Characterization of a reconfigurable CMOS power amplifier with IEEE 802.11ax signals

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***Abstract*—This paper aims to characterize a power amplifier (PA) with modulated signals, using a well know communication standard, IEEE 802.11ax. The standard has minimum values for the Error Vector Magnitude (EVM) and the Adjacent Channel Power Reason (ACPR), which were used to determine the linearity of PA, in conjunction with the efficiency and the power gain of the circuit. The PA has three modes, the low power, the medium power and the high power modes. It was simulated using Cadence Virtuoso simulation environment, and all the metrics were given in relation to the mean output power (Pout). The maximum value of ACPR is -20 dB, and for this value, the maximum Pout for each mode is 16.9 dBm, 20.6 dBm and 22.7 dBm. For the same standard the established EVM value is 2.51 %, for 256QAM modulation, and for this value, the Pout of each mode is 11.8 dBm, 15.6 dBm and 17.7 dBm.**

Keywords - Power amplifier, ACPR, EVM, modulated signals, radio frequency.

I. Introduction

In radiofrequency (RF) circuits, the most important component for transmission is the power amplifier (PA). It is responsible for adding power to small amplitude signals, to travel longer distances and to be received without significant loss of information [1]. The PA is also the circuit that draws the most power in the RF transceiver circuit [2]. For that reason, it is important to find an architecture for the circuit that is the most efficient for a wide range of input mean power from the signal to be transmitted. One of those architectures proposed is the multimode power amplifier, which has several amplifying cells that can be activated according to the input signal, making it more efficient.

This paper details several results for the simulation of a multimode power amplifier, previously presented in [1]. The PA is a differential amplifier developed using a 130 nm CMOS technology to operate at 2.45 GHz. It has 3 different possible operating modes, the low power mode, the medium power mode and the high power mode. The characterization of the circuit is made through several metrics that show important information about its linearity, gain and efficiency. The linearity of the circuit is measured with the metrics error vector magnitude (EVM) and adjacent channel power ratio (ACPR), which have maximum values according to the communication standards. The efficiency of the circuit is measured by the power added efficiency (PAE).

The PA was simulated using the Cadence Virtuoso simulation environment, and the IEEE 802.11ax communication standard was chosen for the simulations. It can operate at the 2.45 GHz and 5 GHz bands, and can operate on several different channel widths, 20 MHz, 40 MHz, 80 MHz and 160 MHz. It can also employ a wide range of digital modulations, such as BPSK, QPSK, 16QAM, 64QAM, 256QAM and 1024QAM [3]. For the simulations in this work, it was chosen the 80 MHz channel and the 256QAM modulation, in the 2.45 GHz operating frequency.

II. Power amplifier

The PA used in this study is represented by Fig. 1. It is a differential amplifier, with three distinct cascode topology cells that can be activated individually, with the digital inputs En2A and EN2B. Each of the cells possesses 4 NMOSFET transistors with same channel width, w = 175 µm, and same channel length, L = 240 nm, but different multiplicity, m1p = 2, m2p = 4 and m3p = 8, for each cell respectively. The biasing voltage Vpolpot is provided by a biasing circuit, which supplies a constant voltage of 1.17 V. The resistors have a value of Rf = 390 Ω, the capacitors have a value of Cf = 743 fF and the inductors have a value of L = 1 nH.

The inputs EN2A and EN2B are activated by a DC voltage of 2.3 V (logical level high) and deactivated by the reference voltage GND (logical level low). At the end of the PA is the impedance match circuit, which is a high-pass L network, with a capacitor, with value C = 4.4 pF, and an inductor, with value L = 1.25 nH. The three operating modes of the circuit were the modes 01 (Low Power), 10 (Medium Power) and 11 (High Power). Where 1 is the logical level high and 0 is the logical level low, and the cells are activated from left to right.

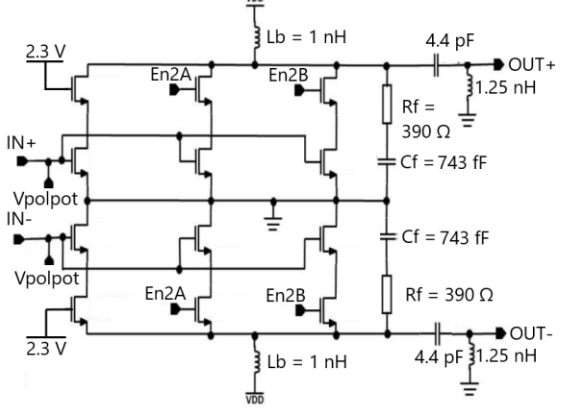

Fig. 1 – Proposed Power amplifier.

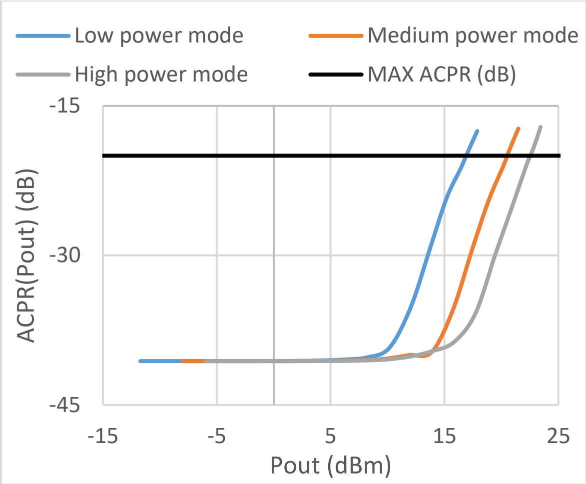

Fig. 2 – ACPR (dB) x Pout (dBm)

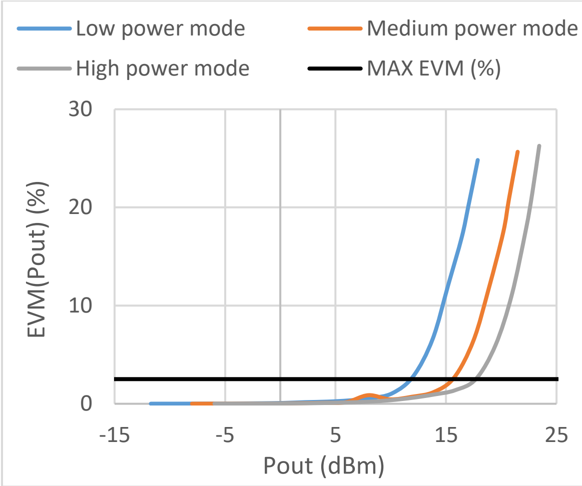

Fig. 3 – EVM (%) x Pout (dBm).

III. Results and discussion.

All the simulations were done using envelope simulations in Cadence Spectre RF, in the schematic level.

The differential output was connected to a 100 Ω impedance load and the measuring probe in parallel, the input was connected to a modulated signal source with a 100 Ω output impedance as well. The average power of the input signal varied from -15 dBm to 19 dBm and the frequency used for the simulations was 2.4 GHz. The communication standard tested was the IEEE 802.11ax with an 80 MHz channel and a 256QAM digital modulation.

The mean output power measured in the load (Pout), EVM, ACPR and PAE, all of them for the range of input power and for each of the 3 modes were then compiled.

For the characteristics tested for this communication standard, the standard limits ACPR and EVM values to -20 dB and 2.51%, respectively. Fig. 2 shows the ACPR x Pout graph, with the maximum value of ACPR shown by the horizontal line. Fig. 2 shows that for all the modes, the maximum ACPR value is surpassed for higher input powers.

From the graph it is possible to take the maximum values of output mean power that result in the established value of ACPR for the communication standard, these are 16.9 dBm, 20.6 dBm and 22.7 dBm.

The EVM x Pout graph is shown by Fig. 3, with the maximum value explicit in the graph. Again, for higher powers, all 3 modes surpass the established value.

From the graph, the maximum values of Pout that result in the established EVM value for the IEEE 802.11ax, are 11.8 dBm, 15.6 dBm and 17.7 dBm.

For all the three modes, and for the Pout that results in the established value of ACPR in the standard, the power spectral density graphs are shown in Fig. 4.

Similar to the power spectral density graph, the constellation diagram for the high power mode, for the established EVM value for the standard, is shown in Fig. 5.

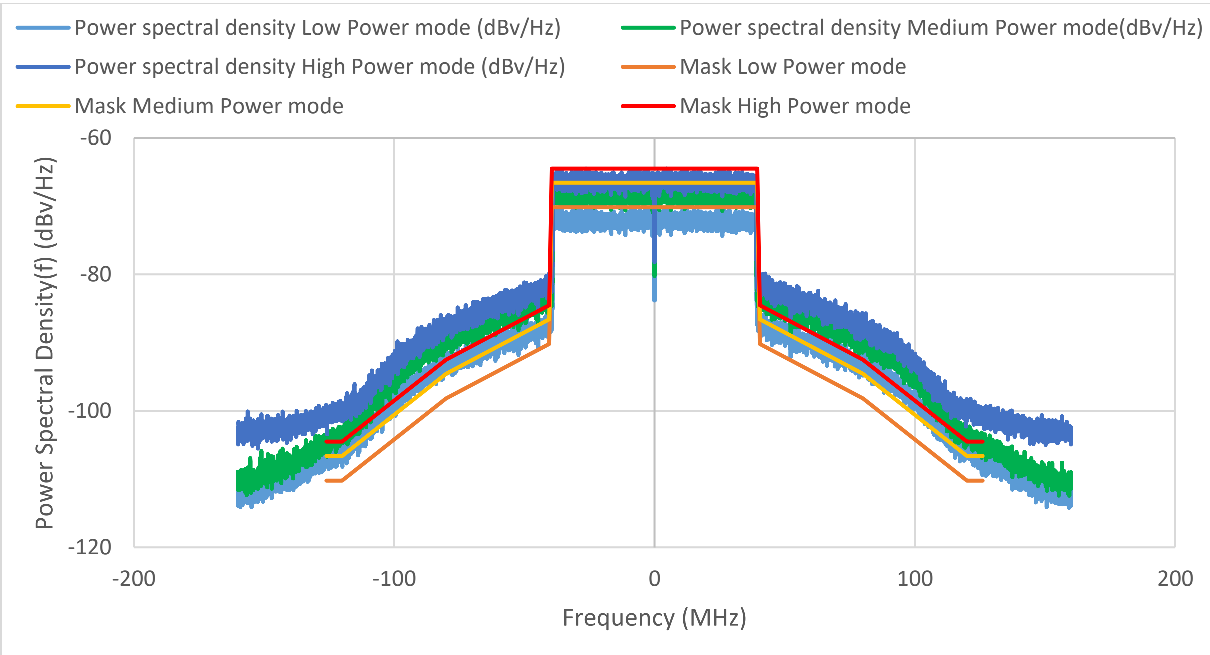

Fig. 4 – Power Spectral Density for the three modes with 16.9 dBm, 20.6 dBm and 22.7 dBm Pout, respectively.

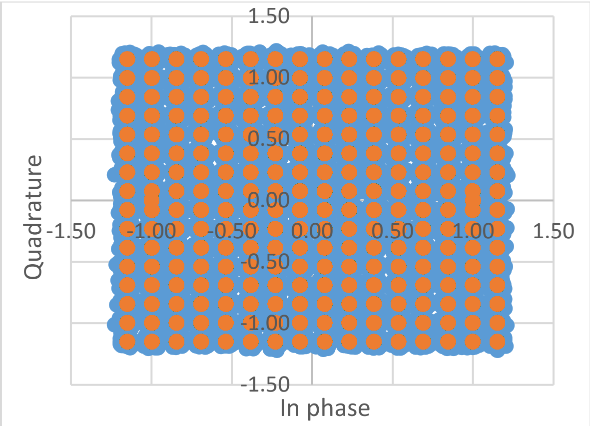

Fig. 5 – Constellation for the High Power mode, with 17.7 dBm Pout.

The PAE x Pout graph is shown in Fig. 6. It is shown that the lower power modes are the most efficient for lower powers, and for high powers, this efficiency falls significantly, highlighting the need for different modes of operation. For the low power mode, the PAE is better than for the other two for output powers lesser than 15 dBm. Similarly, the medium power mode, the PAE is better than the high power mode for output powers lesser than 21 dBm, and after that, the efficiency is better for the highest power mode, until the amplifier saturates, and the PAE falls significantly also.

The values of PAE for the maximum values of Pout that respect the established value of ACPR in the communication standard, can be taken from the graph, and are, for each mode respectively, 1.0 %, 4.7 % and 6.5 %.

Similar to the ACPR, it is possible to take the maximum values of PAE for the maximum Pout that respects the established EVM value for the digital modulation used, these are, for each mode, 0.9%, 1.7% and 2.2%. These values are shown as labels in Fig. 6.

Due to the severe limitations of EVM for the IEEE 802.11ax standard, with a maximum value of only 2.51 %, the PA is forced to operate in a low efficiency region, because of this, it displays low PAE values for the maximum Pout allowed by the communication standard,

Table 1 compiles several values of output mean power that are important to the characterization of the PA, for each of the modes. The first two columns are the maximum values of Pout that result in the established values of EVM and ACPR, the next is the saturation power for all the modes, the next is the compression point for 1 dB (OCP1dB), which is the value of power where the gain falls 1 dB of the linear characteristic of the amplifier. The last column is the PAE for

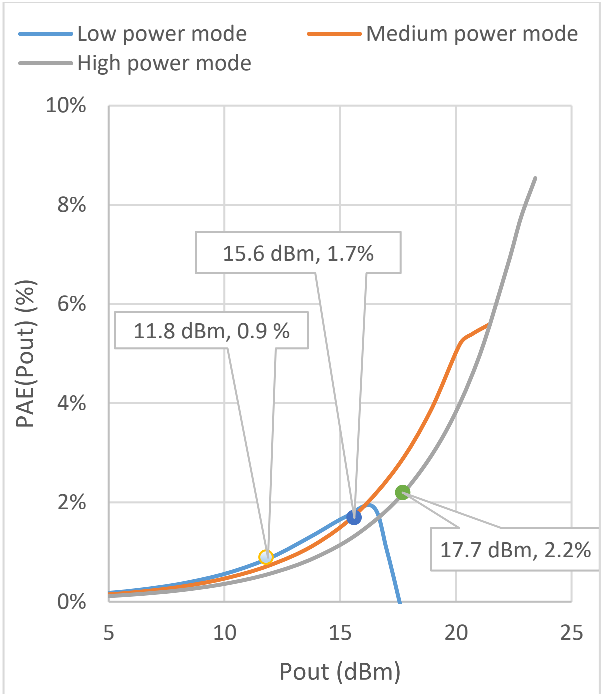

Fig. 6 – PAE (%) x Pout (dBm)

the maximum Pout that respects the values of both ACPR and EVM.

IV. Conclusion

The main purpose of this work was to characterize the PA presented and described in it, with the IEEE 802.11ax communication standard. The work presents several metrics that determine some of the main characteristics desired in a power amplifier, such as the linearity, that is measured through the EVM and the ACPR metrics, and the efficiency. Also, the work shows the maximum output power that the PA can provide for the standard tested.

The PAE curves show the need for different modes in the power amplifier, for higher input powers, the efficiency greatly decreases in lower power modes. For this reason, for a needed mean output power, the best operating mode for the PA must be chosen so that it respects the limits of ACPR and EVM and has the best possible PAE.

The PA studied shows a great range of possible output powers, without significant loss of efficiency, for the communication standard used, because of the various operating modes. The maximum values of Pout, capped by the EVM, is 11.8 dBm, 15.6 dBm and 17.7 dBm. For these values the PAE for each mode are 0.9 %, 1.7 % and 2.2 %.

Mode	Pout for max ACPR (dBm)	Pout for max. EVM (dBm)	Psat (dBm)	OCP1dB (dBm)	PAE for max. ACPR (%)	PAE for max. EVM (%)
Low power	16.9	11.8	17.9	16.5	1.0	0.9
Medium power	20.6	15.6	21.5	20.5	4.7	1.7
High power	22.7	17.7	23.4	21.0	6.5	2.2

Table 1 – Compiled values for the power amplifier.

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