrid is chosen for the IF balun due to its small size and up to 50% bandwidth. The IF balun is implemented with the planar spiral inductors and MIM capacitors.

The major degradation factors for the mixer using nonideal switches are the nonzero ON resistance, the finite OFF resistance and the transition between the complete ON and OFF states. Therefore, the best performance of a resistive HEMT mixer is obtained when the device is biased slightly below its pinch-off voltage and driven with a sufficient high LO power to ensure a hard and fast turn-on and turn-off. Other degradation factors, such as the gate-to-source, gate-to-drain and darin-to-source capacitances, the gate, drain and source series resistances, and the parasitic inductances, are also important, but their effects can be minimized by the matching techniques in most cases. In this mixer design, the devices of the HEMT quad are biased at -1.3V gate voltage while the devices of the active LO balun are biaesd at -0.8V gate voltage.

CIRCUIT FABRICATION

The mixer circuit was fabricated on an MBE-grown wafer with an AlGaAs/InGaAs hetero-structure. Figure 2 shows the device structure. The InGaAs channel layer grown on

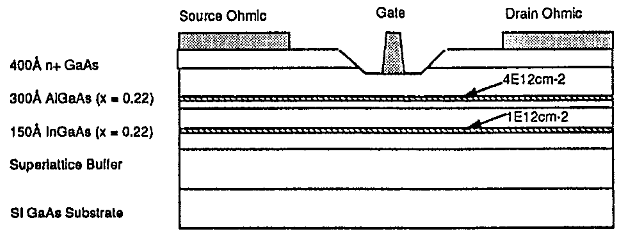

Fig. 2 Cross section of planar-doped channel AlGaAs-InGaAs HEMT.

top of the superlattice buffer is 150Å thick. A 300 Å AlGaAs donor layer and a 400 Å of $6x10^{18}$ cm^{-2} GaAs contact layer are then followed in sequence. The current capability of the device is increased by inserting a silicon planar doping of $1x10^{12}$ cm^{-2} in the center of the InGaAs channel in addition to the $4x10^{12}$ cm^{-2} in the AlGaAs donor layer.

The process begins with a multiple oxygen-ion implantations to obtain device isolation followed by an ohmic contact deposition. A low contact resistance is achieved by using Ni/AuGe/Ag/Au metal with rapid thermal alloying at 540°C. The first-level metal consisting of Ti/Au is then deposited and etched to provide the low-resistance interconnections and the bottom plate of the MIM capacitors. Gate resist is deposited and electron-beam lithography is used to define the 0.2- to 0.25-µm gate patterns. After the gate recess etching, the Ti/Pt/Au gate metal is evaporated and lifted off. Finally, a thin dielectric film (silicon-dioxide) is used to form the MIM capacitors and the top metal is defined using an air-bridge process. Lift-off techniques are used in both dielectric and top metal process steps. After the wafer is thinned to 4 mil thick, then, the backside metalization and via etching steps complete the whole circuit process. Reactive ion etching is used for the thru-substrate-via process to provide a low inductance ground path. Figure 3 shows a photograph of a completed 3.4 x 7.7 mm^2 monolithic mixer chip.

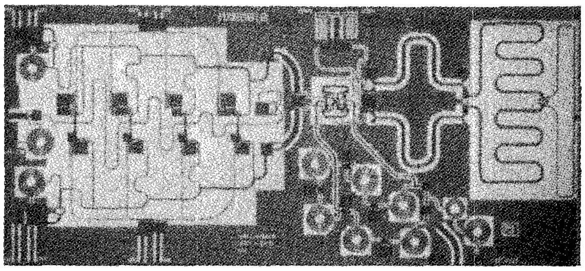

Fig. 3 Photograph of DB resistive HEMT mixer chip (3.4 mm x 7.7mm).

RF PERFORMANCES

Three baluns and the monolithic DB mixer were tested on-wafer with cascade RF probes. Figure 4 shows the measured performance of an active LO balun. The amplitude and phase unbalances between the two balanced ports are less than 1.5 dB and 10°, respectively, over the 1.5 to 15.5 GHz frequency band. However, the simulated performance of the LO balun shows good amplitude and phase trackings between two balanced ports up to 20 GHz.

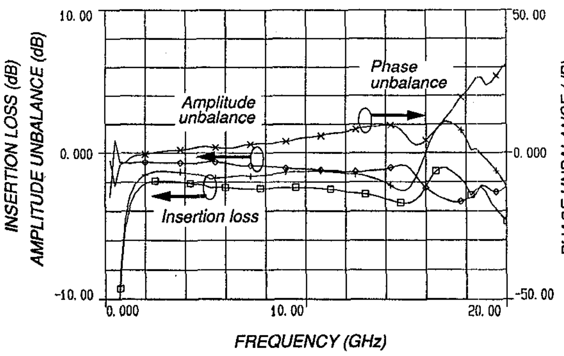

Fig. 4 Measured active LO balun performance.

The performance degradation above 15.5 GHz is believed to be caused by the self resonance of the 6-1/2 turns spiral inductor which was not taken into account in the simulation. The measured insertion loss including the 3 dB power splitting loss is between 1.5 and 3 dB from1.5 to 15.5 GHz. Figure 5 shows the measured performance of the RF balun. The insertion loss including the 3 dB power splitting loss is between 4 and 6 dB from 4 to 20 GHz.

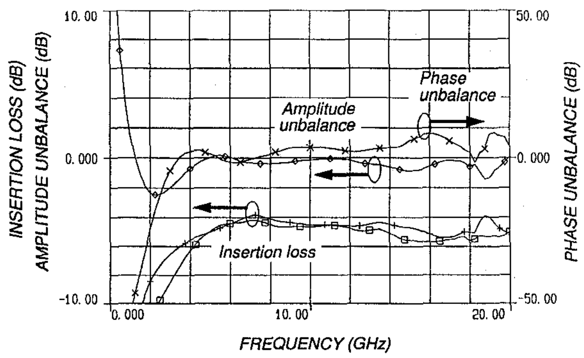

Fig. 5 Measured passive RF balun performance.

The amplitude and phase unbalances between two balanced ports are less than 1.5 dB and 8°, respectively, over the 4 to 20 GHz frequency band. The measured IF balun performance is in a very good agreement with the simulated result. Figure 6 shows the measured amplitude and phase unbalances and the return losses of the two balanced ports. As you can see in Figure 6, the amplitude unbalance is less than 0.5 dB while the phase unbalance is less than 3° from 0.75 to 1.3 GHz. The return loss of the balanced ports is better than 22 dB for the same frequency band.

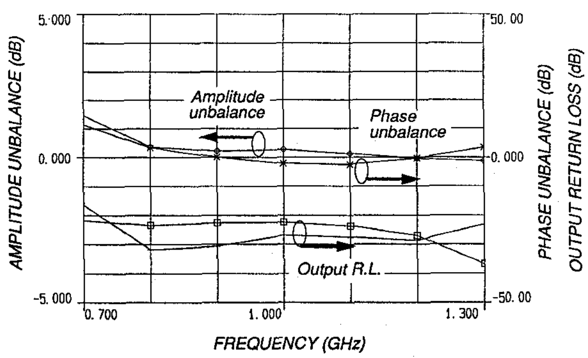

Fig. 6 Measured passive IF balun performance.

Figure 7 shows the comparison between measured and simulated conversion losses of the DB HEMT resistive mixer as function of the RF frequency. A fixed IF frequency of 1 GHz and LO drive of 16 dBm were used. The measured conversion losses are between 7.5 and 9 dB for 4 to 14 GHz RF and 7.5 and 11 db for 3 to 18 GHz RF. The agreement between the measured and simulated is within 2 dB from 2 to 16 GHz. The larger deviation between them at higher frequencies could be due to the self resonance of the spiral inductor in the LO balun which was not taken into account in the simulation. Finally, the third order input intercept (IP_3) is determined to be 26 dBm from a narrow band on-wafer two-tone measurement for 10 to 11 GHz RF. A fixed 1 GHz IF and 16 dBm LO power were used.

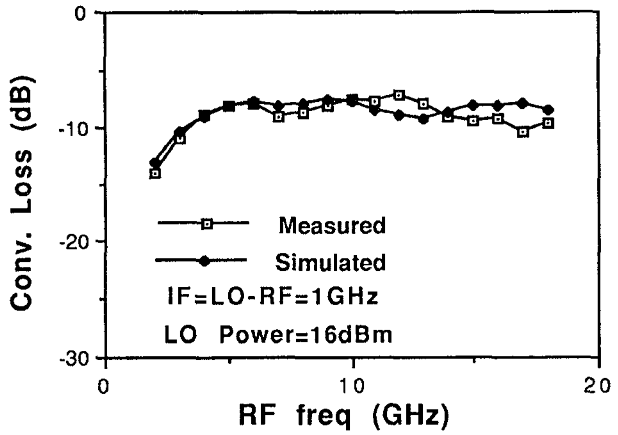

Fig. 7 Measured and simulated performance of DB resistive HEMT mixer.

CONCLUSION

A multioctave DB resistive HEMT monolithic mixer operating over a 3 to 18 GHz range has been successfully designed, fabricated, and tested. This mixer comprises a AlGaAs/InGaAs HEMT quad, an active LO balun, and two passive baluns, RF and IF. The mixer chip has demonstrated a conversion loss of 7.5 to 9 dB for 4 to 14 GHz RF and a conversion loss of 7.5 to 11 dB for 3 to 18 GHz RF. The simulated conversion loss is very much in agreement with the measured results. Furthermore, a third order input intercept of +26 dBm is achieved for 10 to 11 GHz RF and a fixed 1 GHz IF at a LO drive of 16 dBm. The well-performed DB resistive HEMT mixer is believed to be the first design with up to 6:1 bandwidth, making it a very useful component for future wideband systems.

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