Using a Negative Conductance for Optimizing the Resistive Mixers Conversion Losses

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Abstract

This paper describes a novel and simple method of compensation for resistive mixers conversion losses. We show that a negative conductance can be used to optimize the resistive mixers conversion losses. Finally, we present the design and the simulation of an optimized simple MMIC resistive mixer with 0 dB conversion loss.

Introduction

The continual advancement of III-V heterostructure FET-based low-noise amplifiers and their corporation into high performance receivers at microwave and millimeter-wave frequencies has prompted focus on other areas of the receiver subsystem in need of improvement. FET-based mixers have been investigated for many years with emphasis on active single or dual gate FET mixers designs. Drawbacks of the active FET mixers include high noise figure for the dual gate gate design and poor 1/f noise characteristics at low IF frequencies, high IMD levels and low 1 dB - compression for both single and dual gate design.

The FET resistive mixer is a relatively new idea. Passive FET based mixer was first proposed in [1], using the FET as a variable resistance element with no drain bias. The advantages of this approach are very low distortion, low 1/f noise, low DC power consumption and no shot noise.

The conversion loss of such mixer is comparable to diode mixers, around 6-7 dB.

In the resistive mixer topology, the FET device is operated in its common-source configuration and the LO is applied to the gate to modulate the channel conductance from pinch-off to fully conducting. The RF is applied at the drain, which is biased at zero volts, so the varying channel resistance beats with the RF and generates a low frequency IF signal at the drain. Appropriate filtering is used to extract the IF signal from the drain. Choosing a FET representing 20mS of linear conductance, one could match easily the mixer to 50Ω RF source and IF load, in a wide frequency band. The IF signal, extracted from the drain, has to be amplified, and it involves all the problems of microwave wide-band amplification.

In this paper, we propose a very simple and effective method to compensate for the conversion losses of the resistive mixer over a very wide band and with a very low noise.

Performance limitations of the FET resistive mixers

One of the major limitations of the passive mode FET mixers is their conversion loss. To demonstrate it we will use the conversion matrix theory.

Let us consider the circuit of fig. 1. This is a mixer with a time-varying conductance G(t) where R_L represents the load resistance as well as the resistance of the RF source.

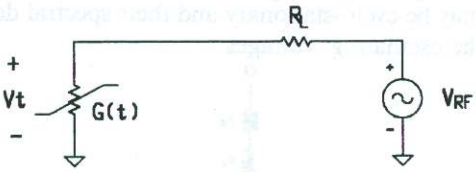

Fig. 1. Time-varying conductance mixer.

If we consider the time-varying conductance as $G(t) = G_0 + 2G_1\cos(\omega_p t)$, where ω_p is the pumping frequency, the network equation for SSB operation is:

$$\begin{bmatrix} I_0 \\ I_1 \end{bmatrix} = \begin{bmatrix} G_0 & G_1^* \\ G_1 & G_0 \end{bmatrix} \begin{bmatrix} 0 \\ V_t \end{bmatrix}$$

$$\text{or} \quad \mathbf{I} = \mathbf{G.V} \qquad (1)$$

where **G** is the conversion matrix, I_0 is the IF current and I_1 the RF current. In the case of matched circuit $R_L = G_0^{-1}$ and thus $|V_t| = 0.5\,|V_{RF}|$.

The available RF input power is :

$$P_{RFav} = \frac{|V_{RF}|^2}{8R_L} \qquad (2)$$

and the output IF power is :

$$P_{IF} = 0.5|I_1|^2 R_L \qquad (3)$$

The conversion loss can be evaluated as:

$$L_C = \frac{P_{RFav}}{P_{IF}} = \frac{1}{G_1^2 \cdot R_L^2} = \frac{G_0^2}{G_1^2} \qquad (4)$$

In figure 2 we show the simulation results of the time-varying conductance of a pumped cold MMIC HEMT from Philips Microwave (fabrication process PHEMT D-02AH, W=1x75 μm). We used a home-made model, the gate was biased at the pinch-off and the LO signal achieved the direct conducting voltage Vd of the transistor. The pumping frequency was 3 GHz.

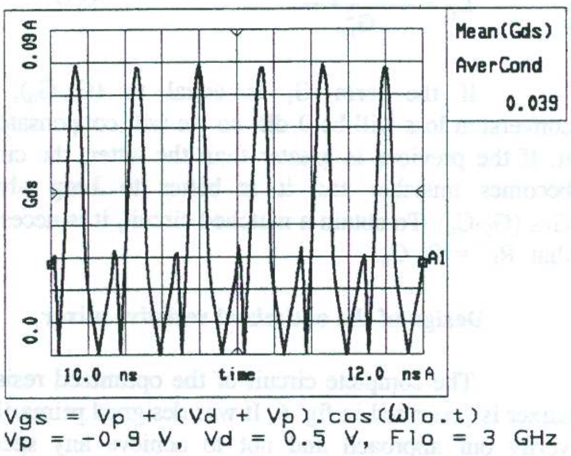

Fig. 2. Time-varying conductance.

Decomposing this waveform in Fourier series and neglecting all terms of higher than 1 order, we obtain for the time-varying conductance of this FET:

$$G(t) = 0.039 + 0.040\cos(\omega_p t) \qquad (5)$$

We are interesting in the SSB operation of the mixer, so the corresponding to the G-matrix of (1) terms are G_0 = 0.039 S and $G_1 = G_1^*$ = 0.020 S. Using the relation (4) we obtain for the minimum losses (neglecting the capacitances of the topology):

$$L_C = 3.8 = 5.8 \text{ dB} \qquad (6).$$

The filters, matching circuits and the parasitic capacitances introduce additional losses and the real conversion loss of a well designed cold FET mixer is about 6-7 dB.

For a passive mode pumped FET the term G_0 is always higher than G_1 and we can never obtain 0 dB loss.

For compensate for the losses we propose to connect a wide band negative conductance in parallel with the time-varying conductance to decrease the average conductance G_0. If the equivalent values of G_1 and G_0 are equals, the corresponding conversion loss [see (4)] will be 0 dB.

Negative conductance

Recently, various authors proposed FET's circuits topologies representing negative conductance or resistance [2,3]. In the microwave region, negative conductance can have many applications. It may be used to compensate for losses in amplifier circuits, in oscillators or as a means of enhancing the Q-factor of microwave filters.

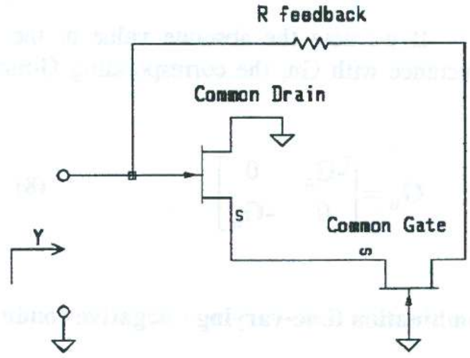

Fig. 3. Negative conductance topology

To obtain a negative conductance, we used the proposed in [3] circuit topology, fig. 3. The simulation results of the performance of the circuit are presented in fig. 4.

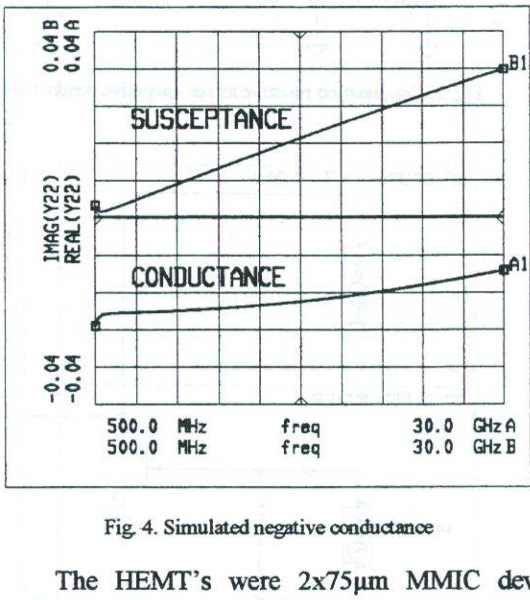

Fig. 4. Simulated negative conductance

The HEMT's were 2x75μm MMIC devices from Philips Microwave (fabrication process PHEMT D-02AH) and we used the model available from the design manual of the foundry. As it can be seen from the presentation, the equivalent conductance is negative and nearly constant over a very wide band of frequencies. The circuit represents also a non negligible capacitance.

As presented in [3], the value of the negative conductance depends on the transconductance of the FET and can be controlled by the transistor's gate width, the gate bias or the value of the feedback resistance.

Using the same approach as in the previous part we can represent the negative conductance via its conversion matrix. The conversion G-matrix of a resistive linear time-invarying element is :

$$\mathbf{G}_L = \begin{bmatrix} G_L & 0 \\ 0 & G_L \end{bmatrix} \quad (7)$$

If we note the absolute value of the negative conductance with Gn, the corresponding G-matrix will be :

$$\mathbf{G}_n = \begin{bmatrix} -G_n & 0 \\ 0 & -G_n \end{bmatrix} \quad (8)$$

Combination time-varying - negative conductance

Let us take now the circuit of fig. 5. It is a combination of a time-varying conductance G(t), presented in part 2, and a negative conductance, part 3.

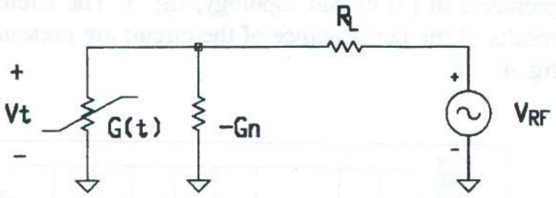

Fig. 5. Combination resistive mixer - negative conductance

Using (1) and (8) we can find the conversion G-matrix of this structure:

$$\mathbf{G}_t = \begin{bmatrix} G_0 - G_n & G_1^* \\ G_1 & G_0 - G_n \end{bmatrix} \quad (9)$$

The conversion losses of the circuit can be evaluated as:

$$L_C = \frac{(G_0 - G_n)^2}{G_1^2} \quad (10)$$

If the term G_1 is equal to $(G_0\text{-}G_n)$, the conversion loss will be 0 dB, so we will conpensate for it. If the previous is greater than the latter, the circuit becomes unstable and it is better to keep always $G_1 \leq (G_0\text{-}G_n)$. To obtain a matched circuit, it is necessary that $R_L^{-1} = G_0\text{-}G_n$.

Design of the optimized resistive mixer

The complete circuit of the optimized resistive mixer is presented in fig. 6. It was designed primarily to verify our approach and not to achieve any specific performance. The left part of the scheme represents a traditionnal FET mixer where the resistance of the RF source represents also the IF load resistance. The pumped cold FET provided the time-varying conductance ($0.039+0.040\cos\omega_p t$) presented in the second part of this paper. We connected a linear conductance (the right part of the circuit) representing about -20 mS from 1 to 15 GHz. Thus the linear

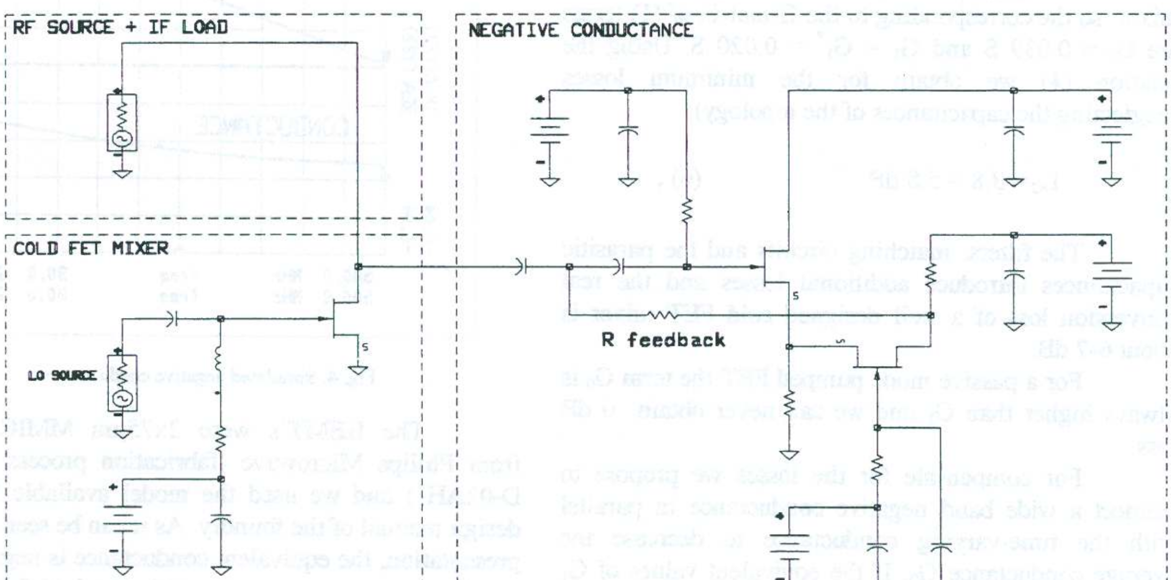

Fig.6. Optimized resistive mixer circuit

conductance represented by the whole mixer circuit was G_0-$G_n \approx 20$mS. The source/load resistance was 50Ω and so the mixer circuit was matched.

All the transistors were MMIC HEMT's from Philips Microwave (Process D-02AH) and we used a home-made model for the cold HEMT and the available from the foundry model for the biased HEMT's. The simulation was performed using the Hewlett-Packard's software MDS.

Performance

Figure 7 shows the simulated output power of the mixer for fixed RF and fixed LO. At a fixed IF frequency, the conversion loss for the difference IF frequency (f_{RF}-f_{LO}) is about 0 dB and the conversion loss for the sum frequency (f_{RF} + f_{LO}) averages 4 dB. This difference for the (f_{RF} - f_{LO}) IF and (f_{RF} + f_{LO}) IF frequencies is due to the non compensated parasitic capacitances.

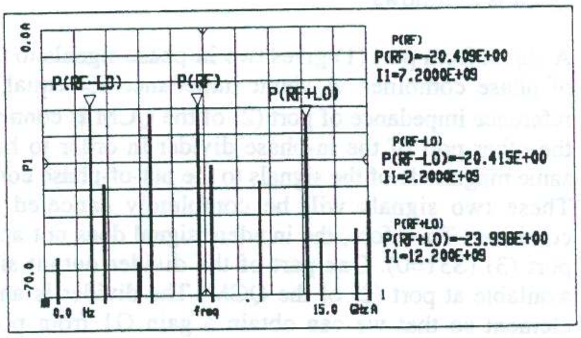

Fig. 7. Simulated output power of the mixer (in dBm)

The RF frequency was 7.2 GHz and the LO frequency 5 GHz. The LO pumping power was 8 dBm and the input RF power -20 dBm. The simulated input return loss was 24 dB.

Figure 8 shows the simulated conversion loss for fixed LO. As we can see, this mixer is a wideband circuit - the conversion loss increases from 0 dB for the lowest RF frequency - 6 GHz to about 2 dB for the highest input RF frequency - 9.5 GHz. The LO frequency and level were the same as for the previous simulation. The RF level was -20 dBm as well. This result shows that with a quite simple design the microwave engeneer could obtain a very wideband mixer. Obviously, the compensation of the parasitic capacitances will improve the frequency performance of the circuit. Higher value of the negative conductance can also compensate for the losses due to the reactive components. The only restriction for the compensation by negative conductance is that the conversion losses have to be always positive (expressed in dB), i.e. no gain can be obtained from this circuit. Of course, if the term G_1 is greater than the term G_0 in (4) the conversion loss becomes a conversion gate but the resistive mixer is a one-port circuit and thus the obtained conversion gain will make the mixer unstable.

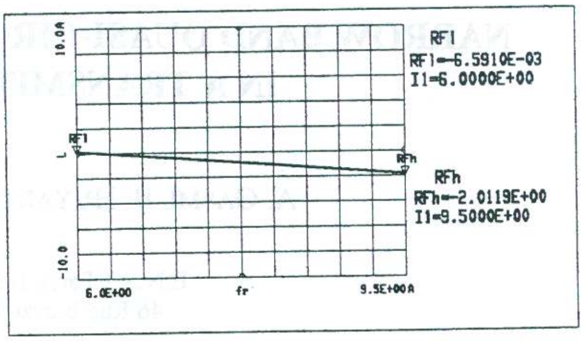

Fig. 8. Simulated conversion loss vs. frequency (in dB)

The optimized resistive mixer could be very useful in the case when the LO power is very low or when a great number of passive components increase significantly the losses of the circuit and the ordinary cold FET mixer cannot achieve a good conversion performance. Using negative conductance losses of 20 or more dB are easily compensated.

Conclusion

This paper has shown that a simple method permits to compensate for the resistive mixers conversion losses over a wide band. Such an optimized mixer is easy to design and the mixer conversion loss can be adjusted electricaly by varying the gate bias of the negative conductance circuit. We also expect that the noise of the combination resistive mixer - negative conductance will be lower than of the combination resistive mixer - amplifier.

References

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