A Novel Active Load Linearizer for HBT Low Noise Amplifier at 2.4 GHz

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ABSTRACT

A novel active load linearizer is introduced to enhance the non-linear performance of a HBT Low Noise Amplifier. This active load is configured as a Current Source. The results of this structure are compared to an equally biased non-active loaded device, obtaining a higher third order Input Intercept Point (IIP3) around 17 dBm, and a higher compression point (G1dB) around -1 dBm.

I. INTRODUCTION

Currently, the increase in communication services has given rise to the necessity of higher restrictions in the electromagnetic spectrum management and electromagnetic compatibility. Since the introduction of second generation systems, a bigger demand in personal communications, which are based in digital modulation and very sophisticated digital signal processing have an enormous demand. New forms of modulations and changes in data traffic have created a demand for higher linear systems.

Due to these demands, several techniques are developed and employed to linearize LNA’s, among other electronic circuits. These techniques include linear feedback, where a linearly scaled version of the output signal is subtracted in the input \[ f \] analog predistortion, where a non-linear element adds a non-linear response before the amplifier, such that the combined transfer function of the two devices is more linear [2], filtering of in and out of band components [3], and postdistortion technique, which is a similar technique as predistortion, and other methods, where the goal is to optimize the input-output port coupling [5, 6], among other methods.

Some of these techniques can only be employed in narrow band applications, since the linearity of the device depends widely on the tones relationship, for example in [4] shows that the third-order input interpoint point (IIP3) is a function of the separation of tones in the non-linear analysis, then, the results obtained of using two different tones \( f_1 \) and \( f_2 \) gives different results by using the excitation \( f_1 - f_2 \) and \( f_2 - f_1 \).

Besides, this method is narrow band since when the operating frequency is changed, the IIP3 is considerably reduced.

Hereby, a novel method is introduced by using an active load configured as a current source, in which the nonlinearities of the active-loaded amplifier (ALCE) output port are compensated, and this compensation is independent of the tone spacing \( (f_1 - f_2) \). Therefore, this technique can be seen as a postdistortion method. The basic idea is shown in figure 1. In this diagram, the model of a common-emitter transistor configuration is displayed. For simplicity a middle band operation analysis is considered; then, the non-linearities are generated mainly by the non-linear conductance \( r_n \), the collector current represented by a non-linear transconductance, \( g_m \), which is in function of two voltages: the base-emitter voltage and the base-collector voltage. When the output resistance non-linearity can not be neglected, the collector current is of the form:

\[
i_c = I_s \exp \left( \frac{V_{BE}}{V_t} \right) \cdot g(V_{CE})
\]  

Where \( I_s \), \( V_{BE} \) and \( V_t \) are the transistor saturation current, the base-emitter voltage and the thermal voltage, respectively, and \( g(V_{CE}) \) is a non-linear function of \( V_{CE} \) only. The idea is to compensate the variations of the current through the non-linear elements in the output port of the transistor by forcing the current intensity to keep stable by the introduction of the current source represented by \( Z_{AL} \) in figure 1. Besides, the non-linearities of the latter compensate the non-linearities of the Early resistance, and in some circumstance, the non-linearities of the non-linear transconductance.

II. CANCELLATION MECHANISM OF THE ACTIVE LOAD

The amplifier can be analyzed in middle-band operation, to calculate the non-linear behavior. Under a simplified scheme, where all reactances are excluded, the output voltage can be described as:

\[
V_{out} = -g_m \cdot V_{in} \left( r_o \parallel R_L \parallel Z_{AL} \right)
\]  

Where \( R_c \) is the real part of the complex load. This equation gives the dependence of the active load, the output resistance and the non-linear transconductance, in which the linear
behavior is also affected by this load. The configuration of the amplifier is shown in figure 2. The active element is a SiGe HBT biased with $V_{CE} = 2.2$ V and $I_C = 10$ mA.

The PNP transistor is configured as a current source to compensate the fluctuations of the non-linear components of the amplifying element. In this case, the amplifier uses a capacitor, $C_{eb}$, to decrease the low frequency operating point modulation by minimizing the sub-harmonic components that can be found in the base of the transistor, which are derived, mostly, by the interaction of the second intermodulation products [3]. The amplifier is highly degenerated by an inductor in the emitter to provide the optimum input impedance to obtain the minimum noise figure of the circuit, besides stabilizing the transistor at high frequencies and improving the linear performance. $R_S$ is employed to stabilize the amplifier at low frequencies. Another amplifier without active load is designed and configured as a common emitter (CE) to compare results. The circuit employs the same heterojunction transistor. This amplifier is also biased with a collector-emitter voltage of 2.2 V and 10 mA of collector current.

III. RESULTS

The active-loaded and non-active-loaded amplifiers were designed and results are compared. Figure 3 depicts the linear behavior of the amplifiers, in which a similar performance regarding gain, input and output reflection coefficients is observed. Both configurations have 1.2 dB of noise figure. The 1 dB compression point is displayed in figure 4, in which it is shown that the ALCE has a great linearity in comparison to the CE amplifier. The ALCE amplifier has an input gain compression point of -1 dBm, while the CE amplifier has an input gain compression point of -7.8 dBm.

Besides these results, the intermodulation behavior is also analyzed, and figure 5 shows the non-linear behavior of the ALCE and CE amplifiers for different tone spacing $(f_1 - f_2)$. In this figure, it is observed that the ALCE amplifier has an IIP3 almost 7 dB higher than the CE amplifier, showing a great increment of the linearity because of the active load postdistorter.

With this kind of method, the amplifier shows a good performance over a wide band operation frequency, another IIP3 analysis was made considering different frequency operations and frequency spacing. In figure 6, these results are observed.

From figure 4, 5, and 6, it is clearly noted that the non-linear behavior of the amplifier is highly improved by using the active load to compensate the non-linearities of the output resistance and the non-linear transconductance of the transistor. The IIP3 is enhanced almost 7 dB compared to a CE amplifier with non-active load. Besides, the 1 dB compression point is also improved by close to 7 dB.
This kind of amplifier is a great option to be built in monolithic applications since it is not dependent of resonant circuits which can not be integrated easily. Moreover, due to this characteristic, the amplifier can also be used in different standards, since it does not have resonances which can limit the operation frequency of the device to a narrower band. Another interesting fact that we can take advantage of, is that this amplifier does not modify the IIP3 for different frequency spacing, then this kind of configuration can also be used in base stations, where multicarrier systems are transcendental, and it can also be employed for different data rates, without modifying the linear behavior.

IV. CONCLUSIONS

In this work, a novel postdistortion method is proposed. An active load circuit configured as a current source is employed to linearize a common emitter amplifier by compensating the non-linearities due to the output resistance and the non-linear transconductance. The method allows the increase of the IIP3 more than 7 dB in comparison to a common emitter amplifier with non-active load, and the compression gain point by more than 7 dB, too.

This kind of structure behaves highly linear for a wide frequency range and for different frequency spacing, obtaining a very good alternative for multi-standard applications and data rates.

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REFERENCES