Linearity characterization of a multimode CMOS Power Amplifier for IEEE 802.11n, IEEE 802.11ax and LTE signals

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Abstract— **The multitude of communication standards that operate in similar frequency bands, demands the wireless devices to be able to comply with those they want to be applied. Two metrics are essential to characterize the power amplifier (PA), operating under wireless signals, error vector magnitude (EVM) and adjacent channel ratio power (ACPR). This paper presents the characterization of a 2.4 GHz PA, which has 11 modes of operation, through post-layout simulations for IEEE 802.11n, IEEE 802.11ax and LTE signals. For the high power mode of the PA, the maximum output power compliant with both EVM and ACPR specifications is 14.4 dBm for IEEE 802.11n, 11.4 dBm for IEEE 802.11ax and 16.5 dBm for LTE using 16QAM modulation. The obtained results demonstrate the feasibility of reducing power consumption when lower output powers are targeted.**

I. INTRODUCTION

In the context of wireless communication, there are several communication standards that operate under the same central frequency. In this perspective it is important that the power amplifier (PA) comply multiple standards, so it is possible to remove the need for dedicated chips for each standard.

Examples of standards that operate nearby the 2.4 GHz band include LTE (Long Term Evolution)and IEEE 802.11 amendments, such as IEEE 802.11n and IEEE 802.11ax .

IEEE 802.11n can operate on 2.4 GHz and 5 GHz, can use 20 MHz and 40 MHz channels reaching a speed of up to 600 Mbit/s [1]

IEEE 802.11ax protocol can also operate under the 2.4 GHz and 5 GHz frequencies, with 20 MHz, 40 MHz, 80 MHz and 160 MHz channels. This standard can reach a speed of 1200 Mbit/s and use BPSK, QPSK, 16QAM, 64QAM, 256QAM and 1024QAM [2].

LTE standardizes the operating frequencies at 700 MHz and 2600 MHz, can use channels with 1.25 MHz, 2.5 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz reaching speeds up to 300 Mbit/s using QPSK or 16QAM moculations [3].

Wireless data transmission is a critical point in communication systems, since the PA must have a trade-off between linearity and power consumption. The linearity evaluations in the wireless communication systems are performed through the Error Vector Magnitude (EVM) and the Adjacent Channel Power Ratio (ACPR) metrics.

With regard to power consumption, some techniques can be employed to reduce it, increasing the efficiency of PA. One of these methods is the use of multi-mode PAs, where each operating mode can reach different output power levels and has different power consumption.

This article is organized as follows. Section II presents the PA topology employed in this paper. Section III presents the results obtained in the PA characterization, and section IV presents the conclusions of the paper.

II. POWER AMPLIFIER

This paper characterizes, through post-layout simulations, a multimode power amplifier, class AB, designed to operate at 2.4 GHz using GLOBALFOUNDRIES 130 nm RF CMOS process.

The PA is presented in [5] and is composed of a gain stage, a reconfigurable power stage (block I), a variable V_{DD} (detail II), a reconfigurable output network matching (OMN) (block III). The architecture of the PA is presented in Fig.1, where, for simplicity, the input & interstage matching, feedback passives and biasing circuitry were omitted.

The OMN is a low pass reconfigurable π matching network composed of two capacitor banks (IV and V blocks) and a fixed inductor. The capacitor banks are enabled by NMOS switches, and in this way it is possible to achieve configurations that increase the power transfer for each mode.

Using the four inputs (A, B, C and D), twelve power modes are reached for the PA. The table I presents the designation of these modes with respective combinations of the power stage and capacitor banks, as well as the value of V_{DD}.

Fig. 2 shows the circuit's layout that has a die area of 1320 μm by 1285 μm including pads.

III. CHARACTERIZATION

PA characterization was done by applying envelope analysis on Cadence Spectre RF, using the sources of the IEEE 802.11n, IEEE 802.11ax and LTE communication standards. The presented results are obtained from post-layout simulations.

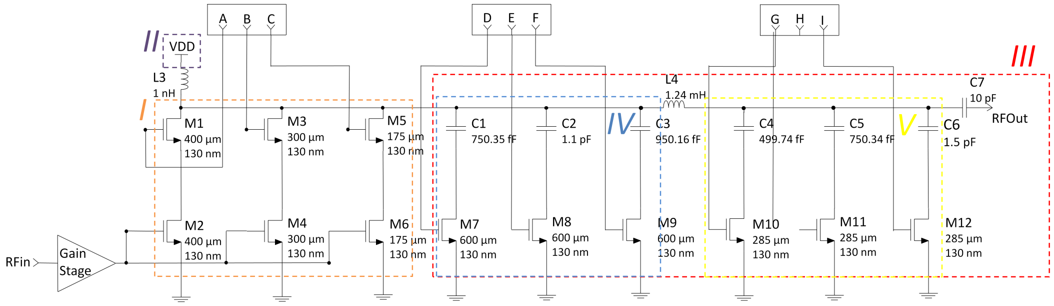


Fig. 1. PA schematic.

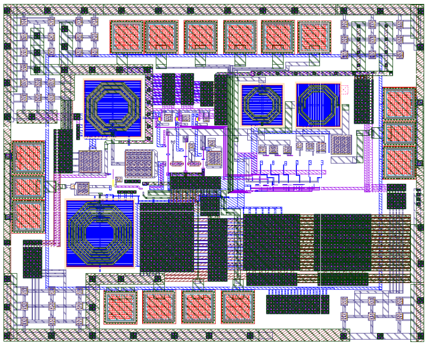


Fig. 2. PA's layout.

TABLE I

DESIGNATION OF OPERATIONS MODES

Designation	Input code (ABCD	$OCP1_{dB}$ (dBm)	P_{DC} @ $OCP1_{dB}$ (mW)
0, high power	0000	18.22	341.4
1	0001	17.27	276.9
2	0010	16.53	231.3
3	0011	16.02	220.6
4	0100	15.54	199.2
5	0101	15.01	178.7
6	0110	14.39	173.4
7	0111	13.87	148.1
8	1000	12.89	127.0
9	1001	11.96	115.4
10	1010	11.04	101.0
11, low power	1011	10.09	94.7

In this paper, several simulations were made following the same setup used in [6]. For each analysis the mean input power (P_{IN}) was set, and then the values of mean output power (P_{OUT}), EVM and ACPR were obtained.

With the target to determine the P_{OUT} limits for each PA's power mode, the power range was set in such a way that the PA exceed the limits established by the communication standard, for any of the evaluated metrics

A. IEEE 802.11n

The IEEE 802.11n communication standard limits EVM to 7.94% and ACPR to -20 dB at 11 MHz, when using 64QAM modulation, operating at 2.4 GHz with a 20 MHz channel bandwidth [1]. Fig. 3 shows the EVM result as a function of mean P_{OUT} for the eleven power modes. It is observed that with the increase of the mean P_{OUT}, the EVM alsos increases. Thus there are output power levels from which the PA does not comply the standard. IEEE 802.11n requirements limit the use of the PA to a mean P_{OUT} of 6.3 dBm for the low power mode, and to 14.4 dBm for the high power mode.

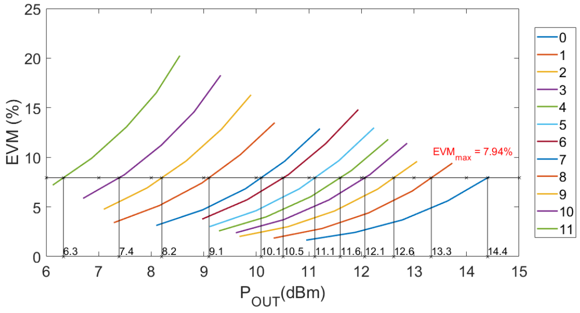


Fig. 3. EVM vs P_{OUT} for the 11 power modes for IEEE 802.11n.

Fig. 4 shows the ACPR as a function of the output power of the PA. Just like the EVM, ACPR increases with the addition of the P_{OUT}. However, for the analyzed power range, none power mode exceeds the limit of ACPR established by the standard.

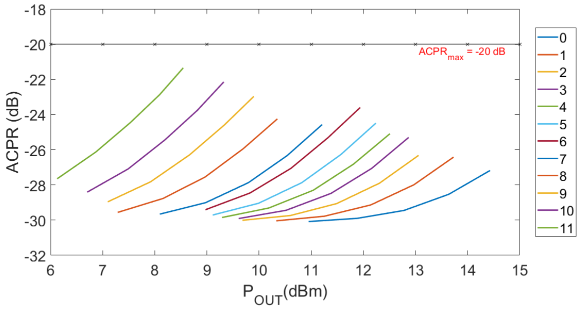
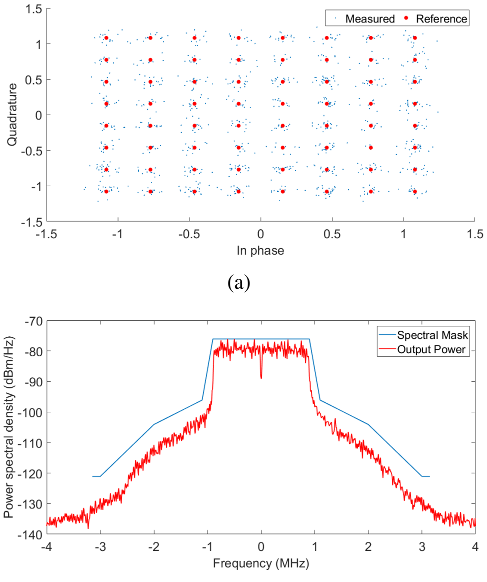


Fig. 4. ACPR vs P_{OUT} for the 11 power modes for IEEE 802.11n.

Fig. 5(a) shows the reference and measurement symbols for the low power mode under IEEE 802.11n signal, for a mean P_{OUT} of 6.13 dBm. The measured EVM is 7.2%, 0.74 p.p. lower than the limit established by the standard. Fig. 5(b) presents the power spectral density at the output and the ACPR mask defined by the standard. The ACPR at 11 MHz is −27.65 dB.



(a)

(b)

Fig. 5. (a) Constellations for IEEE 802.11n and (b) ACPR for IEEE 802.11n.

B. IEEE 802.11ax

The IEEE 802.11ax communication standard limits EVM to 2.51% and ACPR to -20 dB at 40 MHz, when using 256QAM modulation, operating at 2.4 GHz with a 80 MHz channel bandwidth [2]. For this paper, the simulations were performed on channel 7, with a carrier of 2442 MHz.

Fig. 6 shows the EVM result as a function of mean P_{OUT} for all the PA power modes. For this communication standard, the EVM limits the output power of the PA to 11.4 dBm for the high power mode, and to 3.2 dBm for the low power mode.

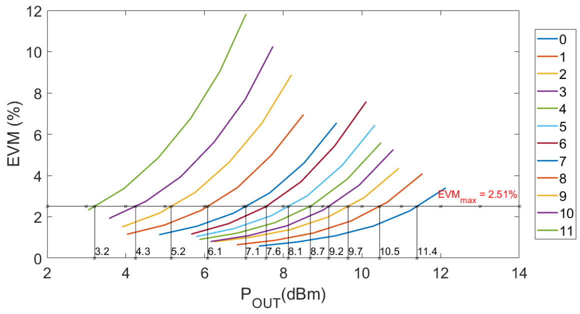


Fig. 6. EVM vs P_{OUT} for the 11 power modes for IEEE 802.11ax.

It is observed, in Fig. 7 which shows the ACPR as function of mean P_{OUT}, that in the analyzed power range the ACPR does not exceed the limit established by the communication standard, as IEEE 802.11n.

Fig. 8(a) shows the reference and measurement symbols for the low power mode under IEEE 802.11ax signal, for a mean P_{OUT} of 3.04 dBm. The measured EVM is 2.31%, 0.19 p.p. lower than the limit established by the standard. Fig. 8(b) presents the power spectral density at the output and the ACPR mask defined by the standard. The ACPR at 20 MHz is −36.57 dB.

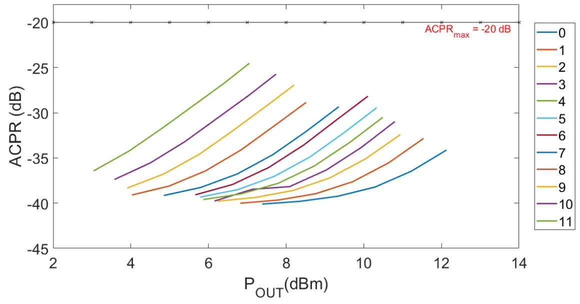
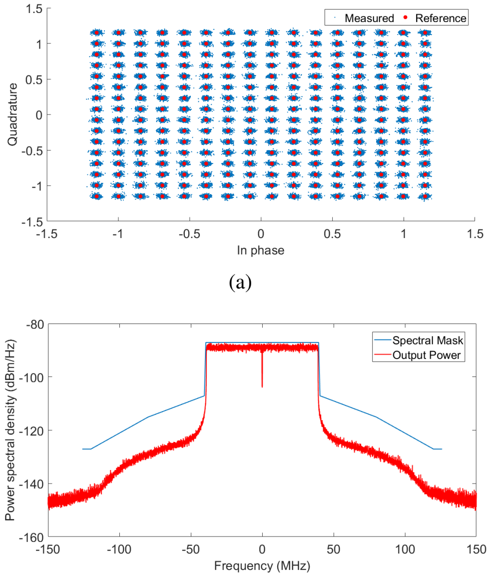


Fig. 7. ACPR vs P_{OUT} for the 11 power modes for IEEE 802.11ax.



(a)

(b)

Fig. 8. (a) Constellations for IEEE 802.11ax and (b) ACPR for IEEE 802.11ax.

C. LTE

The LTE standard limits ACPR to -26 dB at 3.5 MHz, and EVM to 12.5%, when using the 16QAM modulation [3]. The caracterization, in this paper, was made with a 5 MHz bandwidth channel, at the channel number 27710 with a carrier of 2310 MHz.

Fig. 9 shows the EVM as function of P_{OUT}. As in the cases previously shown the increase of the output power results in increased EVM. For the LTE, the EVM limits the output power of the PA to 16.9 dBm for the high power mode, and to 8.8 dBm for the low power mode.

Fig. 10 shows ACPR as a function of P_{OUT}. Unlike the cases previously shown, for the LTE all the power modes exceeds the ACPR limit established by the standard. This

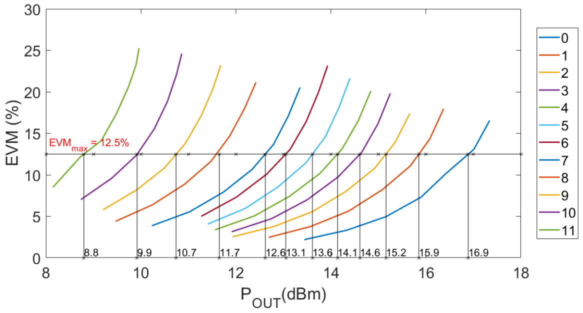


Fig. 9. EVM vs P_{OUT} for the 11 power modes for LTE.

result limits the high power mode to 16.5 dBm and the low power mode to 8.6 dBm.

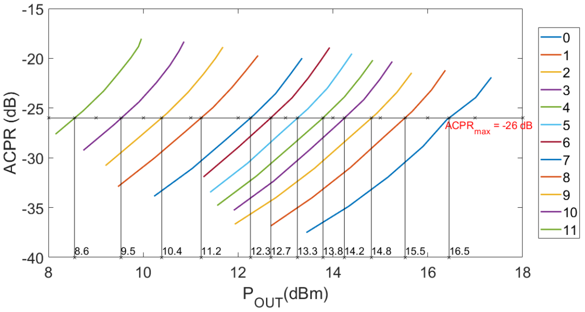
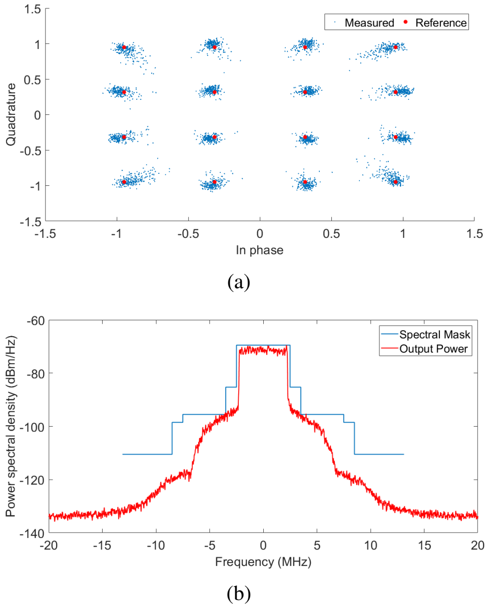


Fig. 10. ACPR vs P_{OUT} for the 11 power modes for LTE.

Fig. 11(a) shows the reference and measurement symbols for the low power mode under IEEE 802.11n signal, for a mean P_{OUT} of 8.15 dBm. The measured EVM is 8.51%, 3.99 p.p. lower than the limit established by the standard. Fig. 5(b) presents the power spectral density at the output and the ACPR mask defined by the standard. The ACPR at 3.5 MHz is −27.62 dB.

IV. CONCLUSIONS

This paper presented a post-layout characterization of a CMOS power amplifier with 11 power modes at 2.4 GHz, through envelope analysis, evaluating the linearity metrics EVM and ACPR. In order to determine the output power limits that the PA still comply with the IEEE 802.11n, IEEE 802.11ax and LTE signals, each analysis was performed for a mean input power resulting in values of P_{OUT}, EVM and ACPR. It was observed that for the Wi-Fi standards the limitation was imposed by EVM, while for the LTE the limiting factor was ACPR. Tab. II showns the mean P_{OUT} limit for each one of the communication standards for all the PA's power modes. IEEE 802.11ax standard limits the P_{OUT} to lower values, especially due to the modulation used, which requires high transmission linearity. The feasibility of reduce power consumption are demonstrated by the results obtained since the PA can be adjust for lower power modes, if possible, that have lower P_{DC}.



(a)

(b)

Fig. 11. (a) Constellations for LTE and (b) ACPR for LTE.

TABLE II

MEAN P_{OUT} LIMITS FOR THE COMMUNICATION STANDARDS ANALYZED FOR ALL POWER MODES.

Power Mode	$P_{OUT_{MAX}}$ (dBm) 802.11n	802.11ax	LTE	P_{DC} @ $OCP1_{dB}$ (mW)
0, high power	14.4	11.4	16.5	341.4
1	13.3	10.5	15.5	276.9
2	12.6	9.7	14.8	231.3
3	12.1	9.2	14.2	220.6
4	11.6	8.7	13.8	199.2
5	11.1	8.1	13.3	178.7
6	10.5	7.6	12.7	173.4
7	10.1	7.1	12.3	148.1
8	9.1	6.1	11.2	127.0
9	8.2	5.2	10.4	115.4
10	7.4	4.3	9.5	101.0
11, low power	6.3	3.2	8.6	94.7

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