A NOVEL APPROACH FOR HIGHLY LINEAR AUTOMATIC GAIN CONTROL OF A HEMT SMALL-SIGNAL AMPLIFIER.

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ABSTRACT

A novel approach for highly linear automatic gain control (AGC) in small-signal amplifiers is presented in this paper. A HEMT based topology was implemented, biasing the transistor in the transition between the saturated and linear operation regions. Gain control with low distortion is achieved by simultaneous adjustments of the gate to source (V_{gs}) *and drain to source* (V_{ds}) *voltages, along the line where the second derivative of the transconductance* ($Gm3$) *has a null. Comparatively to the traditional approach, with the transistor biased in the saturated region, this amplifier has better intermodulation behavior and efficiency, without important reduction in the gain control range.*

INTRODUCTION

Nowadays, there are many communications systems using digital modulation techniques. These techniques generally result in time-varying envelope signals and demand devices, such as amplifiers and mixers, with very high linearity to avoid unwanted frequency components in the adjacent channels [1]. The intermodulation distortion is tightly specified by the communication standard being used, therefore should be minimized in transmitter and receiver circuits. The three traditional methods used to improve the intermodulation performance of RF amplifiers are the predistortion, feedback and feedforward techniques [2]. The predistortion uses a network with a transference function equal to the inverse transference function of the distorting amplifier. The feedback uses negative feedback to compensate the non-linearity, while the feedfoward extracts a fraction of the third order intermodulation product and recombine it out of fase with the output from the amplifier. All of these techniques are complex and expensive. Thus tremendous effort are being placed on optimizing the linearity capabilities of the amplifiers in order to avoid the need of external circuitry or to reduce the requirements to be implement by the external block.

Output power control is also becoming a must in current and future wireless standards [3]. However, the classical way to do that in amplifiers and attenuators do not guarantee a high linearity in the whole control range. Therefore a great interest is appearing on developing highly linear control applications.

PROPOSAL

Normally, an AGC amplifier is designed with the transistor working in the saturated region. The gain control is achieved by adjusting the gate to source voltage V_{gs} from pinch-off to the point of maximum transconductance ($Gm1$), see Fig. 1.

$Gm1$ and $Gm3$ represent the first and third order of Ids derivatives with respect to Vgs for the Taylor-series expansion given in equation (1).

$$\begin{aligned} I_{ds}(V_{gs},V_{ds}) = I_{ds}(V_{GS},V_{DS}) + Gm1*V_{gs} + Gds*V_{ds} + Gm2*V_{gs}^2 + Gmd*V_{gs}*V_{ds} + Gd2*V_{ds}^2 + \\ Gm3*V_{gs}^3 + Gm2d*V_{gs}^2*V_{ds} + Gmd2*V_{gs}*V_{ds}^2 + Gd3*V_{ds}^3 + \cdots \end{aligned} \quad (1)$$

The gain control path drives over points of maximum $Gm3$, being impossible to assure good linearity figures along the whole range.

The authors in [4] proved the existence of (V_{gs}, V_{ds}) pairs along the transition from the lineal to saturated region where $Gm3$ has a null while $Gm1$ experiments an important variation. We then propose to taking advantage of biasing the transistor in this region in order to guaranteeing gain control with low intermodulation levels.

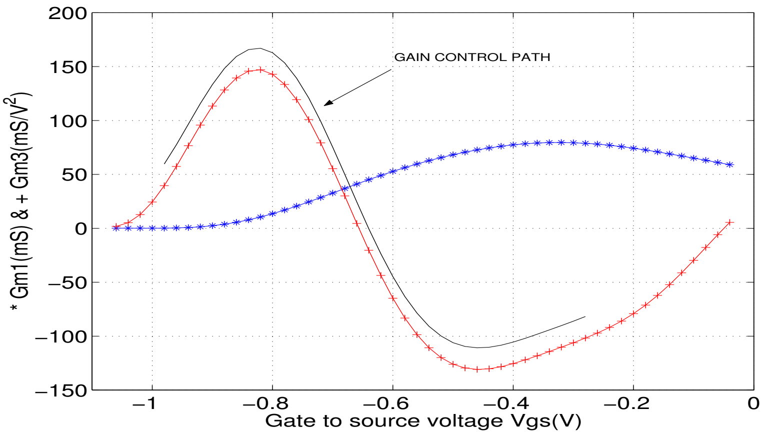

Figure 1: Gain control path when the transistor is biased in saturation.

CHARACTERIZATION AND EXPERIMENT

Following the procedures described in [4] and [5], $Gm3$ and the points where $Gm3$ is null were found for a typical NE3210s01 HEMT device from NEC, see Fig. 2, Fig. 3 and Fig. 4

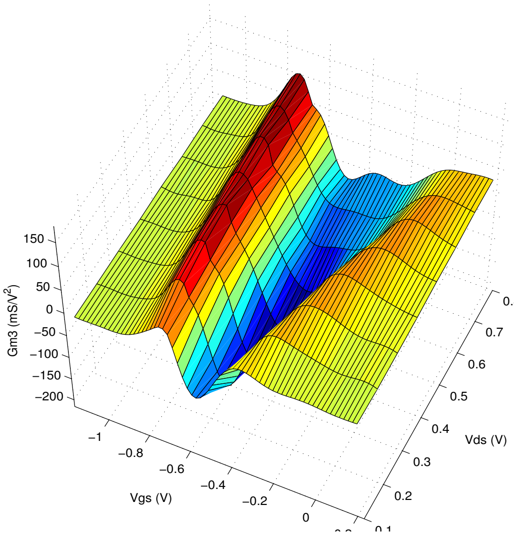

Figure 2: $Gm3$ evolution surface

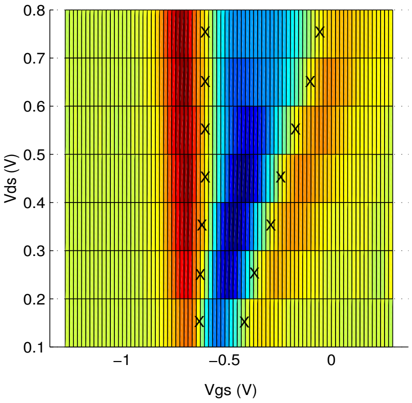

Figure 3: $Gm3$ proyected in the Vgs-Vds plane. The marks correspond to the first and second $Gm3$ null

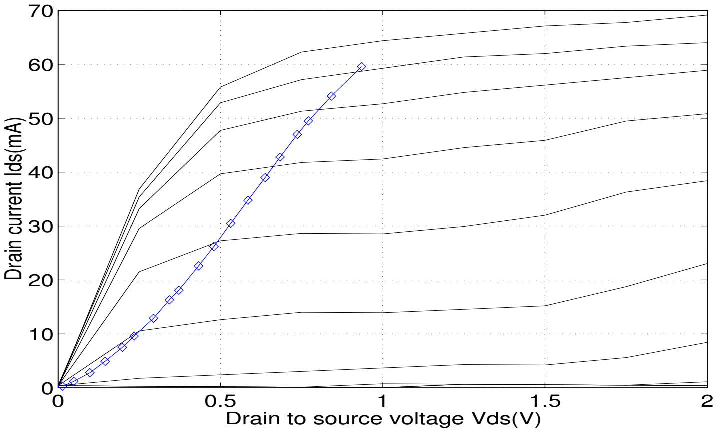

Figure 4: $\diamond$ $Gm3$ second null evolution along the I/V DC characteristic

Two amplifiers were implemented using the characterized device, one operating in the transition region and the other biased in saturation. The two-tones experiment was carried out with tones at 1800 MHz and 1801 MHz as excitation frequencies. The input power levels were selected as high as possible, while assuring operation in small-signal regime.

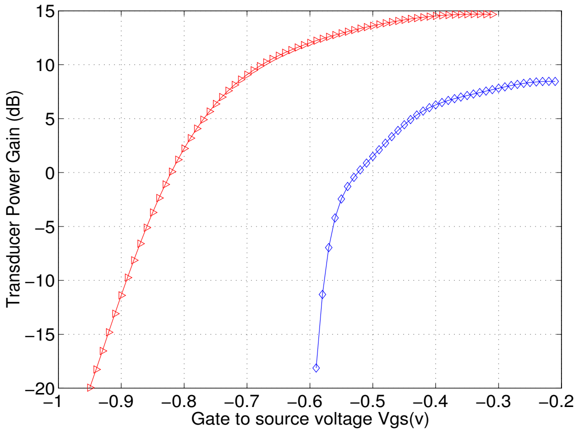

Figure 5: Measured Amplifiers Transducer Gain. ◇ Proposal. ▷ Conventional.

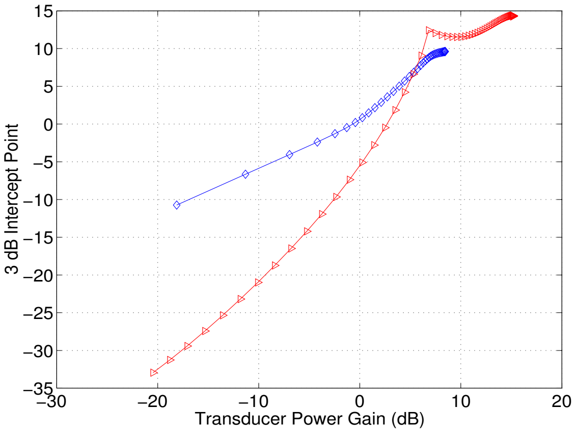

Figure 6: Measured Amplifiers 3dB Intercept Point. ◇ Proposal. ▷ Conventional

Fig. 5 shows the gain achieved in both amplifiers, being the maximum gain and the control range of the new AGC approach only 8dB worse than the conventional solution.

The output IP3 evolution is shown in Fig 6. It can be noticed that the amplifier operating in saturation has one optimum point associated with the Gm3 null defining the pinch-off point. However, for the rest of the control region the proposed approach shows a better performance.

Due to the relevance of assuring high linearity and also preserving good efficiency [6], the RF output power and the output IP3 per DC power consumption were computed and shown in Fig 8 and Fig.7.

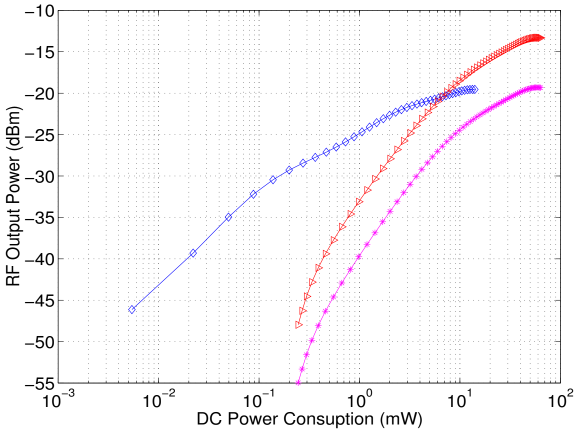

Figure 7: RF output power versus DC power consumption. ◇ Proposal. ▷ Conventional with same RF input power. ∗ Conventional with same RF output power.

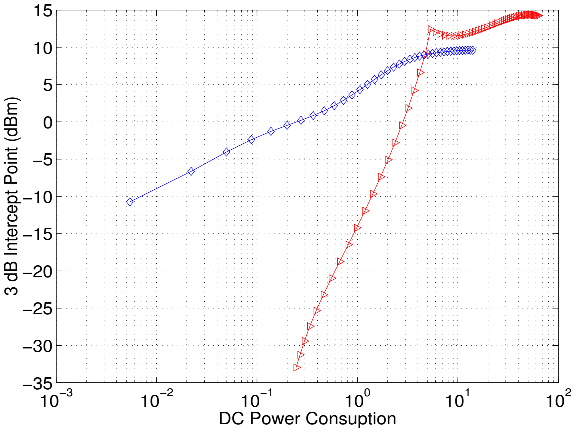

Figure 8: IP3 versus DC power consumption. ◇ Proposal. ▷ Conventional.

As it can be appreciated, the new AGC amplifier provides a better linearity/efficiency trade-off, constituting a promising solution for its use on mobile terminals.

In this work one goal was to measure the evolution of 1 dB compression point along the gain control path, since it was expected to have a poor behavior when the transistor is biased in the proposed operating region. In Fig. 9, it can be appreciated that the proposal has a similar evolution than the conventional AGC amplifier with just 5 dB of maximum deviation respect to the conventional 1 dB evolution curve.

Finally, it would be interesting to evaluate the capabilities of this technique when exciting with digital or multicarrier signals. Using the results in [7], it is possible to extend the two-tones linearity figures to estimate the adjacent channel power ratio (ACPR).

$$ACPR = \frac{\int\limits_{\omega_1}^{\omega_2} C_1^2 \frac{N_o}{2} d\omega}{18 \int\limits_{\omega_h}^{\omega_h + B_\omega} C_3^2 \left(\frac{N_o}{2}\right) \left(\frac{\omega^2}{2} - \left(B_\omega + \omega_h\right)\omega + \frac{\left(B_\omega + \omega_h\right)^2}{2}\right) d\omega} \tag{2}$$

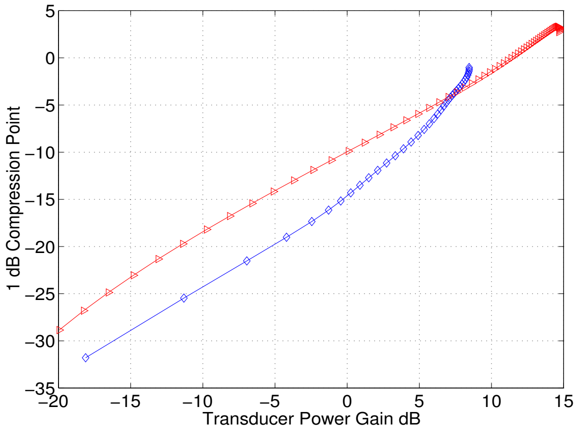

Figure 9: 1 dB compression point evolution. ◇ Proposal. ▷ Conventional.

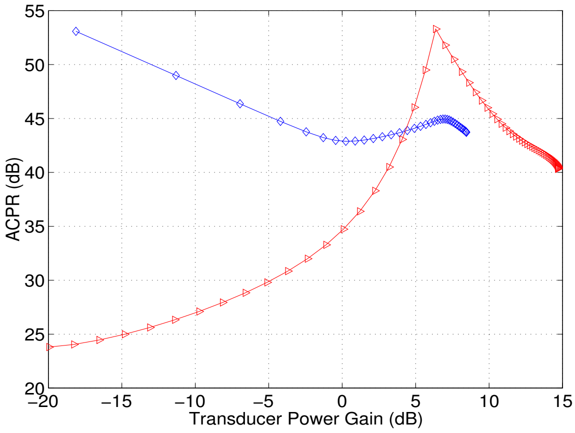

Figure 10: Output ACPR relation. ◇ Proposal. ▷ Conventional.

The equation (2) was applied to obtain the ACPR evolution of the new AGC approach for a W-CDMA signal to be employed in the future UMTS wireless standard, see Fig. 10. As it can be seen, the new AGC amplifier would satisfy an ACPR requirement of 43 dB in the whole gain control range, while the amplifier operated in saturation only satisfies a 23 dB request.

A quantitative analysis of the novel approach has shown that these results could be extended to large-signal regime and this will be the objective of a future work.

CONCLUSIONS

A new AGC amplifier technique has benn proposed. The new approach provides good intermodulation performance and low power consumption. It may constitute a promising solution for the availability of efficient and highly linear output-power control in mobile terminals.

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REFERENCE

[1] L.E. Larson, *RF and Microwave Circuit Design for Wireless Communications*, 1996 Artech House, Norwood Massachusetts.

[2] C. S. Aitchison. “The Current Status of RF and Microwave Amplifier Intermodulation Performance,*IEEE Radio Frequency Integrated Circuits Symposium 2000*, pp. 113-116.

[3] ETSI TS 125101 and 125102 (2000-2001), *Universal Mobile Telecommunications Systems (UMTS)*, UE Radio Transmission and Receptions (FDD and TDD).

[4] J. A. García et. al. “Resistive FET Mixer Conversion Loss and IMD Optimization by Selective Drain Bias”, *IEEE Trans. Microwave Theory and Techniques*, vol. 47, No. 12, pp. 2382-2392, Dec. 1999.

[5] J. Pedro and J. Pérez. “Accurate simulation of GaAs MESFET’s intermodulation distortion using a new drain-to-source current model”, *IEEE Trans. Microwave Theory and Techniques*, vol. 42, pp. 25-33, Jan. 1994.

[6] D. B. Kenington, *High Linearity RF Amplifier Design*, 2000 Artech House, Norwood Massachusetts.

[7] J.C. Pedro and N.B. Carvalho. “On the Use of Multitone Techniques for Assessing RF Components’ Intermodulation Distortion”, *IEEE Trans. Microwave Theory and Techniques*, vol. 47, No. 12, pp. 2393-2402, Dec. 1999.