Impact of Carrier Frequency Dependent Power Amplifier Behavior on 802.11a WLAN System

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***Abstract*— A revealing new study is presented on the impact of frequency-related performance variation of power amplifiers (PAs) for 802.11a WLAN systems. A look-up table (LUT) model that addresses such, so called, memory effects was developed for an example PA and used to study frequency dependent non-linear effects on WLAN system performance parameters, such as spectral regrowth (e.g. ACPR) and error vector magnitude (EVM). The results show significant frequency-dependent variations in these critical system parameters and underline the importance of memory-effect modeling for PAs used in OFDM WLAN systems.**

I. Introduction

Wireless transmitters often utilize power amplifiers (PAs) as the final amplification stage. Together with the high gain provided, the nonlinear PAs also cause distortions to the input signal both in-band and out-of-band, which have serious impact on the communication quality. Therefore, accurate PA modeling is needed to help troubleshoot the impairments and optimize the trade-off between the efficiency and nonlinearity. Most often used parameters to describe the nonlinearities of the PAs include AM-AM distortion, AM-PM distortion, 1 dB compression point (P1dB), and 3rd order interception point (IP3). Typical parameters used to evaluate the effects of the model on a system are error vector magnitude (EVM) and adjacent channel power ratio (ACPR).

Lots of studies have been done and reported on efficient and accurate PA modeling [1-14]. Generally, the models can be divided into two categories: memoryless models and models with memory effects (i.e. previous input signal affects the present output signal). Memoryless models utilize only AM-AM and/or AM-PM parameters in the characterization process [1-7]. Saleh [1] proposed two rational functions to model the AM-AM and AM-PM compression effects, which is widely used in PA modeling [2]-[4]. Polynomial functions are widely used to model the gain compression, as shown in [5,6]. Linear functions are also used to simplify the modeling of the AM-PM effect [7].

Memory models use two-tone intermodulation measurements to describe the frequency response of the matching network, nonlinear capacitances and response of the bias network [8-11]. The memory effects can be modeled using long delay linear time-invariant (LTI) system in parallel as shown in [8], tapped-delay-line (TDL) [9], dynamic Volterra kernels [10] or filtering [11,12]. In [13,14], direct mathematical manipulation on the AM-AM and AM-PM curves were reported to account the frequency-related effects of the amplifier under study (shifting and scalling are the main operation). Obviously, the limitation would be that it requires the AM-AM and AM-PM curves to maintain their shapes, which may not always be the case.

Even though with all the reported work on the PA modeling, the characterization of the performance variation of the PA vs. carrier frequency still needs to be studied to overcome the limitations illustrated above. Furthermore, the corresponding effect of the PA variation on the wideband system performance needs to be explored as well.

Therefore, it is the purpose of this paper to propose a simple look-up-table (LUT) PA model that fully considers the carrier frequency effect. By applying the PA model in an 802.11a WLAN transmitter, it is illustrated that this model can capture the significant performance variation of the system at different carrier frequencies, which is of great importance for system evaluation and validation. .

II. 802.11a WLAN System Overview

802.11a Wireless Local Area Network (WLAN) standard uses Orthogonal Frequency Division Multiplexing (OFDM) modulation technique because of its ability to offer high data rates while combating the multipath effects encountered in high speed wireless channels.

Figure 1 shows typical transmitter and receiver block diagrams for 802.11a WLAN system [15]. The baseband signal goes through several procedures like coding, scrambling, interleaving, mapping, inverse fast Fourier transform (IFFT) before it is up-converted and amplified for transmission. At the receiver end, the received signal is down converted, digitized and these digital samples are processed to recover the transmitted information.

With all the advantages of the OFDM technique, it has its own disadvantages, one of which is that the OFDM modulated signals have high peak-to-average power ratio (PAPR). The PAPR is defined as

$$PAPR = \frac{max(s(t))^2}{average(s(t))^2} \tag{1}$$

where s(t) is the OFDM modulated signal.

Figure 2 presents the power level of a simulated OFDM signal versus time. The signal is split into two parts: the preamble part and data part. The preamble portion can be observed explicitly at the start which has 8 μs short training sequence and 8 μs long training sequence; the data portion shows a large variation in the power level, which is the intrinsic property of an OFDM modulation.

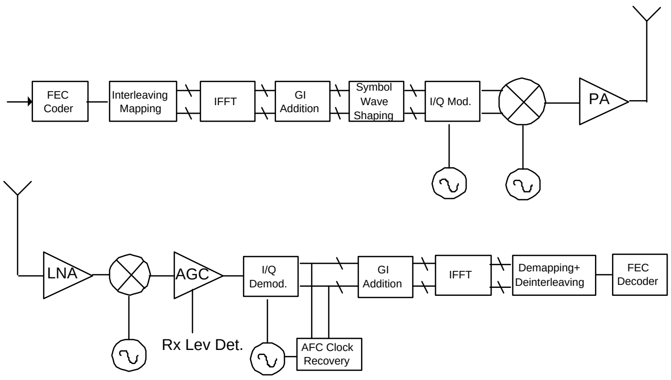

Fig. 1. 802.11a WLAN system transmitter and receiver diagram (excerpt from standard [15])

TABLE I
FREQUENCY PLAN OF 802.11A WLAN SYSTEM.

Band (GHz)	Operating Channel Numbers	Channel Center Frequencies (MHz)
lower band (5.15-5.25)	36	5180
	40	5200
	44	5220
	48	5240
middle band (5.25-5.35)	52	5260
	56	5280
	60	5300
	64	5320
upper band (5.725-5.825)	149	5745
	153	5765
	157	5785
	161	5805

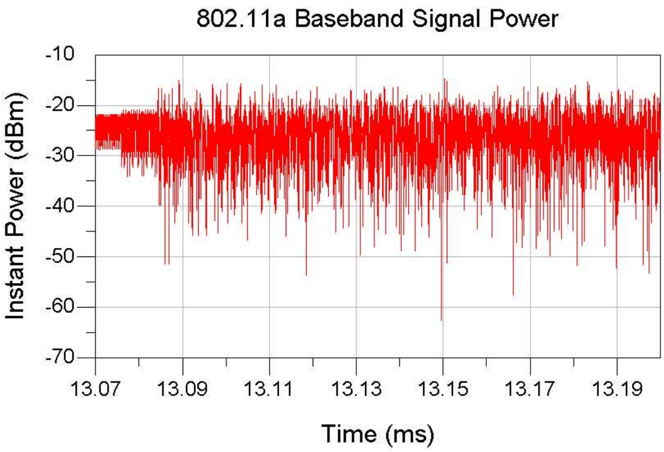

Fig. 2. Simulation of a 802.11a OFDM signal: power vs. time.

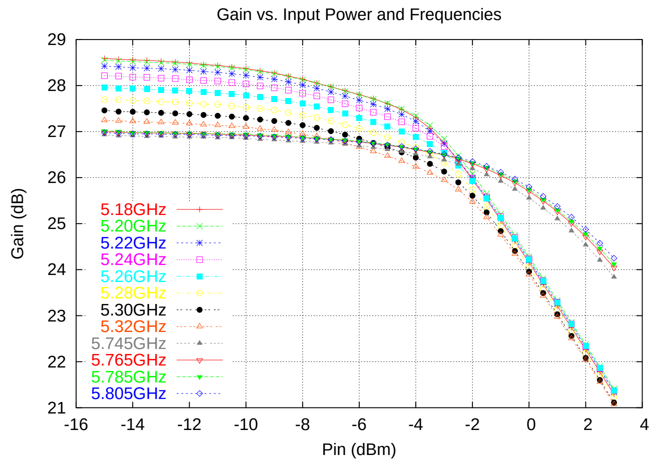

Fig. 3. Measured AM-AM of a Murata XM5060 PA used in 5GHz WLAN system.

High PAPR signals require the PA to be linear in a large range of input power levels; otherwise clipping may occur that distorts the signal, leading to significant performance loss, large EVM and high bit-error-ratio (BER) [1]. Linearity of a PA is a trade-off of efficiency and battery life. Therefore, PAs used in the WLAN system have to be designed/selected carefully to obtain optimal combination.

According to the 802.11a standard, WLAN systems provide up to 54 Mbps data rate and its 12 channels distribute in approximate 700MHz range, as shown in Table I. The multi-channel system is another problem for PAs since during this large frequency span, the performance of the PAs won't be constant. The variation in the performance is important for system evaluation and validation. However, to the authors' awareness, this variation related with the carrier frequencies has not been fully studied yet. In the following sections, the newly proposed model is introduced and its influence on the simulation results is studied in detail.

III. FREQUENCY-RELATED PA PERFORMANCE AND MODELING

In general the AM-AM and AM-PM effects tend to change at different carrier frequencies, as shown in Figure 3 and Figure 4. The figures present the AM-AM and AM-PM parameters of a Murata GaAs XM5060 PA measured at different carrier frequencies specified by the 802.11a WLAN standard. Table I lists the detailed frequency allocation, which is grouped in three (lower, middle and upper) bands.

As shown in the figures, this specific power amplifier has higher gain at lower and middle bands than at upper band, while the 1dB compression point is higher at the upper band. On the other hand, the AM-PM effect is significant at lower and middle bands, decreasing with the increment of carrier frequencies. The phase response of the amplifier is almost constant at upper band. Note that different PAs may have a different performance over the 802.11a WLAN frequency band.

A look-up-table model is constructed based on the measurement results. Carrier frequency is the main index that refers to the individual AM-AM and AM-PM measured data files. This model is implemented in ADS 2003A using the Data Access Component (DAC), as shown in Figure 5. As a verification of the LUT model, the simulated AM-AM and AM-PM results are compared to the measured results, illustrated in Figure 6.

IV. SIMULATION USING THE NEW PA MODEL

To study the PA effect on the WLAN system performance, an 802.11a WLAN transmitter is then constructed using this LUT PA model. The baseband signal is up-converted to three different channels and fed to the power amplifier model. The EVM, ACPR and CCDF are measured at the output port.

Figure 7 shows the simulated EVMs vs. input power level at the three carrier frequencies, specifically channel 48 (5240

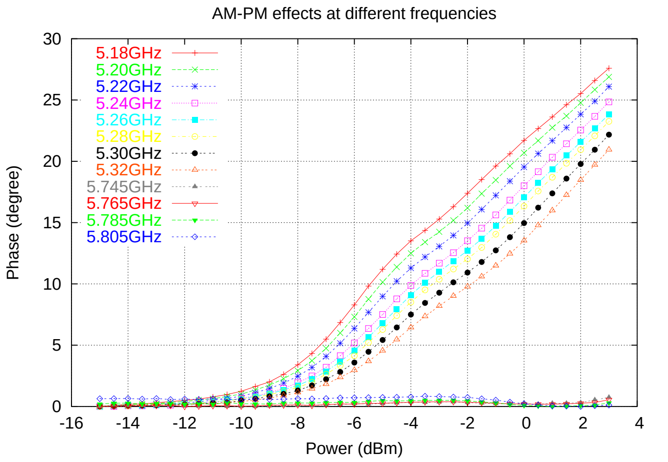

Fig. 4. Measured AM-PM of a Murata XM5060 PA used in 5GHz WLAN system.

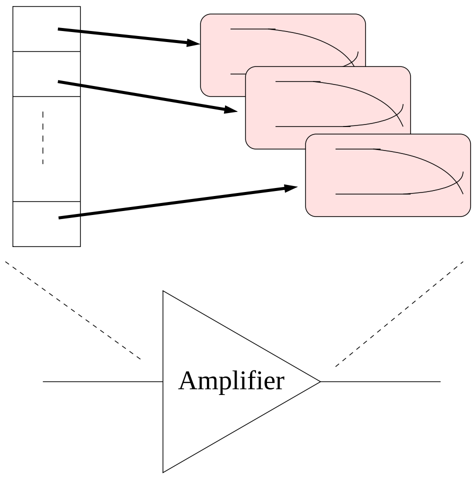

Fig. 5. Diagram of the LUT PA model.

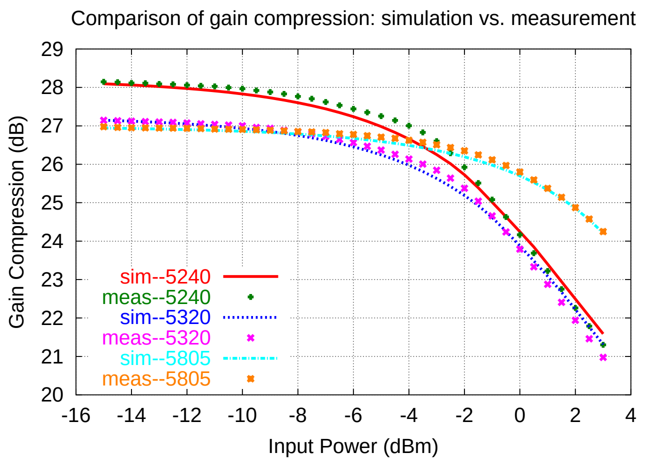

Fig. 6. AM-AM Comparison of the model and the measurement results.

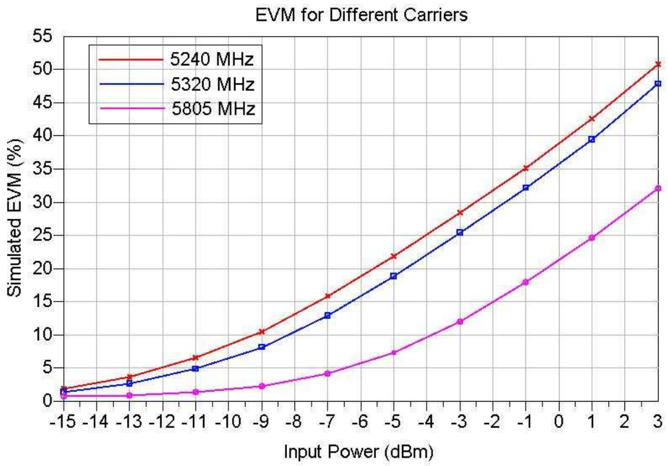

Fig. 7. Simulation of the EVM at different carrier frequencies. The frequency effect on the simulated results is obvious.

MHz), channel 64 (5320 MHz) and channel 161 (5805 MHz). According to the measurement results shown in previous section, at 5240 MHz, the PA has the highest gain, however the lowest 1dB compression point and the largest AM-PM effect. This causes the highest EVM as shown in Figure 7. At 5320 MHz, the EVM improves a little bit, mainly due to the improved 1dB compression point. The EVM at 5805 MHz is much better than the former results. This is contributed to the low AM-PM distortion and the high 1 dB compression point at the upper band.

The difference among the EVM curves at different carrier frequencies illustrates the importance to model the frequency-dependent property of a PA. For example, if 5% EVM is required for the system, then the input power level has to backoff to -11 dBm so that all the carriers can meet the specification. If only one static model is used in the simulation, the simulated result may mislead the designers to believe the system can meet the standard at input power level at -7dBm.

Figure 8 shows the spectral regrowth due to the distortion of the PA at different carrier frequencies. At 5240 MHz and 5320 MHz, the signal power spectrum is right on the edge of the spectral mask specified by the 802.11a standard. However, at 5805 MHz, the spectral regrowth is much less, because of the high 1dB compression point and low AM-PM distortion at this carrier frequency.

Figure 9 presents the simulation of Complementary Cumulative Distribution Function (CCDF) curves using the new PA model. CCDF is a useful statistical value to evaluate the signal power distribution properties. It is defined as the probability of the signal that is at or higher than a given amplitude. In the figure, it is obvious that the PA-processed signal at 5240 MHz experiences the largest clipping, which is consistent with the PA's low 1dB compression point at that frequency.

V. Conclusion

In this paper a LUT PA model is constructed that considers the frequency effect on the PA performance. This model aids in predicting frequency-related nonlinear phenomena and improves the accuract of the simulation results. The model is utilized in an 802.11a WLAN system simulation and the simulation results capture the impact of the carrier frequency on the critical system parameters.

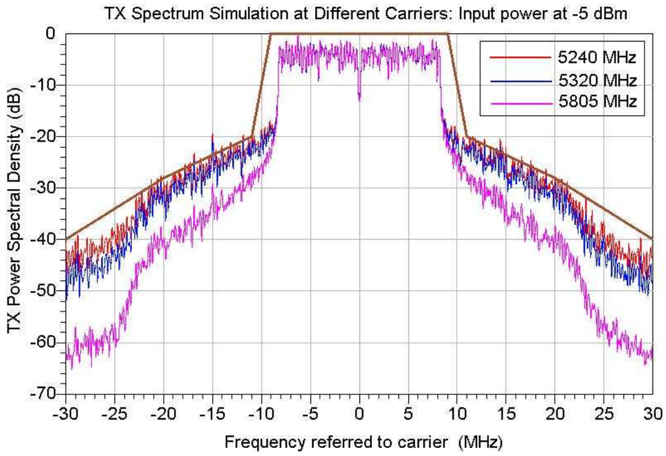

Fig. 8. Simulation of the ACPR at different carrier frequencies. The input power level is at -5 dBm.

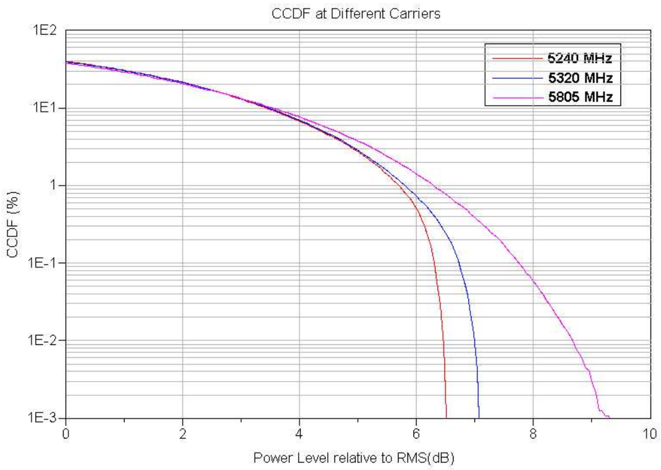

Fig. 9. Simulated CCDF curves at different carrier frequencies.

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