A NOVEL HIGHLY LINEAR AMPLIFIER ACTIVE ANTENNA

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Abstract-In this paper, a novel highly linear amplifier active antenna is presented. In the proposed approach, the antenna serves as an in-phase power combiner of two HEMT-based amplifier branches. The auxiliary branch is added for cancelling the third order intermodulation distortion (IMD3) current of the main branch, without diminishing its gain.

I. INTRODUCTION

In recent years, different communication systems for identification and localization have been developed. The main applications of these systems, operating in the ISM bands (2.4 GHz-5.8GHz), are security, access control, work tracking for factory automation, etc. Antennas are key components in all these systems because their dimension is critical.

On the other hand, active antennas present great advantages in wireless communications. Some key requirements for the components and systems, to be used in wireless applications, are compactness, light weight and low cost, which can be satisfied with printed antennas. At the same time, there are other requirements like signal gain and high DC-to-RF conversion effiency that can be satisfied with the improving performance of solid state devices.

In recent years, several research works have combined both elements, trying to achieve high efficiency in power amplifiers for transmission, as well as high sensitivity in low noise amplifier for reception [1]. However, a very important requirement to be imposed to the RF amplifiers in modern communication systems, the linearity, has not been studied in detail in active antennas.

To achieve linearity, two strategies can be followed: the design of an intrisically linear amplifier and/or the use of system level linearization techniques. Intrinsic linearity is difficult to achieve and often compromised for increased power dissipation. Many classical system-level amplifier linearization techniques exist, such as predistortion [2], feedforward [3] and cartesian feed-back [4]. They all require complex hardware, reason why a lot of work is recently been focussed on device-level topologies.

Derivative superposition is one promising technique of this kind [5], where an auxiliary device with opposite IMD3 contribution has been added in a parallel branch to a main device in MMIC technology implementation.

In this paper, a new highly linear amplifier active antenna is proposed. In this approach, the input signal is divided and feeds two HEMT-based amplifiers, Fig 1. A second (auxiliary) branch is used as in [5] for getting the same third order intermodulation distortion current of the main branch, but with a 180º phase shift. At the same time, the phase of the main frequency current in both branches has to be equal. So, using the antenna as an in-phase power combiner, the radiated power from each branch at the IMD3 products is cancelled, while the radiated power at the main frequency is combined.

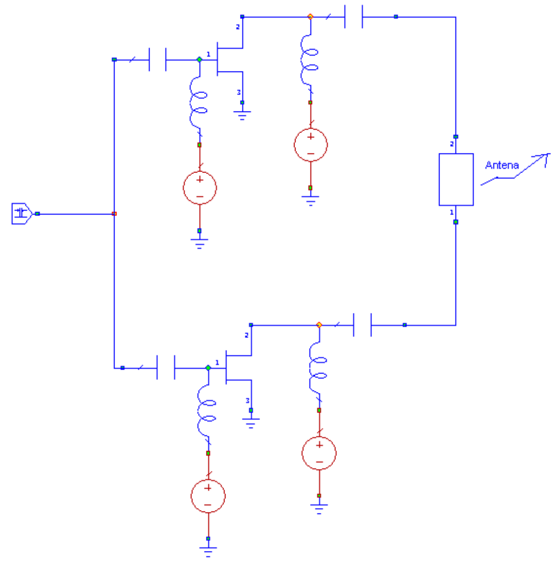


Figure 1- Novel highly linear amplifier active antenna

II. LINEARIZATION TECHNIQUE

The main nonlinearity in HEMT transistors, the drain to source current, can be characterized by a two-dimensional Taylor series expansion given by equation Eq.1:

$$Ids(Vgs, Vds) = Id(V_{GS}, V_{DS}) + Gm1 \cdot vgs + Gds \cdot vds + Gm2 \cdot vgs^2 + Gmd \cdot vgs \cdot vds + Gd2 \cdot vds^2 + Gm3 \cdot vgs^3 + Gm2d \cdot vgs^2 \cdot vds + Gmd2 \cdot vgs \cdot vds^2 + Gd3 \cdot vds^3 + \ldots \quad (1)$$

where $Ids(V_{GS}, V_{DS})$ is the DC drain current at the bias point, the coefficients $Gm1$, Gds are the transconductance and the output conductance respectively, and the other coefficients are their derivatives respect to the gate to source voltage Vgs and the drain to source voltage Vds, at the referred bias point.

In normal load conditions, the dominant contributions in Eq.1 are those related to the gate voltage control. Thus, *Ids(Vgs, Vds)* can be reduced to Eq.2,

$$Ids(Vgs) = \frac{\partial Ids}{\partial Vgs}\bigg|_{V_{GS},V_{DS}} \cdot vgs + \frac{1}{2} \cdot \frac{\partial^2 Ids}{\partial Vgs^2}\bigg|_{V_{GS},V_{DS}} \cdot vgs^2 + \frac{1}{6} \cdot \frac{\partial^3 Ids}{\partial Vgs^3}\bigg|_{V_{GS},V_{DS}} \cdot vgs^3 = Gm1 \cdot vgs + Gm2 \cdot vgs^2 + Gm3 \cdot vgs^3 \quad (2)$$

In a two-tone test with frequencies $\omega 1$ and $\omega 2$, the desired current components are determined by the first order term in Eq.2 . However, the IMD3 components, with frequencies $2\omega 1$-$\omega 2$ and $2\omega 2$-$\omega 1$, are mainly generated by the third order term. In this way, while *Gm1* determines the amplifier gain, *Gm3* is responsible for the undesired distorting power levels.

Fig.2 shows the measured first and third order derivatives of the *Ids(Vgs)* characteristic for a typical NE3210s01 HEMT device from NEC, whose pinch-off voltage *Vp* is about – *0.7V*. Selecting a bias voltage for maximum gain, V_{GS} = *-0.44V* (point A), the associated *Gm3* term would be significant and negative, resulting in a poor linearity performance of such an amplifier.

Adding an auxiliary device in parallel, of the same type, two bias voltages (point B and C) can be selected to obtain a *Gm3* value with the same magnitude but opposite sign to the one previously obtained. Selecting one or the other, the IMD3 resulting current could be cancelled. However, as one of them has a higher *Gm1* value, its contribution to the global gain would be higher.

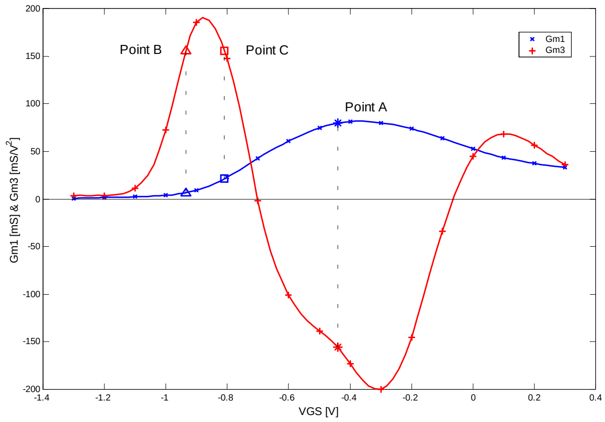


Figure 2- The typical Gm1(x) and Gm3(+) derivative characteristics of a HEMT device as a V_{GS} function, at V_{DS} = 2V.

III. ANTENNA DESIGN

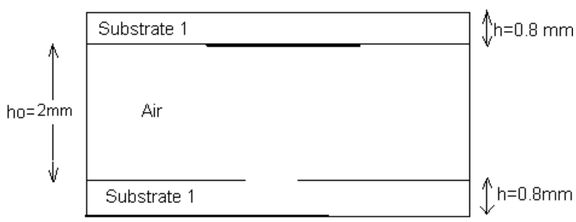
The antenna should behave as a radiating element as well as an output *0º* hybrid circuit, with the additional advantage that the antenna has not the losses that a printed hybrid structure usually may have.

For most applications that require small size, aperture coupled patch antennas are the preferable antenna choice because they allow to separate the feed layer from the radiating patch, resulting in a high front-to-back ratio.

In Fig. 3, the designed antenna is shown. In the lower layer, the patch antenna has two microstrip feeds placed at the same side. There is one slot in the ground layer, shared by the two microstrip feeds. With this type of feeding, the modes excited with each microstrip line are the same, resulting in a poor isolation between them.

Both, the patch and feed microstrip lines, where the slots are also included, have been implemented in substrate N25 with ε_r = *3.25* and thickness of *0.8 mm*. They are separated *2 mm* by air.

An EM simulator, Ensemble, has been employed to analyse the input matching, the isolation, and the radiation patterns.



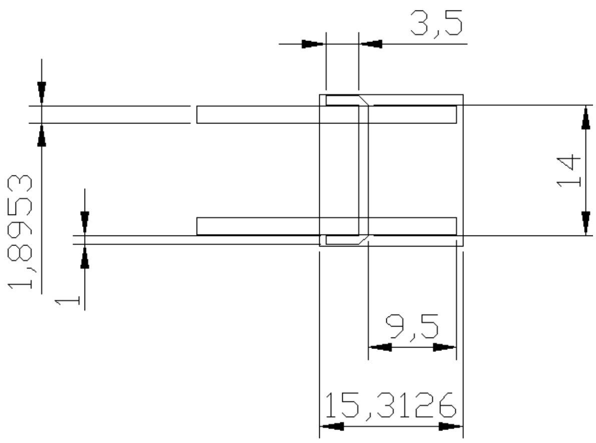


Figure 3- Aperture patch antenna side view and top view

In Fig. 4, the simulated and measured input matching and the isolation between the input ports are shown.

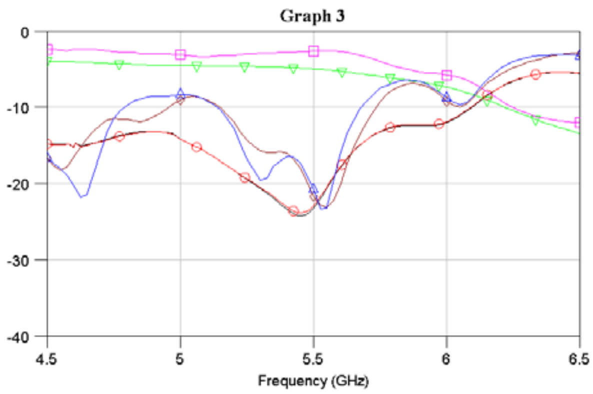


Figure 4- Measured (blue & brown→Δ) and simulated (red→o) input matching, as well as measured (pink→□) and simulated (green→∇) isolation.

IV. DESIGN APPROACH

If the amplifier part were only implemented with one branch, and were fed with two equal tones of *–17 dBm*, at *f1=5.8 GHz* and *f2=5.81 GHz*, the desired and distortion currents would be those shown in Table 1:

Frequencies	Module current	Phase Current
f1=5.8 GHz	*3.98*	*-0.10º*
2f1-f2=5.79 GHz	*0.04*	*179.92º*

Table 1- Current results achieved with one branch

With these currents, the radiation patterns of the designed antenna can be simulated, and the maximum achieved values can be observed in the table below:

Frequencies	*ϕ=0º*	*ϕ=90º*
5.8 GHz	*Eϕ=25.07* *Eθ=161.7*	*Eϕ=161.6* *Eθ=26.12*
5.79 GHz	*Eϕ=0.302* *Eθ=1.947*	*Eϕ=1.949* *Eθ=0.3159*

Table 2- Maximum achieved values for radiated fields with one branch

The ideal solution would consist in adding a second branch amplifier, biased at the point C selected in section II. But as the antenna has poor isolation between its input ports, this bias point does not really constitute the optimum solution.

For this reason, a second analysis was made considering the antenna behaviour. The second branch gate bias was tuned until approximately achieving the same current and a *180º* phase shift at *5.79 GHz*.

In Table 3, the tuned current results are shown :

<u>First Branch Amplifier</u>

Frequencies	Module current	Phase Current
5.8 GHz	*2.88*	*0.54º*
5.79 GHz	*0.011*	*-172.71º*

<u>Second Branch Amplifier</u>

Frequencies	Module current	Phase Current
5.8 GHz	*1.78*	*-1.6º*
5.79 GHz	*0.011*	*0.11138º*

Table 3- Current results obtained with two branches and considering antenna behaviour.

The radiation pattern were again obtained when the antenna input ports are fed with these currents and the maximun values are shown in the Table 4:

Frequencies	*ϕ=0º*	*ϕ=90º*
5.8 GHz	*Eϕ=7.137* *Eθ=189*	*Eϕ=189* *Eθ=11.59*
5.79 GHz	*Eϕ=0.1393* *Eθ=0.05737*	*Eϕ=0.05797* *Eθ=0.1393*

Table 4- Maximum values for the radiated fields with two branches

In Fig. 5 and Fig. 6, the measured radiation patterns (with and without a second amplifier branch) can be observed at *5.79 GHz* and *5.8 GHz* respectively, in ϕ = *0º*:

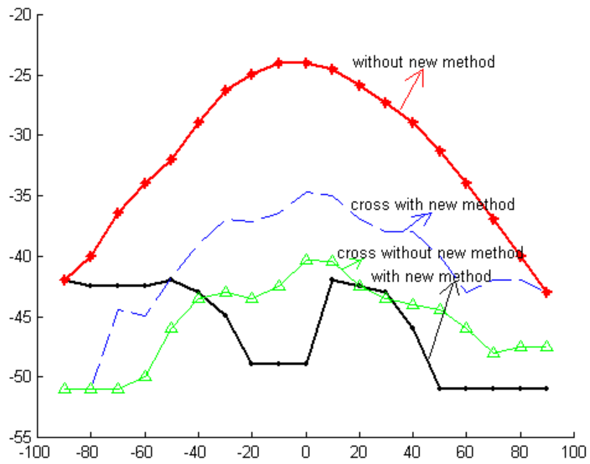


Fig. 5-Radiation pattern (ϕ=0º) at 2f1-f2=5.79 GHz.

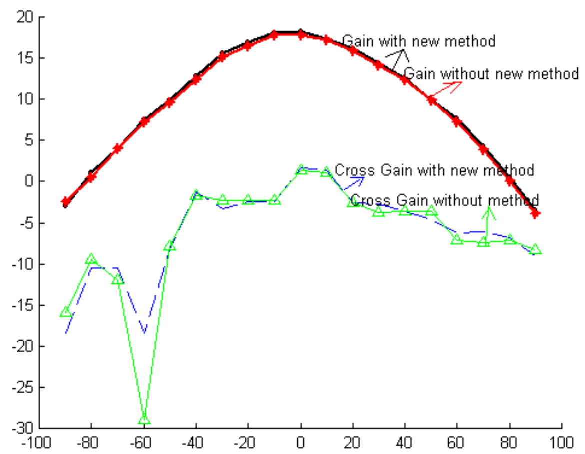


Fig. 6- Radiation pattern (ϕ=0º) at f1=5.8 GHz.

The radiated gain at the intermodulation product decreases about *25 dB* in the main direction, at the expense of a small increment in the cross polarized component. Otherwise, at the desired frequency, the radiated field improves in about *0.4 dB* while the cross polarization ratio is conserved.

The Third Order Intercept Point, IP3, is a good parameter for comparing small signal intermodulation behaviour because it considers the fundamental and the IMD3 power levels. In Fig.7, the measured IP3 with and without the inclusion of the auxiliary branch, has been plotted:

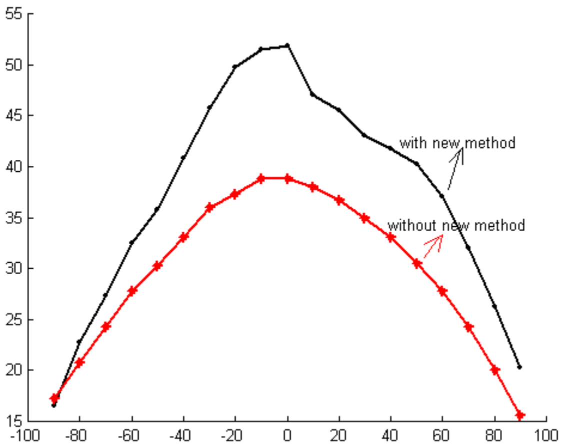


Fig. 7- IP3 with and without the proposed technique

The IP3 improves in about 13 dB in the main direction.

V. CONCLUSIONS

A new highly linear amplifier antenna has been proposed, where the intermodulation distortion levels have been significantly cancelled. This radiating structure could be efficiently used in transmitting arrays, for those communication standards where linearity is a must.

VI. ACKNOWLEDGEMENT

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