A Zero-Bias Single-Device Balanced E-PHEMT Mixer with Conversion Gain for RFID Applications

José A. García, Emigdio Malaver*, and Lorena Cabria

Dept. of Communication Engineering, Univ. of Cantabria, 39005 Santander, SPAIN. jangel@ieee.org

*Dept. of Electronic and Communication, Univ. of Los Andes, Mérida, VENEZUELA

Abstract — **A zero-bias single-device singly-balanced mixer, using an Enhancement mode Pseudomorphic HEMT (E-PHEMT) is proposed. The mixer takes advantage of the slightly positive pinch-off voltage in this kind of device, for providing gain conversion with an acceptable linearity and avoiding the use of DC bias. A lab model has been designed to be used in an RFID tag, where a low frequency local data signal is up-converted to the 900MHz frequency band, once the device is excited with an interrogating carrier.**

I. INTRODUCTION

In recent years, the huge introduction of computers for security and control tasks has determined a tremendous development of automatic identification systems, and in particular of those working at a distance. That is the case of the radio frequency identification schemes (RFID), where transponders are interrogated by a microwave beam that forces them to emit a generally coded response. Simple backscattering techniques with amplitude [1], SSB [2], or other kind of modulation are being used, with their associated limited features. The evolution towards a high performance control system necessarily implies the introduction of complex formats [3], however, this evolution is continuously faced with the imperious need for minimizing the tag DC power consumption (to avoid the use of batteries, or simply to extend their lifetime).

The use of frequency translating functions is, as a way of illustration, limited to the combination of simple unbiased diode mixers and low-power CMOS chips for the local data signal generation. Diode mixers, besides requiring significant local oscillator (LO) power levels, having poor linearity and noise figure, also introduce important conversion losses; resulting in a strong limitation on the interrogation distance.

FET mixers, so extended through RF and microwave applications, could offer gain in active configurations at the expense of power consumption. They could also provide high linearity without DC consumption (resistive mixer), but with conversion losses and requiring a negative bias [4]. These features perfectly justify their limited acceptance in the RFID field.

In this paper, a zero-bias single-device singly-balanced FET mixer with conversion gain is proposed for its introduction in RFID applications. It takes advantage of the slightly positive pinch-off voltage of E-PHEMT devices, and combines an unusual mixer idea [5] with recent studies about single-device balanced structures [6].

II. FET MIXER BIASING POINTS

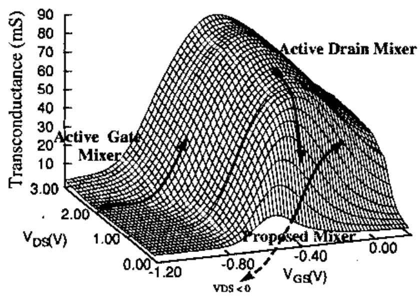
FET mixers are usually biased in a region where a maximum change of a first order equivalent circuit parameter, with respect to a control voltage, may be obtained [4]. In active mixers, the transconductance (*Gm*) variation is determinant, a role that is played by the output conductance (*Gds*) in resistive mixers. The analysis of a FET *Gm* and *Gds* evolution with the gate-to-source and drain-to-source biasing voltages could reveal, in a first approach, the optimum biasing points and the operating principles for different kind of mixers. In Fig. 1, as a way of example, these parameters have been plotted for a typical NE3210s01 Depletion-mode PHEMT.

It is evident, that operating in the saturated region, a maximum *Gm* variation with the gate-to-source voltage appears around the V_{GS} pinch-off value. The same happens with the G_{DS} versus V_{GS} change for cold operation. Active-gate and resistive mixers should be thus operated around these points for maximum conversion efficiency, something accepted in the community. However, this maximum rate of change concept around pinch-off may also be extended to explain the biasing selection and operation in other mixing topologies. That is the case of the active-drain mixer, which takes advantage of the significant *Gm* change with V_{DS} in the high part of the knee (see Fig. 1). This region, if considered in terms of the gate-to-drain control voltage, could be perfectly associated with the V_{GD} pinch-off voltage.

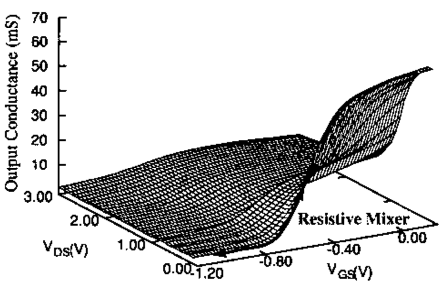
Observing this *Gm* variation around the V_{GD} pinch-off value, we could also think about taking advantage of it but

0-7803-7695-1/03/$17.00 © 2003 IEEE

in another direction, perpendicular to the V_{GD} axis. Such a control voltage variation could be possible if conveniently feeding the LO pumping signal by the source terminal, an idea already suggested by the authors in [7] in order to produce a sort of "quadratic" mixer. The term "quadratic" was then employed due to the fact that a *Gm* variation with the LO excursion seemed to be possible in a region with minimum $Gm3=1/6.\ ^3Ids/\ Vgs^3$ change.



(a)



(b)

Fig. 1. a) *Gm* and b) *Gds* evolution in an NE3210s01 PHEMT.

A time-varying Volterra-series analysis could show, that rejecting the influence of out of band components, second order combinations and cross terms, the absolute value of the first (desired) and third order (intermodulation distortion) up-converted RF *Ids* components, $|Ids^1(\omega_{RF1})|$ and $|Ids^3(2\omega_{RF1}-\omega_{RF2})|$, could be approximated by,

$$|\ Ids^1(\omega_{RF1})| \quad |Gm^1{}_{LO}|.|Vgs^0(\omega_{IF1})| \tag{1}$$

$$|Ids^3(2\omega_{RF1}-\omega_{RF2})| \quad 3/4.|Gm3^1{}_{LO}|.|Vgs^0(\omega_{IF1})|^2.|Vgs^0(\omega_{IF2})| \tag{2}$$

Taking this into account, the mentioned linear performance could be explained. In the same way that a maximum variation in *Gm* determines a maximum amplitude of the time-varying $Gm(t)_{LO}$ and the highest magnitude of its first harmonic $Gm^1{}_{LO}$; a minimum variation in *Gm3* would result in a minimum amplitude of the time-varying $Gm3(t)_{LO}$ and in the lowest absolute value of its first harmonic $Gm3^1{}_{LO}$.

This kind of atypical mixer operation could not be considered as novel, since it was analogous to the one proposed by Tomassetti [5]. Taking into account that the FET behavior is nearly symmetric around $V_{DS} = 0V$, if the V_{GS} control voltage used in the positive part were substituted by the V_{GD} variable for the inverse operation [7, 8], we could perfectly match both kind of operating principles.

III. Single-Device Balanced Mixer

Mixing in any of these proposed regions may have some problems, such as a required LO power higher than in gate-active or resistive mixers, the difficulty for injecting and extracting the signals, or a narrower bandwidth. Biasing the device in $V_{DS} = 0V$, for avoiding DC power consumption, half of the LO excursion is not effectively used in terms of conversion. Although this is also typical in the rest of mixer classes, here it could make the conversion-to-necessary LO power ratio quite low.

In [6], a family of single-device balanced resistive mixers was proposed. The minimization of the unwanted frequency components was accomplish in a simple way using a balun connection of the drain and source terminals to the RF and IF signal ports. The problems usually associated with device pairing were so avoided.

This kind of solution, together with the previous analysis, suggested us the possibility of taking advantage of both zones ($V_{GD}\quad Vp$ for $V_{DS} > 0V$ and $V_{GS}\quad Vp$ for $V_{DS} < 0V$) through the introduction of a balun structure for applying the LO signal to the drain and source terminals. In Fig. 2, a simplified diagram of the proposed topology is shown. A low IF signal could be applied to the gate, and the desired RF could be extracted at the drain using the same LO balun. This could be the typical case of an RFID tag, where a locally generated data signal has to be transmitted at a radio frequency when the device is interrogated with a carrier excitation. The resonant circuits were introduced to guarantee an operation near the desired trajectory.

IV. E-PHEMT Particular Characteristics

An Enhancement mode Pseudomorphic HEMT (E-PHEMT) has a pinch-off voltage near zero, in the positive region, as observed from the characteristic in Fig. 3. Taking this into account, and considering that a shift in the optimum conversion point towards a voltage below pinch-off is usually experimented with the LO power in FET mixers [4]; it could be expected that under certain LO pumping conditions, a good conversion efficiency might appear at $V_{GS} = V_{GD} = 0V$. That has been certainly proved for the case of a resistive mixer [9], motivating us to the design proposed in the following section.

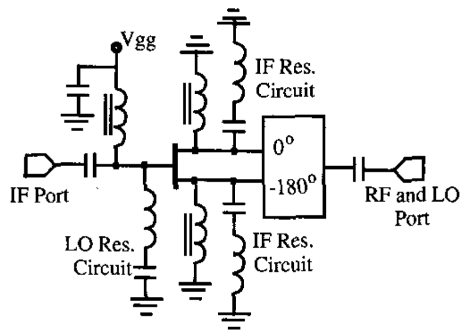


Fig. 2. Simplified diagram for the proposed mixer.

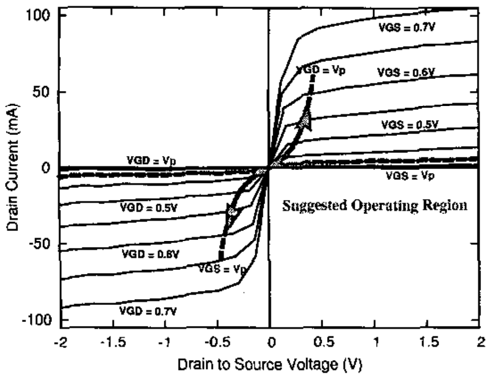


Fig. 3. DC characteristic for the ATF-55143 E-PHEMT. The suggested operating region has been highlighted.

V. Singly-Balanced E-PHEMT Design

Two models [7, 8] with improved nonlinear prediction out of the saturated region were adjusted to the dynamic I/V characteristic of the previously introduced ATF-55143 device from Agilent, models that were used for introducing the diagram of Fig. 2 in an HB nonlinear simulator. The analysis of the structure, using both approximations and without paying particular attention to the port matching, revealed the possibility of obtaining gain conversion around $Vgg = 0.3V$, the pinch-off voltage, for relatively low LO power levels (P_{LO} - *6dBm*). At higher LO levels, the gain could be increased and the optimum bias zone became wider and was shifted towards *0V*.

Based on these results, a first lab model with gate bias control was constructed and characterized. The signal levels were measured through the introduction of a directional coupler at the RF/LO terminal. In Figs. 4a, 4b and 4c, the results for conversion gain, local oscillator matching (LO-RF isolation) and output third order intercept point have been plotted. The LO power was varied from *–10* up to *20dBm*, while a two-tone IF signal with *–20dBm* per tone was applied at the gate.

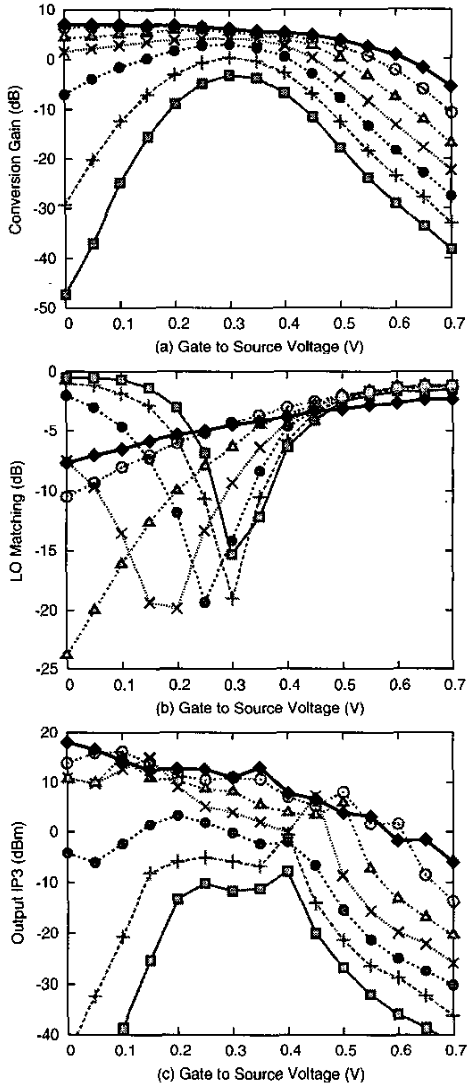


Fig. 4. a) Conversion gain, b) LO power matching, and c) OIP3 characteristic @ P_{LO} = (■) *-10dBm*, (+) *–5dBm*, (●) *0dBm*, (×) *5dBm*, (▲) *10dBm*, (O) *15dBm and* (◆) *20dBm*.

It can be verified that the optimum conversion point is shifted to the left of the V_{GS} axis with the LO power, and that the conversion gain level does not grow significantly over a *10dBm* pumping value. The possibility of using an unbiased E-PHEMT for obtaining gain conversion at the desired gate bias, *0V*, is evident for any LO power level higher than *3dBm*, supporting the validity of the proposed idea. In this point, the LO matching is optimum for a *10dBm* pumping level, and the linearity is optimum over *5dBm*.

Finally, an unbiased mixer model was constructed (see Fig. 5) for being later introduced in an experimental up-converting RFID device. Optimizing the device matching, an *8.5dBm* level mixer was achieved. In Fig. 6, an image from a spectrum analyzer confirms the obtained conversion gain and linearity performance, through the output power and the carrier to intermodulation ratio measured for an IF excitation of *–10dBm* per tone).

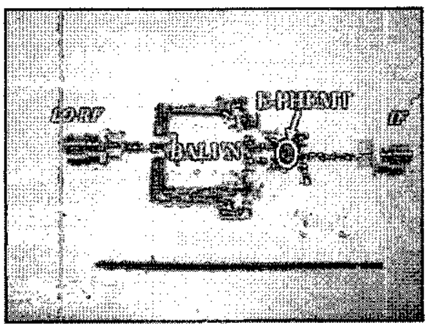


Fig. 5. Photograph of the designed mixer.

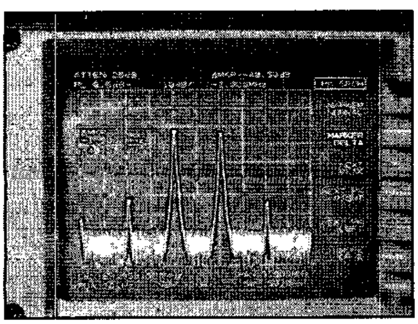


Fig. 6. Measured two-tone linearity characteristic.

The LO frequency was set to *800MHz*, while the IF tones were set near the upper limit imposed by the balun bandwidth (*158* and *159*MHz). Please note that the signals were measured from the coupled port of the directional coupler, with characterized losses of *11.67 dB* at the LO frequency and *12 dB* at the RF band.

As a way of summary, it is significant to note that a *4.17dB* conversion gain and a *23.3dB* LO matching were obtained. The values of the OIP3 and OP_{1dB} were as high as *14.5dBm* and *2.3dBm* respectively.

VI. Conclusion

A zero-bias single-device singly-balanced mixer with gain conversion has been presented. This simple and relatively novel topology takes advantage of a FET behavior around $V_{DS} = 0V$, when the proper V_{GS} or V_{GD} variables are used as control parameter. The maximum change in transconductance around pinch-off, is combined with the slightly positive value of this parameter for an Enhancement-mode PHEMT. The possibility of obtaining gain conversion with good linearity, for a moderate LO power level and without the need for DC bias, is then proved. This simple topology is highly valuable for its introduction in sophisticated RFID schemes.

Acknowledgement

This work has been supported by MCyT through TIC2002-0484-C03-03. J.A. García and E. Malaver are respectively grateful to the Ramón y Cajal Program and the Vicerrect. de Investigación, Univ. of Cantabria. The authors also thank the comments from the TPC reviewers.

References

[1] "An automatic vehicle ID system for toll collecting," Lawrence Livermore National Laboratory, Rep. No. UCRL-TB-113409, Apr. 1993.

[2] T. Ohta, H. Nakano, and M. Tokuda, "Compact microwave remote recognition system with newly developed SSB modulation," *1990 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 957-960, June 1990.

[3] C. W. Pobanz and T. Itoh, "A microwave noncontact identification transponder using subharmonic-interrogation,"*IEEE Trans. Microwave Theory and Tech.*, vol. MTT-43, no. 7, pp.16731679, July 1995.

[4] S. A. Maas, *The RF and Microwave Circuit Design Handbook*, Boston: Artech House, 1998.

[5] G. Tomassetti, "An unusual microwave mixer," *Proc. 16th European Microwave Conf.*, pp. 754-759, 1986.

[6] K. Yhland, N. Rorsman, and H.H.G. Zirath, "Novel single device balanced resistive HEMT mixer," *IEEE Trans. Microwave Theory and Tech.*, vol. 43, no. 12, pp. 2863-2867, Dec. 1995.

[7] J. A. García, J. C. Pedro, M. L. De la Fuente, N. B. Carvalho, A. Mediavilla, and A. Tazón, "Resistive FET mixer conversion loss and IMD optimization by selective drain bias," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-47, no. 12, pp. 2382-2392, Dec. 1999.

[8] K.. Yhland, N. Rorsman, M. García, and H. Merkel, "A symmetrical, nonlinear HFET/MESFET model suitable for intermodulation analysis of amplifiers and resistive mixers," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-48, no. 1, pp. 15-22, Jan. 2000.

[9] J. J. Kucera and U. Lott, "A zero DC-power low-distortion mixer for wireless applications," *IEEE Microwave Guided Wave Lett.*, vol. 9, no. 4, pp. 157-159, April 1999.