DIELECTRIC RESONATOR 12.5 GHz HEMT MIXER

Edmar Camargo and Denise Consoni
Laboratorio de Microeletronica
Universidade de São Paulo
CEP 01051 - Cx.P 8174
São Paulo - Brazil

ABSTRACT

The design and performance characteristics of a HEMT mixer for converting the 12250 - 12750 MHz RF band to the 900 - 1400 MHz IF band is presented. The mixer exhibited a conversion gain of 4 dB ±0.2 dB over the IF band, and 4 dB average SSB noise figure, which compares favourably with MESFET counterparts. A dielectric resonator coupling structure is proposed for separating the LO and RF signals, while applying both at the device gate.

INTRODUCTION

Recently there has been a great interest in the application of HEMT devices in low noise amplifiers[1], where they have shown superior noise performance compared to MESFETs. Low noise figures of HEMT devices are due to their higher transconductance at lower bias currents, associated with lower gate-to-source capacitances and parasitic resistances. The application of this device to other circuit functions such as oscillators and mixers has also been investigated for millimeter waves[2], and the published results are comparable or superior to MESFETs.

The subject of this paper is to present the design and performance characteristics of a HEMT mixer for converting the 12250 - 12750 MHz RF band to the 900 - 1400 MHz IF band. The device's non-linear transconductance characteristic is used for mixing purposes, and the transconductance compression usually observed in HEMTs is shown not to affect appreciably the mixer performance. Also, a simple and easily implementable structure is proposed for adding the RF and LO signals at the input gate.

HEMT CHARACTERISTICS

The active device employed in the design is a low noise packaged HEMT, type 2SK677 by SONY, featuring a gate area of 0.5x300 sq. microns. It boasts a nominal minimum noise figure of 1 dB at 12 GHz with associated power gain of 11 dB. The MOCVD technology is employed for the AlGaAs/GaAs heterojunction formation and its geometry is defined by standard UV contact photolitography. Further construction details of this device can be found in the literature[3].

The dynamic transconductance, g_m in function of gate voltage, as measured at 100 MHz is shown in figure 1. It is observed that the transconductance increases with gate voltage from -1 V to -0.36 V where it reaches its maximum value, which equals 63 mS. Beyond that voltage, g_m suffers a degeneration effect caused by parasitic conduction[4] in theAlGaAs layer .

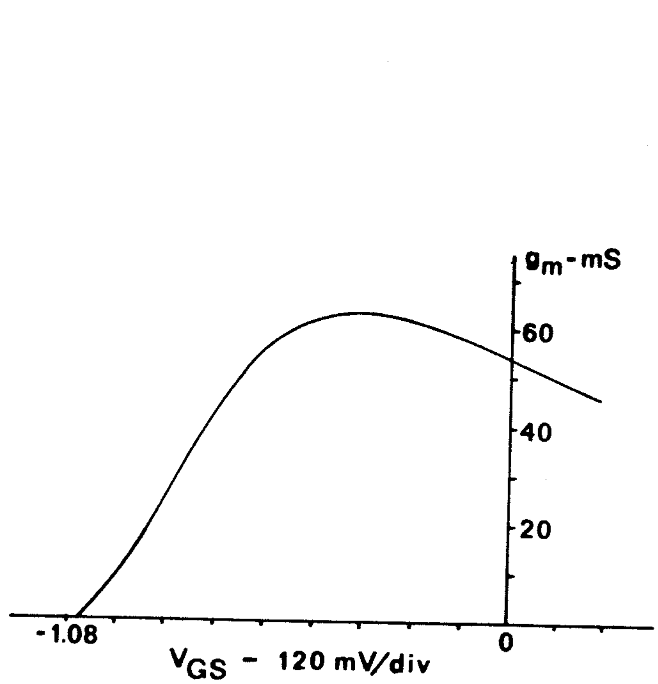


Fig 1 - Dynamic transconductance as a function of gate voltage

The input and output capacitances of the chip are low but are considerably affected by the package parasitics. For instance, the chip input capacitance, C_{in}, of 0.25 pF at V_{GS} = - 0.6 V is increased to 0.5 pF for the packaged version. However, as it will be shown this is not a serious limitation for narrow bandwidth designs.

DESIGN CONSIDERATIONS

A high LO dynamic voltage applied to the gate, which is biased at pinch-off, causes the transconductance to become a time varying function, $g_m(t)$. The mixing effect takes place at the drain, since a low RF voltage also applied to the gate appears in the drain multiplied by $g_m(t)$. The conversion gain, Gc[5], is affected by this process through the fundamental component of the transconductance waveform, g_{m1}, as expressed in equation (1). Matched input conditions for a simplified unilateral transistor model is assumed in the derivation of this expression. Therefore, only an estimate of the gain characteristics can be obtained.

$$Gc = \frac{g_{m1}^{2} \cdot R_L}{w^2 C_{in}^{2} \cdot R_{in}} \qquad (1)$$

where,

R_{in} = equivalent input resistance
R_L = load resistance

Based on this equation and on the g_m characteristic of figure 1, one concludes that conversion gain increases with the LO level up to the maximum transconductance. Higher LO levels result in g_m waveforms which contain lower

g_{m1} components and hence lower conversion gain. Inspection of figure 1 shows that an approximate square waveform for $g_m(t)$ can be obtained if a dynamic voltage, Vpeak = 0.96 V, is applied to the gate which is biased at V_{GS} = - 1.1 V. The LO power, Pe, required for this excursion can be estimated from equation (2), which was derived under the same assumptions considered for equation (1).

$$Pe = \frac{R_{in}}{2} \cdot (Vpeak\, w\, C_{in})^2 \tag{2}$$

The device employed in the design may be modelled by an equivalent series RC input circuit (R_{in} = 5 Ohms and C_{in} = 0.5 pF). Then, the required LO power at 11.35 GHz for full g_m modulation is calculated to be + 4.7 dBm. For this power level, g_{m1} equals 20 mS giving a conversion gain of 4.2 dB, according to equation (2).

The drain circuit indicated in figure 2, consists of a $\lambda/4$ open stub at 11.35 GHz at a distance θ_2 from the lead, such that the effective device impedance is series resonated by the virtual ground imposed by the stub. This conventional procedure assures that the dynamic drain voltage is zero for the LO signal and the dynamic current remains in the saturated region. Second harmonic is reduced by placing a $\lambda/8$ open stub at the fundamental frequency virtual ground. The IF impedance of the device was not matched at the output due to its high value over the IF bandwidth.

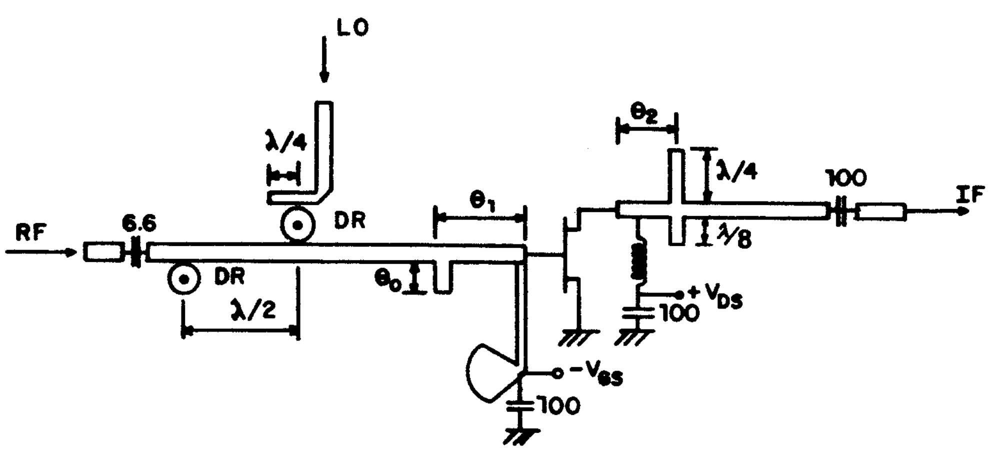


Fig 2 - Mixer equivalent circuit
(Capacitances are in pF)

The design of the gate circuit is more complex since it must simultaneously match the LO and RF generator impedances. A rigorous design would require the aid of linear and non-linear programs, involving network synthesis and optimization procedures. However,there is an alternative approach consisting of direct impedance measurement by means of a network analyzer. This method gives faster and reasonably accurate results for narrow RF bandwidth design, especially when packaged devices are employed, since they are difficult to model. Applying this latter technique leads to the conclusion that the input can be matched by a single open stub (length = θ_0), located approximately at $\lambda/2$ (length = θ_1) from the gate at the LO frequency. The gate bias network is such that the IF band is terminated by a low reactance.

One of the problems imposed by single gate devices, when used for mixing purposes, is the need for applying two signals (LO and RF) into a single access (gate), while maintaining a high degreee of isolation between them. A solution is proposed in this paper, consisting of a coupling circuit, which makes use of dielectric resonator bandpass and bandstop filters, as shown in figure 2. The frequency response of the LO coupling circuit is indicated in figure 3. A minimum insertion loss of 2 dB and maximum LO-to-RF isolation of 20 dB at the LO frequency can be observed. This structure causes an insertion loss lower than 0.1 dB within the RF band. The total RF loss from the SMA input to the gate lead is less than 0.35 dB.

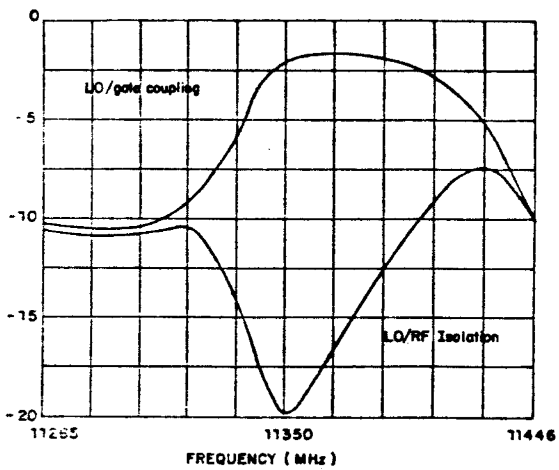


Fig 3 - LO coupling circuit frequency response

The circuits were manufactured employing thin-film technology on 0.4 mm thick alumina substrates. The coupling circuit is finely tuned by adjusting the resonant frequency of the dielectric resonators, by means of a large screw located in the cover of the unit. A photograph of the mixer is on figure 4.

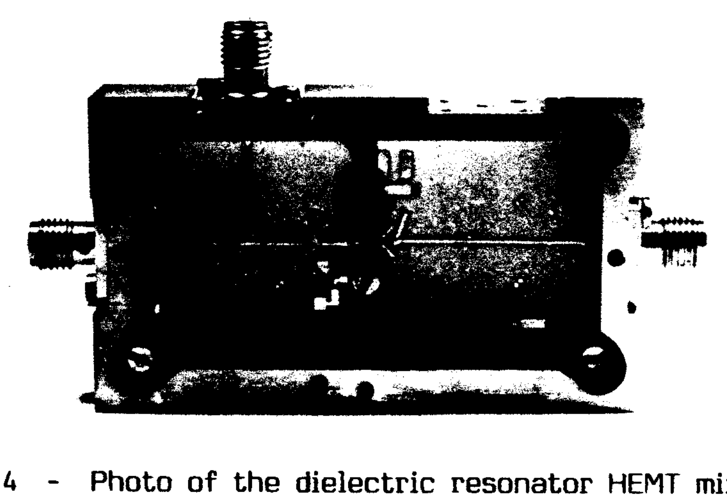
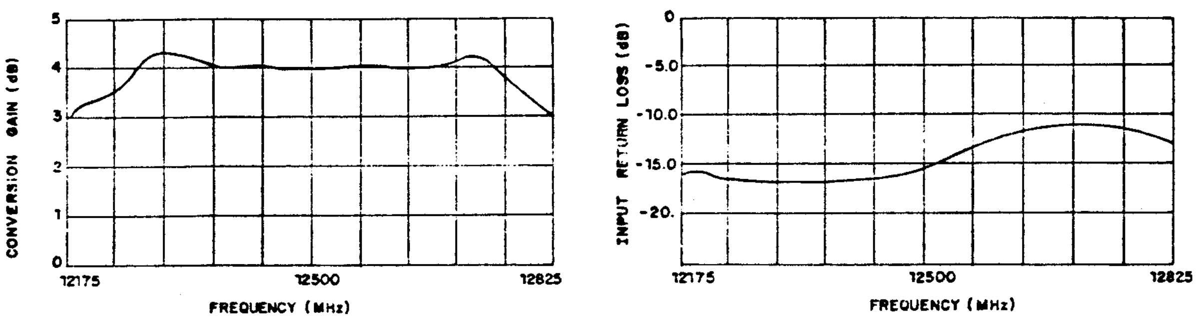


Fig 4 - Photo of the dielectric resonator HEMT mixer.

EXPERIMENTAL RESULTS

The mixer was initially adjusted for maximum conversion gain tuned at 12.5 GHz, with the device biased at V_{GS} = - 1.1 V and V_{DS} = + 2.5 V. The LO power was set at + 7 dBm, greater than the estimated value through equation (2),to account for losses in the coupling circuit. Under these conditions a maximum conversion gain of 3.8 dB was obtained. Then, different gate bias and LO power were investigated for a higher gain performance. It was found that at V_{GS} = - 1.25 V and for a LO power of + 9 dBm the gain was raised to 6 dB. The next step was the adjustment of the input circuit for flat gain response. The results are displayed in figure 5.



(a) (b)

Fig 5 - Conversion gain (a) and RF return loss (b) as a function of frequency.

A gain of 4 dB with a ripple less than 0.2 dB over the 500 MHz IF band could be attained. The 1 dB bandwidth exceeds 600 MHz. The input return loss shown in figure 5, reaches a minimum value of 12 dB, corresponding to a VSWR lower than 1.7 . The IF impedance was not matched and requires a low VSWR load. The minimum output power within the band, at the 1 dB compression point equals 0 dBm. The SSB noise figure is shown in figure 6, with a minimum at 3.8 dB and a maximum value of 4.5 dB. This result was obtained with a little increase in the LO power to + 10 dBm and a slight decrease in the drain bias to 2 V. This procedure does not affect the gain response but reduces the maximum output power.

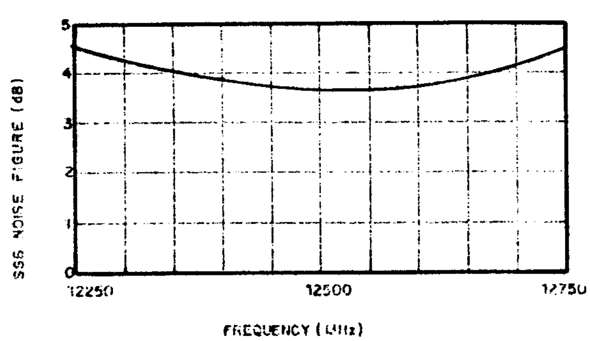


Fig 6 - SSB Noise figure frequency response

CONCLUSIONS

This paper described the design, realization and performance of a packaged HEMT mixer for operation at 12 GHz, with a high IF frequency. A method of employing dielectric resonators for separating the LO and RF generators and applying both signals to the gate has been proposed. The coupling structure proved to be easy to adjust and presented good electrical characteristics. The mixer exhibited a noise figure performance that compares favourably with that presented by MESFET counterparts. Finally, it can be suggested that the overall electrical performance of this type of mixer recommends its application also in the design of microwave X-band receiver front-ends.

ACKNOWLEDGEMENTS

This work received the financial support from the CPqD - TELEBRAS Research & Development Center, Campinas-Brazil. Thanks are also due to Mr Antonio Sandro Verri for his contribution in the circuit realization steps.

REFERENCES

1 - Sholley, M. et al. - "36 - 40 GHz HEMT low-noise Amplifier", IEEE Int. Microwave Symp. Digest, pp 555 - 558, June 1985.

2 - Sholley, M. et al. - "HEMT mm-wave Amplifiers, Mixers and Oscillators", Microwave Journal pp 121 - 131, August 1985.

3 - Takakuwa, H. et al. - "A Low-Noise Microwave HEMT Using MOCVD", IEEE Trans. on Elect. Devices, vol ED-33, Nº 5, pp 595 - 600, May 1986.

4 - Lee, K. et al. - "Parasitic MESFET in (Al,Ga)As/GaAs modulation doped FET's and MODFET characteristics", IEEE Trans. on Elect. Devices, Vol ED-31, pp 29 - 35, Jan 1984.

5 - Maas, S. A. , "Design and Performance of a 45 GHz HEMT mixer", IEEE Trans. on Micro. The. and Tech., Vol MTT-34, Nº 7, pp 799 - 803, July 1986.