20-GHz 5-dB-Gain Analog Multipliers with AlGaAs/GaAs HBTs

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ABSTRACT

From-DC-to-above-20-GHz monolithic Gilbert cell analog multipliers have been developed using AlGaAs/GaAs HBT technology. As a double balanced active mixer, it exhibits very high conversion gain of above +5 dB with extremely high LO-IF isolation of 33 dB for RF/LO inputs up to 20 GHz. As a detection mixer in coherent optical heterodyne receivers, it can operate for RF/LO inputs up to 15 GHz under a less than -7.5 dBm LO input condition.

I. INTRODUCTION

From-DC-to-ultra-high-frequency Gilbert cell analog multipliers using AlGaAs/GaAs HBTs, can be used for double balanced active mixers and upconverters in microwave applications, and for highly sensitive detection mixers in coherent optical heterodyne receivers. Coherent optical continuous phase FSK (CPFSK) transmission systems have been intensively studied for future long-span and high data rate optical communication systems[1].

Comparing with conventional diode double balanced mixers, the bipolar transistor active double balanced mixer has advantages of low LO drive power with high linearity, the ability to provide positive conversion gain, and eliminating the need for bulky hybrid balun circuitry. To date for these purposes, Si bipolar double balanced active mixers[2] and the GaAs HBT upconverter[3] up to 6 GHz have been developed.

In this paper, DC-to-above-20-GHz double balanced active mixers using AlGaAs/GaAs HBTs are described including the circuit design aimed at improving conversion gain, bandwidth and sensitivity. The measured results for the fabricated analog multipliers reveal the best performance ever reported with any technology.

II. CIRCUIT DESIGN

Two types of analog multipliers of similar circuit design but different emitter coupled pair structures have been designed. A schematic circuit of the developed analog multiplier is shown in Fig. 1. The Gilbert cell configuration is selected for its double balanced implementation which offers high conversion gain and improved spur performance in a very compact size. The RF or IF signal enters a lower amplifier formed by the emitter coupled pair. The LO signal enters an upper cross coupled quad of devices. Wideband impedance matching is set by 50 Ω resistors in shunt with the high input impedances of the RF or IF and LO devices, and by a 10 Ω resistor in series with the low output impedance of the emitter follower. Several MIM capacitors are newly adopted to enable single ended operation of the RF or IF and LO ports

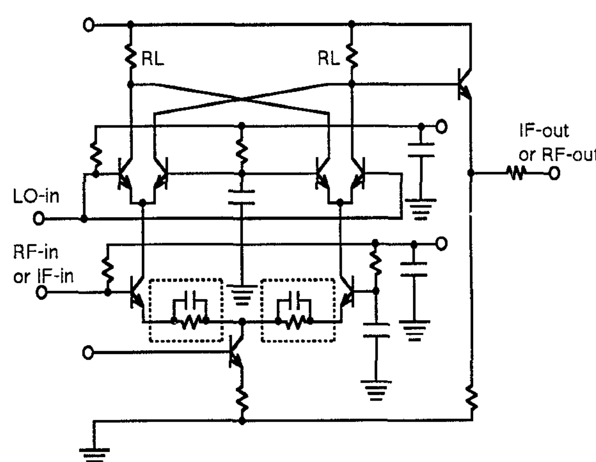

Fig.1 Circuit Configuration of an Analog Multiplier

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without baluns. The circuit does not use a balun, and is constructed very simply so as not to impair the HBTs' high performance.

(1) High-Gain and Wide-Band Mixer and Upconverter

To obtain a double balanced mixer and an upconverter in microwave applications, the series of negative-feedback emitter resistors and peaking capacitors enclosed in broken lines in the Fig. 1 were removed from the circuit. Using this configuration, a very high conversion gain from DC to ultra high frequency can be obtained by fully exploiting the HBTs' high performance.

(2) Wide-Band Detection Mixer

On the other hand, in the design of a detection mixer in coherent optical heterodyne receivers, the series of negative-feedback emitter resistors and peaking capacitors remain in the circuit. With this configuration, broad -3 dB bandwidth with adequate conversion gain under a low LO power condition can be obtained by adjusting the resistor and capacitor values.

III. EXPERIMENTAL RESULTS

The two types of analog multipliers described above were fabricated on an MBE-grown wafer using AlGaAs/GaAs HBTs with a self-alignment SSBE technology[4]. The cutoff frequency (fT) and the maximum oscillation frequency (fmax) were about 90 GHz and 60 GHz, respectively. A micro photograph of the analog multiplier MMIC chip is shown in Fig. 2. Chip size is 1.0 mm x 1.0 mm, and the layout of the circuit is symmetrical to obtain highly balanced circuit operations. To realize good matching at input and output ports, 50 Ω coplanar transmission lines were employed. All measurements were done on-wafer using coplanar RF probes.

(1) Mixer and Upconverter in Microwave Applications

Figure 3 shows the measured conversion gains versus LO frequencies for the double balanced mixers with various load resistor (RL) values of the Gilbert cell. The RF frequency is the LO frequency plus the IF frequency of 1 GHz. The LO input power level is only 0 dBm. In case of RL=400 Ω, the conversion gains are +9 dB for 5 GHz LO input, and +5 dB for 20 GHz LO input with 33 dB LO-IF isolation. Figure 4 shows the conversion gain of the mixer (RL=400 Ω) versus

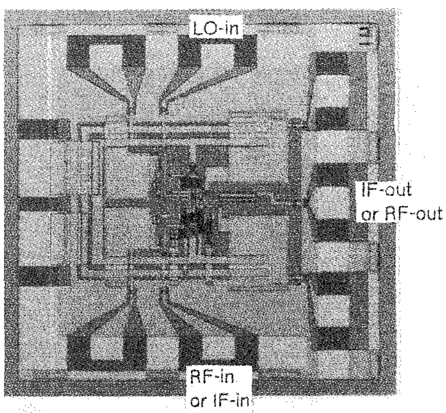

Fig.2 Micro photograph of an Analog Multiplier MMIC Chip

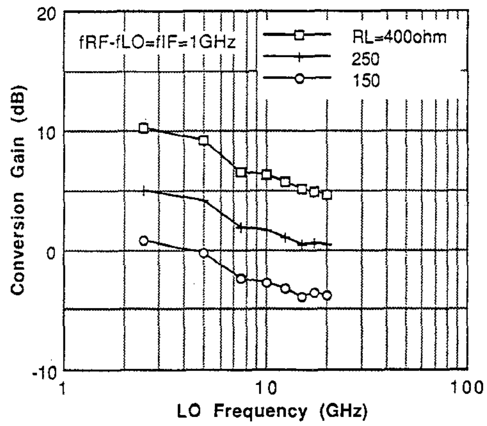

Fig.3 Conversion Gain vs LO Frequency; swept fRF and fLO, fIF=1GHz, PLO=0dBm

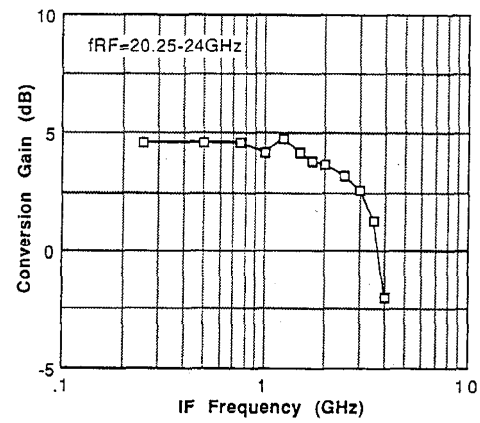

Fig.4 Conversion Gain vs IF Frequency; swept fRF, fLO=20GHz, PLO=0dBm

IF frequencies for fixed 20-GHz-LO input. The conversion gain decreases 3 dB and extends to 3.5 GHz. The measured input and output impedance matching characteristics are shown in Fig. 5. The RF/LO input matchings were kept below -10 dB from DC to above 20 GHz, and the IF output matching was also kept below -10 dB from DC to above 20 GHz. A plot of IF output power versus RF input power of the mixer (RL=400 Ω) for 20 GHz LO input is shown in Fig. 6. The circuit achieves an IF output power of -1.3 dBm at 1-dB compression. The circuits operated at power supply voltage of +9 V with power dissipation of only 90 mW.

The conversion gains for analog multipliers measured as double balanced upconverters are +5 dB for 5 GHz RF output, and 0 dB for 8.5GHz RF output with 23 dB LO-RF isolation in the case of RL=400 Ω, IF=1 GHz fixed and PLO=0 dBm.

(2) Detection Mixer in Coherent Optical Heterodyne Receivers

In coherent optical heterodyne CPFSK receivers, a delay differential detector circuit consisting of a double balanced mixer and a delay element, is used. This mixer is required to have ultra broad bandwidth of both RF/LO inputs and an IF output, high sensitivity, and large LO/RF-IF isolations.

Figure 7 shows the measured conversion gain of the mixer versus LO frequencies under a -7.5 dBm LO input condition. The RF frequency is the LO frequency plus the IF frequency of 0.5 GHz. The conversion loss is a very small 1 dB and increases 3 dB and extends to as wide as 15 GHz. Figure 8 shows the conversion gain versus IF frequencies when the LO frequency is 5 GHz fixed and the RF frequency is changed from 0.5 to 4.5 GHz and from 5.5 to 9.5 GHz. The conversion gain decreases 3 dB and extends to more than 4.5 GHz. The measured IF signal power to LO/RF signal power ratio at the IF output port versus LO and RF input power, is

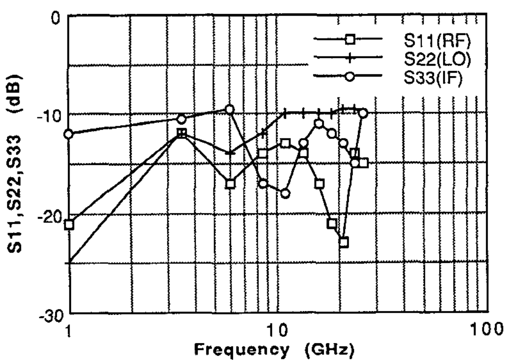

Fig.5 Input and Output Matching Characteristics; S11(RF),S22(LO),S33(IF)

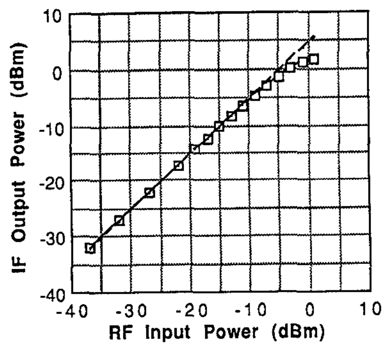

Fig.6 IF Output Power vs RF Input Power; fRF=21GHz,fLO=20GHz,fIF=1GHz, PLO=0dBm

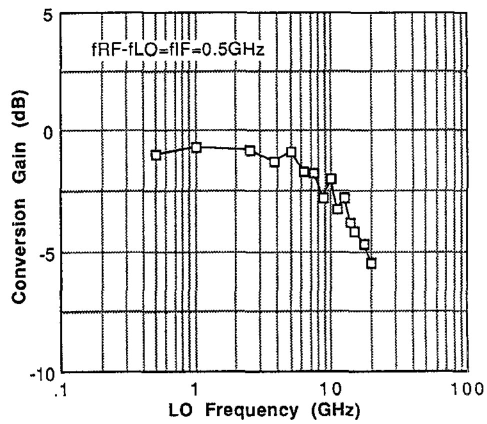

Fig.7 Conversion Gain vs LO Frequency; swept fRF and fLO, fIF=0.5GHz, PLO=PRF=-7.5dBm

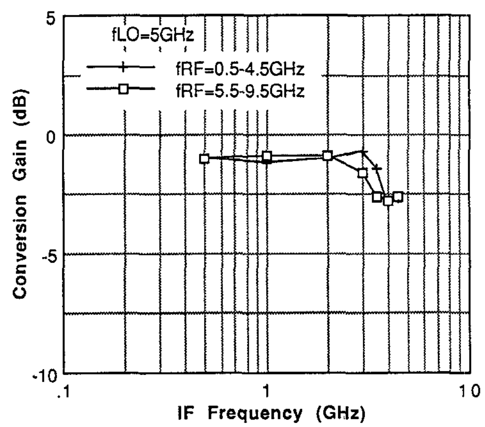

Fig.8 Conversion Gain vs IF Frequency; swept fRF, fLO=5GHz, PLO=PRF=-7.5dBm

shown in Fig. 9. In this figure, two measurement conditions (fRF=5 GHz, fLO=3.75 GHz, fIF=1.25 GHz, and fRF=3.75 GHz, fLO=5 GHz, fIF=1.25 GHz) are considered. The measured results show theoretically predicted linear characteristics. The worst-case ratio at -7.5 dBm LO and RF input power, is more than 24 dB. Since Fig. 10 shows conversion gain versus LO and RF input power for 5 GHz LO input, the mixer has high sensitivity even at the low LO and RF input power of -30 dBm. These results enable the realization of above-2.5-Gbit/s coherent optical heterodyne receivers.

IV. CONCLUSION

DC-to-above-20-GHz wide-band positive-gain monolithic Gilbert cell analog multipliers have been developed using AlGaAs/GaAs HBT technology.

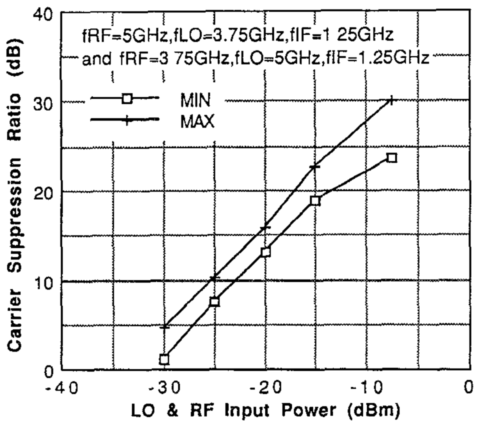

Fig.9 Output Carrier Suppression Ratio vs LO and RF Input Power

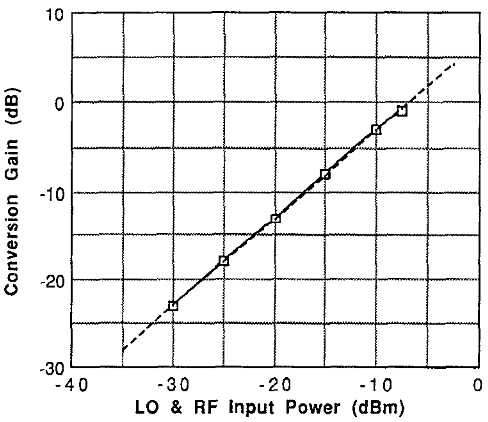

Fig.10 Conversion Gain vs LO and RF Input Power; fLO=5GHz,fRF=5.5GHz, fIF=0.5GHz

As the double balanced active mixer in microwave applications, it exhibits above +5 dB conversion gain for RF/LO inputs up to 20 GHz with 33 dB LO-IF isolation. As the double balanced upconverter, it exhibits positive conversion gain for RF output up to 8.5 GHz with 23 dB LO-RF isolation.

As the detection mixer in coherent optical heterodyne receivers, it can operate for RF/LO inputs up to 15 GHz under a less than -7.5 dBm LO input condition. This enables to realize above-2.5-Gbit/s coherent optical heterodyne receivers.

These performances for analog multipliers are the best reported to date in the world.

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