A HIGHLY COMPACT, WIDEBAND GaAs MESFET X - Ku BAND RECEIVER MMIC

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ABSTRACT

A fully integrated MMIC receiver was designed and fabricated using the ion-implanted GaAs MESFET 0.5 µm process. This MMIC receiver incorporates a two-stage RF amplifier, a two-stage LO amplifier, an IF amplifier and a singly balanced diode mixer to form this highly compact monolithic IC receiver. Better than 10 dB conversion gain is achieved from 9 to 20 GHz. The LO to IF isolation is better than 30 dB. This chip operates from a single + 5 Vdc and draws 175 mA. Total chip size is 3.5 mm x 3.0 mm.

INTRODUCTION

In recent years, monolithic integrated circuit technology has matured for individual microcell designs such as amplifiers and mixers. These developments have allowed the higher levels of integration to form MMIC's with more complex functions [1].

This paper presents the successful design, fabrication, and test of an octave bandwidth, receiver chip for X-thru Ku-band application. The receiver downconverts an input X-to Ku-band frequency to a S-band IF frequency (2.5 to 3.5 GHz) in two modes of operation, depending on the LO injection. The operating RF frequency range is from 9.5 to 15.25 GHz with high side LO injection and measured conversion gain of 11 to 16 dB. The other RF frequency range is from 12.5 to 19.5 GHz with low side LO injection and measured gain is 12 to 15 dB.

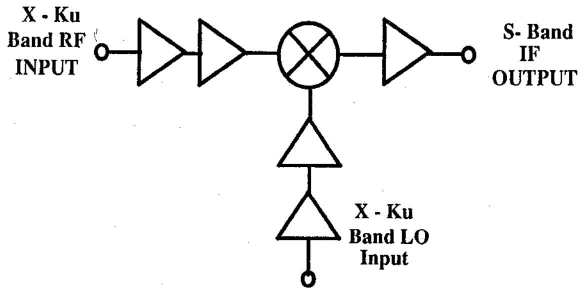


Figure 1 : Block diagram of MMIC receiver chip

RECEIVER DESIGN

Figure 1 shows the circuit configuration of the complete MMIC receiver. It consists of a two-stage RF amplifier, a two-stage LO amplifier, a singly-balanced diode mixer and a single-stage IF amplifier. The RF and LO amplifier share the same circuit design except with different layout to conform to the overall chip outline. The chip, shown in Figure 2, measures 3.5mm x 3.0 mm.

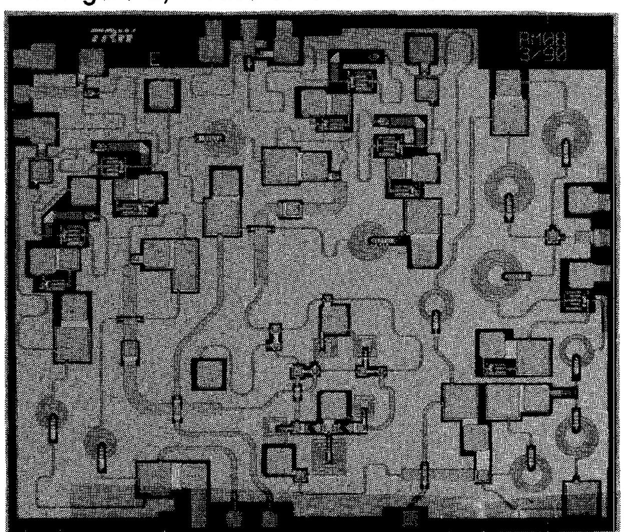


Figure 2 : Fabricated MMIC receiver chip

RF/LO AMPLIFIER

Figure 3 shows the circuit schematic of the RF and LO amplifiers. They incorporate negative feedback and bandpass matching networks to assure wideband coverage for RF (9.5 - 19.5 GHz) and LO (11.5 to 16.5 GHz) performance. Each stage employ 300 µm devices. Included in the design are active 150 µm current source's connected series with RF FETs. Both stages are biased at 50% Idss to provide moderate gain ≥ 10dB / noise figure ≤ 6dB and power handling characteristics (P1dB ≥ +12dBm). One advantage of this bias scheme is that 50% Idss is maintained across the wafer regardless of pinch-off voltage variation.

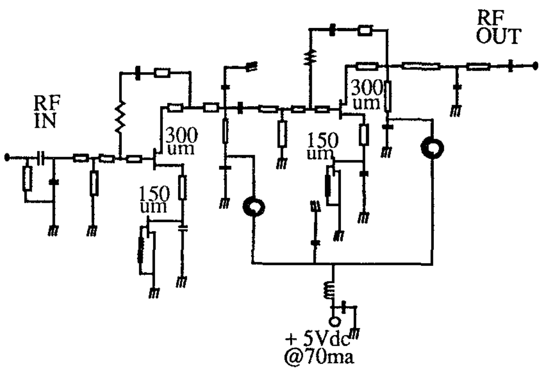


Figure 3 : Schematic RF/LO amplifier

SINGLY BALANCED MIXER DESIGN

The mixer employs a singly balanced circuit topology. Two 0.5 µm x 20 µm Schottky diodes are used as the mixing elements. The input balun constructed from high/low pass filter networks and covers a 9.5 - 19.5 GHz band [2]. These networks also provide the necessary RF and LO matching networks. Figure 4 shows the mixer circuit schematic. The IF signal of the mixer is extracted thru a low pass IF filter. RF and LO matching networks are realized with MIM capacitors and high impedance transmission lines. Capacitors are used to block IF signal from RF and LO ports as well as couple RF and LO signals to the diodes. Lowpass filter couples the IF signal from the diodes to the input of the IF amplifier. The lowpass filter was realized with spiral inductors, MIM capacitors and high impedance transmission lines.

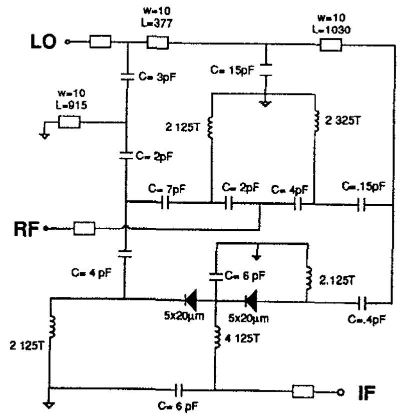


Figure 4 : Singly balanced diode mixer schematic

IF AMPLIFIER

The IF amplifier(Figure 5) is a single-stage amplifier uses a 0.5µm x 300µm MESFET. It is also self-biased with a 150µm FET current source. The design utilizes a lossy-R and bandpass matching network for the input impedance matching. The IF amplifier operated from 2.5 to 4GHz.

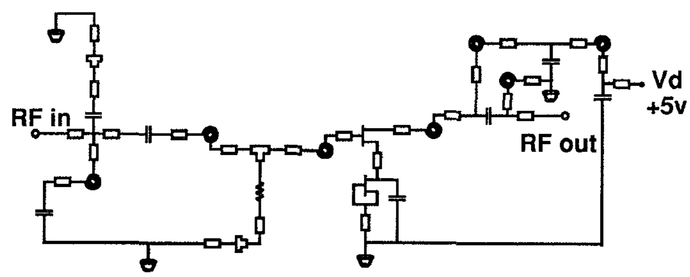
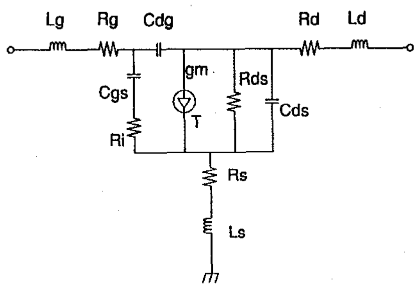


Figure 5 : IF amplifier schematic

FABRICATION

The MESFET's were fabricated using one of TRW's readily available FOUNDRY processes for 0.5µm MESFET's. Other's include sub-micron HEMT and HBT processes at our FOUNDRY. This 0.5µm GaAs MESFET baseline process formed the necessary structures (FET's/Diodes) for this design. Figure 6 shows the equivalent circuit for the 0.5µm x 300µm MESFET used in this design. For diodes , a size of 0.5 x 20µm was chosen. At zero bias, these diodes have a series resistance about 30 ohm , a junction capacitance about 0.04 pF, this corresponds to an f_t of 133 GHz.



Lg	Rg	Cgd	Cgs	Ri	gm	tau	Rds	Cds	Rs	Ls	Rd	Ld
.034	3.9	0.039	.223	1.1	.037	2.9	191	.073	0.4	.009	2.1	.026

Figure 6: MESFET equivalent circuit device model

RF PERFORMANCES

Monolithic receiver chip, RF/LO amplifiers, mixer, and IF amplifier were fabricated using MESFET technology. The measurements were done using automatic on-wafer probe station.

Measurements on the RF (Figure 7) and LO (Figure 8) show the desired passband response. Both ampifier's exhibited ≥ 10dB gain/ ≤ 6.5dB noise figure with P1dB ≥ +12dBm.

Figure 9 shows the measured performance of the singly balanced mixer's conversion loss ≤ 13dB and with ≥ 30dB isolation across the band.

Figure 10 shows the conversion gain responses of the receiver chip for both modes of operation, high side and low side LO(3dBm) injection. Figure 10(a) is the response with high side LO injection. In this case, the RF(-10dBm) is swept from 7.25 to 15.25 GHz, and the LO is swept from 10 to 18 GHz for a fixed 2.75 GHz IF frequency. The measured conversion gain is 13.5 ± 2.5 dB from 9.25 to 15.25 GHz. Figure 10(b) is the response with low side LO injection. In this case, the RF(-10dBm) is swept from 12 to 21 GHz, and the LO is swept from 9.25 to 18.25 GHz for a fixed 2.75 GHz IF frequency. The measured

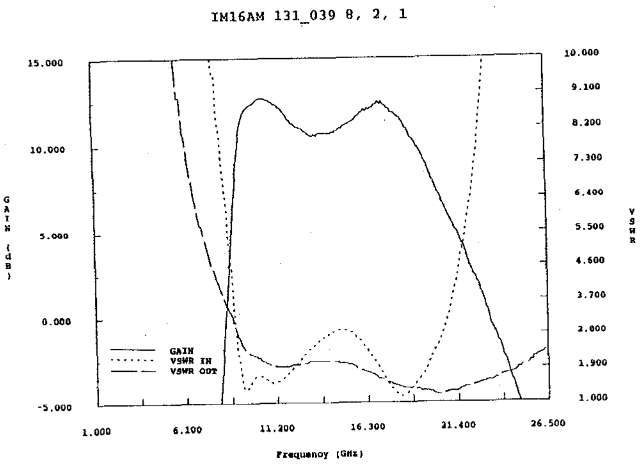


Figure 7 : RF amplifier measured response

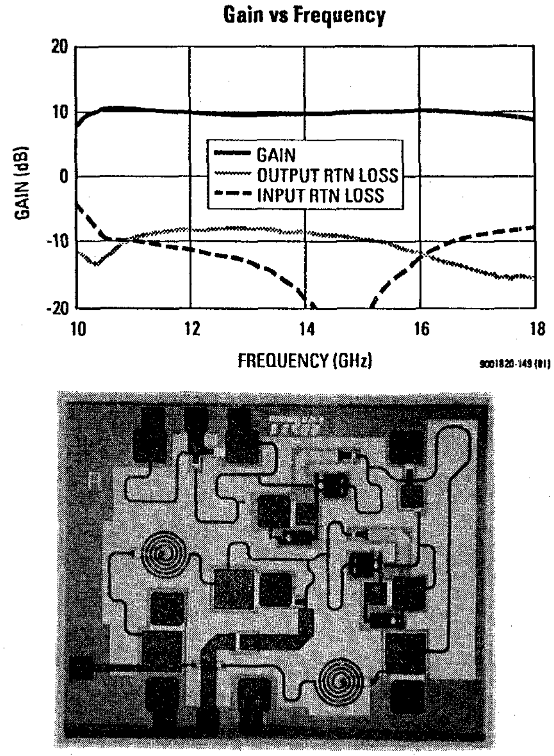


Figure 8 : LO amplifier measured response and fabricated microcell

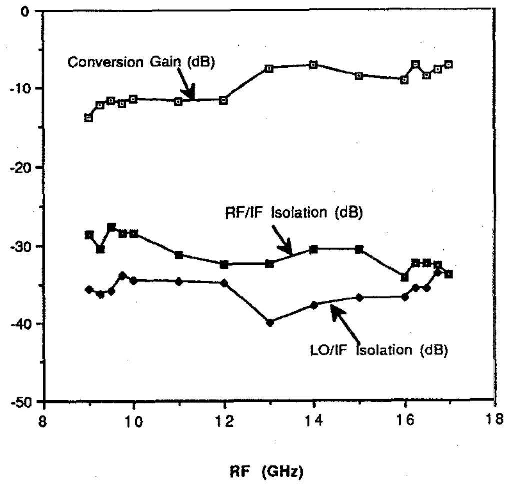


Figure 9 : Singly balanced mixer conversion loss and isolation measurements

conversion gain varies from 12 to 15 dB from 12.5 to 19.5 GHz.

Figure 11 shows the measured output Ip3 of the receiver chip at X-Band and Ku-Band frequencies. X-Band Ip3 revealed 15.5 dBm. At Ku-Band Ip3 measured 18.5 dBm. Pin was @ -16dBm, with Plo set to 4dbm. Input RF 2 tone separation was 100MHz. IF output measured at X-Band/Ku-Band was -3.7dBm/-3.5dBm respectively. Overall receiver chip noise figure measured between 8-9 dB DSB across X-Ku-band (RF to IF noise figure).

The circuit operates from a single +5Vdc and draws a total 175 mA.

CONCLUSION

A Highly compact, wideband GaAs MESFET X-Ku-band octave bandwidth receiver MMIC has been demonstrated. Higher levels of integration are possible as this technology develops. This opens new areas for very compact receivers in monolithic form. Along with this will be the ability to mass produce cost effective units and lighter weight systems.

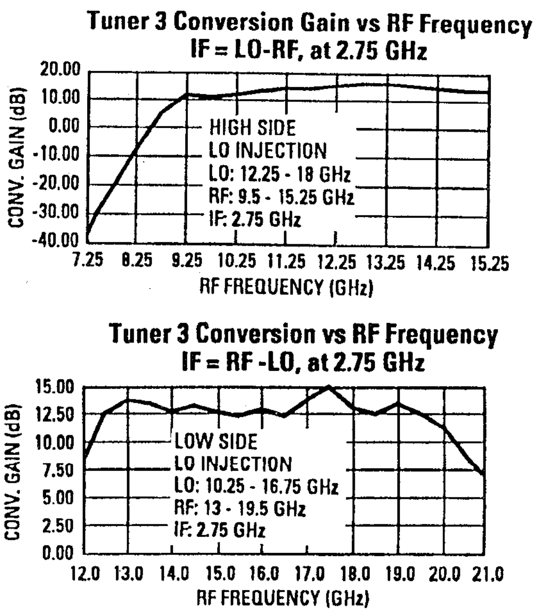
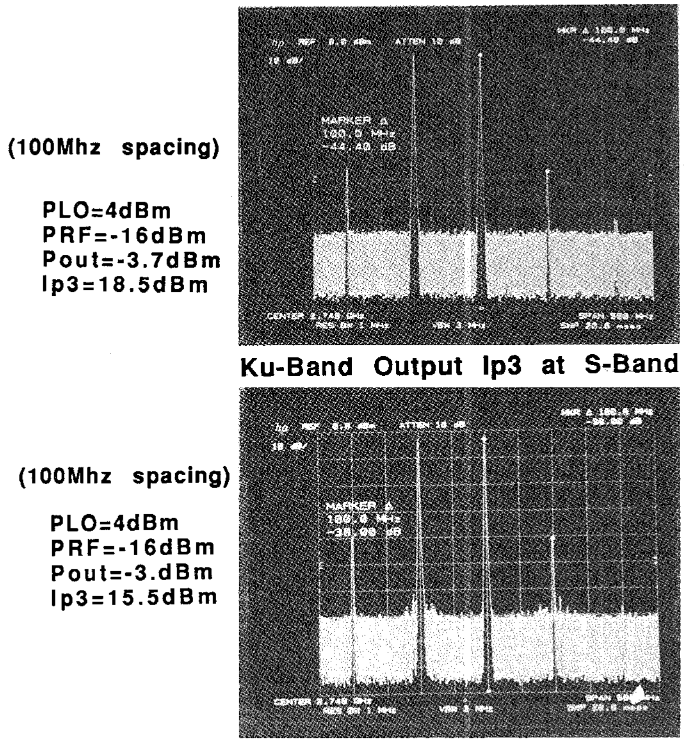


Figure 10 : MMIC receiver conversion loss X - Ku - band measurements



X-Band Output Ip3 at S-Band

Figure 11 : Output IP3 measurements of receiver

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REFERENCE

[1] R. Ramachandran, et al, 'An 8-15 GHz Monolithic Frequency Converter', in IEEE MMIC Symp dig., 1987, pp. 31-34.
[2] T.N. Ton,et al, 'An X-band Monolithic Double Double-Balanced Mixer for High Dynamic Receiver Applications', in IEEE MMIC Symposium dig., 1990 , pp. 115-118.