INVESTIGATION OF RF POWER AMPLIFIERS FOR 802.11a MOBILE TERMINALS

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***Abstract* –In this paper, the performances of various bias classes of Power Amplifiers (PA) working in 802.11a transmitters are presented. Computer simulations of a complete 802.11a transmitter have been made in order to investigate the PA efficiency and Adjacent Channel Power Ratio (ACPR) at the output of the non-linear PA. A high-level power amplifier model is used to model the different classes of amplifiers (class A, class B, class AB and class C) according to the conduction angle at the output signal of the PA. Other behaviors given in real amplifiers, such as the saturation level and compression near saturation are modeled as well. Results of PA efficiency, ACPR and output spectra are presented.**

I. INTRODUCTION

Wireless Local Area Networks (WLAN) supporting broadband multimedia communications are proliferating. IEEE 802.11a is one of the standards used in those networks, which provides data rates up to 54 Mbps in the 5 GHz band.
The main characteristics of the IEEE 802.11a standard are shown in Table I.

Characteristics	
Operating frequencies	5.15-5.25, 5.25-5.35 and 5.725-5.825 GHz
Data rates	6,9,12,18,24,36,48, and 54 Mbit/s
Modulations	BPSK, QPSK, 16- QAM, 64 QAM.
Physical layer	OFDM
Number of subcarriers	48 data subcarriers, 4 pilot subcarriers
FEC code and coding rates	Convolutional, ½, $^2/_3$, or ¾ coding rates

Table I.IEEE 802.11a characteristic [1]

Orthogonal Frequency Division Multiplexing (OFDM) is the transmission scheme specified in the 802.11a standard.
The general block diagram of the transmitter for the OFDM PHY is shown in Fig. 1.

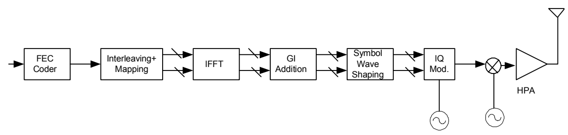

Fig. 1. Transmitter block diagram for the OFDM PHY [2]

The OFDM signal exhibits a wide range of envelope values leading to an increase in the Peak-to-Average Power Ratio (PAPR) of the signal. In consequence, the use of highly linear transmitters is required [3].
The problem is specially found in the PA of the transmitter, which dissipates the highest amount of power. High linearity normally implies low efficiency, since large back off needs to be applied. For mobile terminals however, PA efficiency is crucial since it normally has a dominant effect on the 'talk-time' for a given battery capacity.
This paper consists of the following sections. In Section II, basic concepts about RF power amplifiers are covered; in Section III, a short study about the power consumption in WLAN PC Cards in 802.11a mobile terminals is presented; in Section IV, a high level PA model is described; in Section V, simulations and calculations needed are explained; results and discussions are presented in Section VI.

II. RF POWER AMPLIFIERS

The main classes of linear amplifiers are A, AB, B and C with class-A generally being the most linear and the least efficient of the four [4]. Characteristics such as architectures, linearity or efficiency make different the classes of RF power amplifiers but the major difference is the bias point (I_{DC}) and therefore the different output waveforms depending on the applied bias. The main characteristics of class A, classes AB, class B and class C bias operation are shown in Table II.

	Class A	Class AB	Class B	Clas s C
Bias point	$I_{ds}\approx 0.5I_{dss}$ $V_{ds}\approx 0.5V_{ds,max}$	Between A and B	$I_{ds}\approx I_{dss}$ $V_{ds}\approx V_{ds,max}$	$I_{ds}<I_{dss}$ $V_{ds}\approx V_{ds,max}$
Conduction Angle	Both polarities (360°)	More than one polarity (> 180°)	One polarity (180°)	Peak of one polarity (<180°)
RF gain	High	High/moderate	Moderate	Low
RF power	High	High	High	Low
Drain efficiency	Low (≤ 50%)	Moderate (50%-78.5%)	High (≤ 78%)	Very high (78.5%-100%)
Non-linearity	Low	Moderate	High	Very high

Table II. Bias operation summary [4]

III. POWER CONSUMPTION IN 802.11a MOBILE TERMINALS

An estimation of the power consumption of 802.11a WLAN chipsets is given. The power consumption of the total chip including digital and analog part (without PA); both in transmit and receive modes and power dissipation of the PA for the 802.11a output powers is shown in Fig. 2.

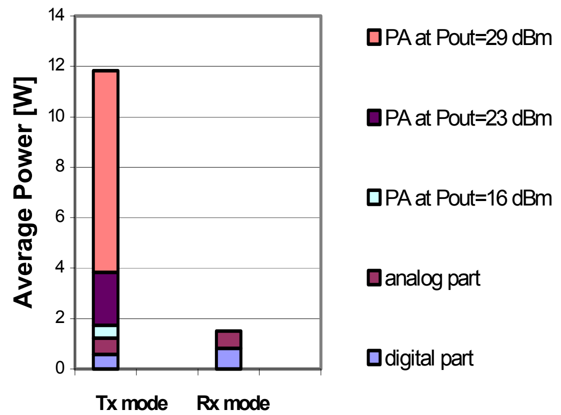

Fig. 2. Averaged power consumption for 802.11a mobile terminals

As Fig. 2 shows, the PA used in transmission is critical regarding to power consumption.
The PA power consumption will strongly depend on the specific output power. Considering an average PA efficiency of η_{PA}=7.5%, the powers dissipated at the output powers specified in the 802.11a standard (16 dBm, 23 dBm and 29 dBm) are equal to 0.5 W, 2.6 W and 10.6 W respectively. A drastic increase in the PA power consumption can be observed for the highest 802.11a output power.

IV. PA MODEL

A high-level power amplifier model is described in this section, which has been used to study PA efficiency and distortion in a 802.11a transmitter. A PA design will model the different classes of amplifiers (class A, class B, class AB and class C). The schematic of the PA model is shown in Fig. 3:

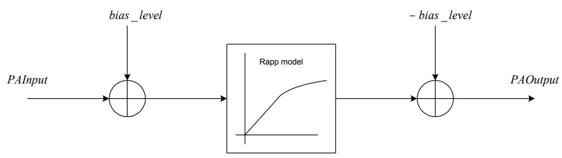

Fig. 3. PA model schematic (class A, class B, class AB and class C)

The main parameters of the model are the *bias level* (dependent on the conduction angle), *saturation level*, *compression* and *gain*.
The bias level is added to the PA input signal and it is computed by Eq. 1:

$$bias\_level = -abs(Psat)\cdot \cos\left(\left(\frac{\pi}{180}\right)\left(\frac{conduction\_angle}{2}\right)\right) \quad (1)$$

where *Psat* is the saturation level and *conduction_angle* is the current angle (degrees) at the output.
The numerical values of bias level for the different classes normalized to the maximum voltage level are shown is Table 3:

Class	Conduction Angle	Bias Level
A	360°	0.5
AB	360°<θ <180°	0.5<level<0
B	180°	0
C	180°<θ <0°	0<level<-0.5

Table 3. Bias levels

Amplification and the maximum output voltage are limited by the finite power supply to the amplifier, hence the output starts to saturate at a certain input voltage level. This PA model is based on the well know Rapp model with knee parameter, b [5]. The output voltage of the Rapp model, V_{out_model}, is given by Eq 2.

$$V_{out\_model} = v \cdot \frac{V_{in,biased}}{\sqrt[2b]{1+\left(\frac{v \cdot V_{in\_biased}}{V_{LIM}}\right)^{2b}}} \qquad (2)$$

After the clipping of the signal, bias level is removed obtaining the output signal of the PA model.

V. SIMULATIONS

Simulations of a complete 802.11a transmitter using the non-linear PA model described in Section IV have been made. The 802.11a OFDM signal used to study the non linearity of the PA model will be generated by a transmitter included in the WLAN Design Library from ADS, which is compliant with the 802.11a specifications (Fig.1).

In Hptolemy simulator from ADS, signals are represented by a complex lowpass representation; however, in our simulations a conversion to real bandpass representation of the signal has been required.

Simulations have been performed using a sequence of 25 OFDM symbols. The PAPR of this sequence is 12.5 dB. The sample rate of the signal also has to be taken into account. Up-sampling the signal by a factor higher than 3.8 gives in our simulation accurate results, and in consequence realistic information about out- band distortion and back off power are obtained. Further information about it can be found in [6].

VI. RESULTS AND DISCUSSION

PA efficiency versus conduction angle using 802.11a OFDM signals is shown in Fig. 4. The efficiency for the classical modes of operation defined in terms of conduction angle shows that a class A amplifier presents efficiencies between 4% and 9 % (back off from 7 dB to 1 dB from the saturation); a class AB amplifier conducting 270° presents efficiencies between 7% and 13 % (back off from 7 dB to 1 dB from the saturation) and conducting 200°, PA efficiencies up to 20% (backing off 3 dB the input from saturation) are achieved. A class B operation amplifier presents a PA efficiency of around 22% ~ 23%. The higher PA efficiencies are given by class C amplifiers, which have efficiency around 24 % conducting 170° and 32% conducting 90° of the RF cycle.

Class B shows a negligible difference in efficiency for different back off input power levels. DC supply power varies with the RF input signal amplitude (different applied power back off), thus efficiency remains almost constant for any power back off.

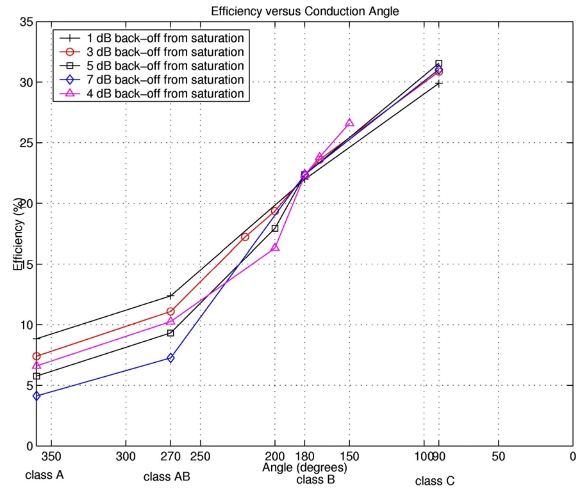

Fig. 4. Efficiency versus Conduction Angle (5.2 GHz carrier frequency)

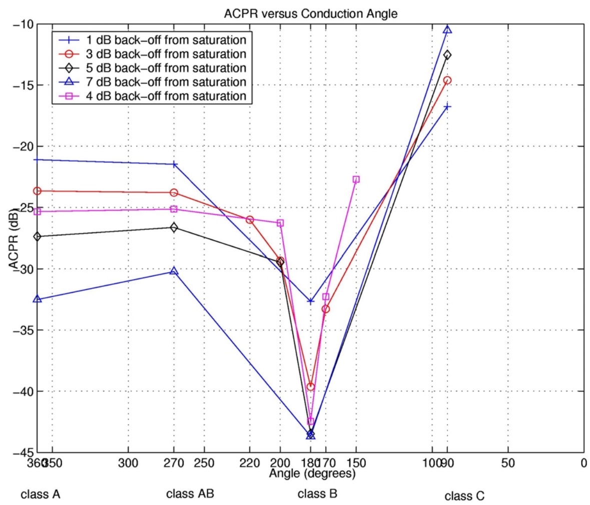

Fig. 5. ACPR versus Conduction Angle (5.2 GHz carrier frequency)

Adjacent Channel Power Ratio (ACPR) versus conduction angle is shown in Fig. 5. Results shows how odd order intermodulation products become lower when the conduction angle decreases from around 240° to class B operation, where only even order distortion is generated. This is the reason the lowest ACPR is achieved for class B operation. Even order intermodulation product frequencies are outside the frequency range of interest and they can easily be filtered out by a band pass filter. In class C operation, a faster increase of the out-band distortion is shown.

Fig. 6 and Fig.8 show the output spectra for the different classes.

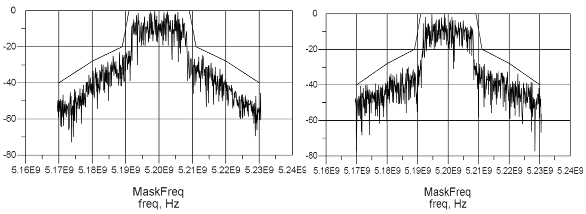

Fig. 6. a) Class A (360°, 5 dB back off from saturation) b) class AB (200°, 5 dB back off from saturation)

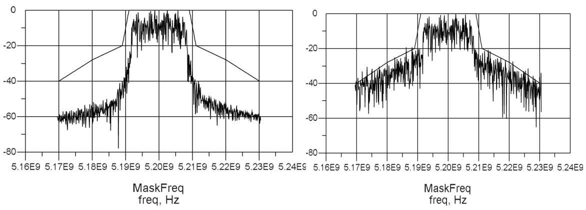

Fig. 7. a) Class B (180°, 5 dB back off from saturation) b) class C (150°, 4 dB back off from saturation)

Minimum back off input power required to fulfil the 802.11a spectrum mask is shown. Results shows that for class A and class AB (300°~260°) operation at least 6 dB back off power from the saturation level are needed in order to have the output spectrum below the 802.11a spectrum mask. However, it is clear that working in a class AB operation, even closer to class B, 200°~180°, improvements in at least 1 or 2 dB can be achieved. For a class C operation, the minimum back off will depend strongly on the conduction angle.

Looking into the results explained previously, class B, class AB and C conducting near class B, present higher PA efficiency and the best results in out-band distortion. It makes operation in those classes an interesting solution for the design of RF power amplifiers for WLAN, achieving better overall performances than class A operation.

VII. CONCLUSION

Computer simulations and results of efficiency and ACPR of various classes of PA for 802.11a transmitter are presented. Poor efficiency (6%-13%) for class A and class AB near A is shown. Higher efficiency and lower ACPR is presented for class B and class AB operation due to the suppression of odd order distortion in class B operation.

VIII. FUTURE WORK

This work can be completed by a study of improvements in efficiency and distortion achieved by linearization of the PA transfer function.

ACKNOWLEGMENT

I would like to thanks Patrik Eriksson and Ulf Handel at Acreo for technical discussion and help with this work.

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