Measurement-based Modeling of a 5 GHz WLAN Transmitter

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***Abstract* — This article describes an accurate way to model a WLAN transmitter in a Co-Simulation Environment. Simulated and measured results are shown to be in good agreement for a 5 GHz 802.11a RF transmitter. The model was then used to explore the optimum operating point of the system by tuning the result for the Complementary Cumulative Distribution Function (CCDF) and Error Vector Magnitude (EVM).**

***Index Terms* — Co-Simulation, RF Modeling, DSP Modeling, WLAN, Transmitter**

I. INTRODUCTION

Many studies have been done in the area of creating accurate transmitter models [1-13]. By and large, the models can be separated into two categories: RF models and DSP models. RF models use a continuous wave (CW) signal to represent the input of the device under test (DUT), not taking into account any baseband limitations [3, 13]. Likewise with DSP models, generic RF blocks are used to simulate the working system [2]. While there have been some papers on co-simulation of RF and DSP models, these papers do not cover all major RF and DSP parameters, such as what type of simulation models to use to accurately represent a WLAN transmitter. These papers also use perfect OFDM signals and simplified RF functional models to represent the system under test [1, 7].

This paper will describe file-based simulations that can be used to get a very accurate representation of the system in an efficient simulation time. These models enable engineers to fine tune the devices to obtain the optimum operating conditions of many types of systems otherwise not seen by using RF and DSP models separately.

II. INTRODUCTION TO 5 GHz WLAN TRANSMITTER AND WLAN TEST ENVIRONMENT

The 5 GHz WLAN Transmitter uses OFDM Technology and delivers up to 54-Mbps data rates. The WLAN solution includes a single chip baseband processor/MAC, which outputs a 20 MHz OFDM signal. Two half-duplex converters; one Baseband-to-IF board which outputs an 810 MHz OFDM signal and one IF-to-RF board which outputs a 5 GHz OFDM signal. The transmitter also employs an 810 MHz Saw bandpass filter after the BB-to-IF board and before the IF-to-RF board. A GaAS power amplifier with a power gain of 29dB is used. All Transmitter components comply with the 802.11a standard. Figure 1 shows the 5 GHz WLAN transmitter.

In order to properly measure and model the transmitter's baseband and RF characteristics, a bits-to-bits communications test environment is needed. The test environment used to measure and model the transmitter integrates an Agilent Vector Signal Generator (ESG), an Agilent Vector Signal Analyzer (VSA), a Spectrum Analyzer, 1GHz Oscilloscope, and a custom-built Multipath Emulator along with computer aided design (CAD) tools like Matlab, Advanced Design System (ADS), and Signal Studio (from Agilent). The test-bed setup is very flexible in that it allows generation of various signal waveforms, measurements and modeling of the RF devices under different stimulus conditions. It also allows for modeling of the wireless radio channel and optimization of the transceiver components. Figure 2 shows the transmitter integrated into the 5 GHz bits to bits WLAN communications test-bed. One of the advantages is that the VSA is used to obtain both the measured dataset and simulated dataset (a data link in ADS connects to the VSA software dynamically). By using the same instrument to measure the hardware and modeled data sets, stronger correlation between measured and modeled data can be realized.

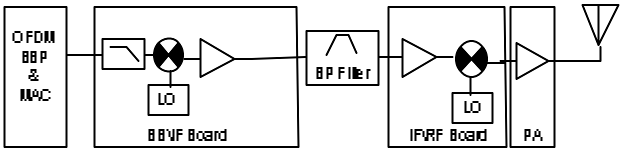

Fig. 1. 5 GHz WLAN Transmitter

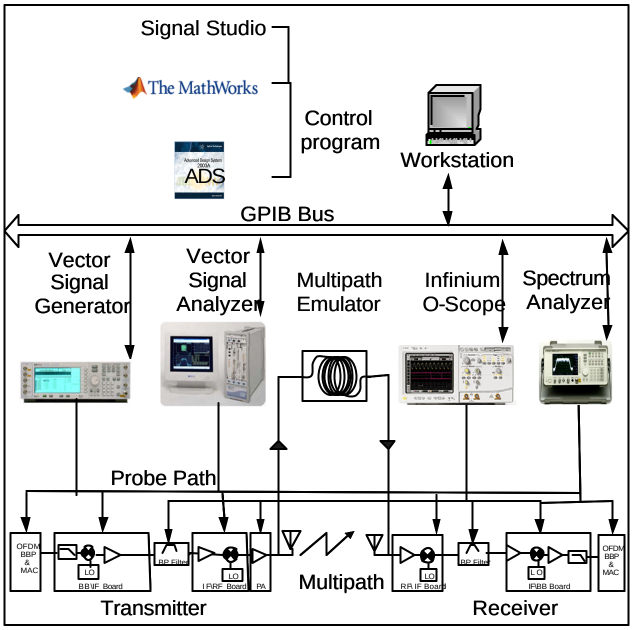

Fig. 2. 5 GHz WLAN Transmitter integrated into 5 GHz Bits- to-Bits WLAN Communications Test-Bed with various probe points

III. METHOD FOR OBTAINING DATA FROM RF COMPONENTS

In order to properly represent the transmitter several parameters were measured and or collected. To represent the two half-duplex converters, conversion gain and intermodulation mixer tables (IMTs) were measured for each board. IMT file-base data was used in order to more accurately represent the spectral content at the output of the two half-duplex converters [13]. For the 810 MHz bandpass filter, small signal data was collected via a vector network analyzer (VNA) and s2p file-based data was used in the model. For the P.A., s2d file-based data was used in the model. S2d file based data was used because it uses the measured S-parameters for matching, and models the large signal amplifier transfer characteristic by fitting a polynomial to the fundamental gain and phase compression characteristic of the PA[15]. The s2d data was collected via a VNA.

IV. INTEGRATION OF BASEBAND SIGNAL WITH RF MODEL

The transmitter model described above is implemented in ADS 2003A. To simulate the RF front-end section, Circuit Envelope simulator was used because it can evaluate the analog models in both time and frequency domain [1]. This is desirable because this simulation technique can cut the simulation time by representing signals as time varying spectra and separating the carrier from the envelope data. This method allows the sampling rate to be reduced and enable utilization of analog models together with baseband processing models.

In the baseband processing model, Ptolemy Data Flow (DF) controller is used. This controller allows the user to control the simulation sequence. This controller also works simultaneously with the circuit envelope simulator. The co-simulation setup enables the integration of the accurate analog models with the Ptolemy baseband signal processing, therefore enabling the simulation of the EVM, CCDF and other digital signal figures'-of-merit.

Furthermore, the VSA was used to record the output of the ISL3877 baseband board. This output was then played back into the transmitter BB\IF board model via Synchronous Data Flow (.sdf) file in ADS. The reason for using the recorded file is to study the system under a realistic environment so that the performance simulated can replicate real system operation. Figure 3 represents the RF model used in a Co-Simulation environment.

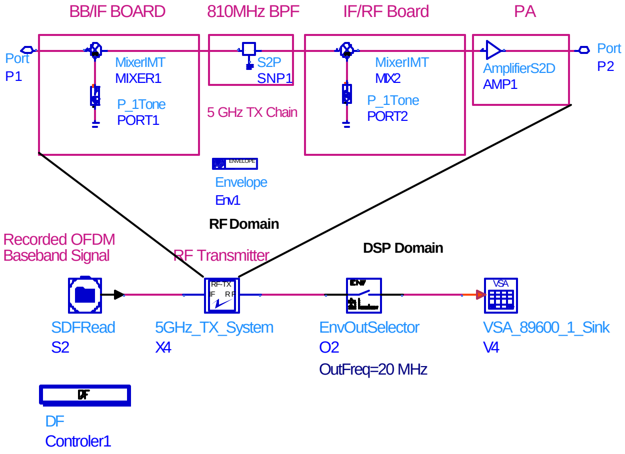

Fig. 3. 5 GHz WLAN system model constructed in ADS

V. MEASURED RESULTS VS. MODELED RESULTS

In this section, several measurement/simulation results were collected using the VSA to verify the accuracy of the transmitter model. Figure 4 shows the measured and simulated spectrum at the output of the PA. As can be seen, there is high level agreement between the two recorded data sets.

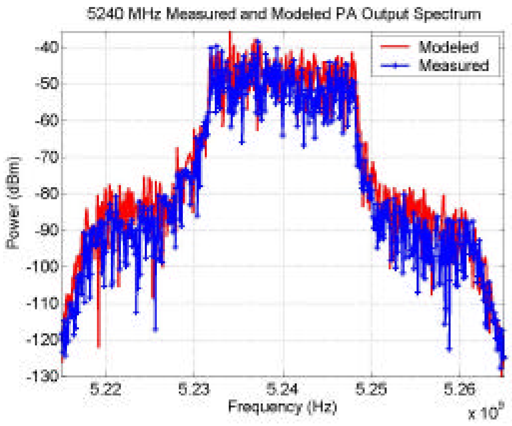

Fig. 4. 5 GHz Measured and Modeled Frequency Spectrum

In figure 5 the Complementary Cumulative Distribution Function (CCDF) curves are given. CCDF is a useful statistical value used to evaluate the signal power distribution properties. It is defined as the probability that the signal is at or higher than a given amplitude. As can be seen in figure 5 the model fits well to the measured data except at the higher power levels. This is because 5 micro-seconds of real-time data was recorded and used as the baseband input signal for the transmitter and it is not large enough to cover all the possibilities. By increasing the record time, a more accurate representation is possible, but the simulation time is dramatically increased as well.

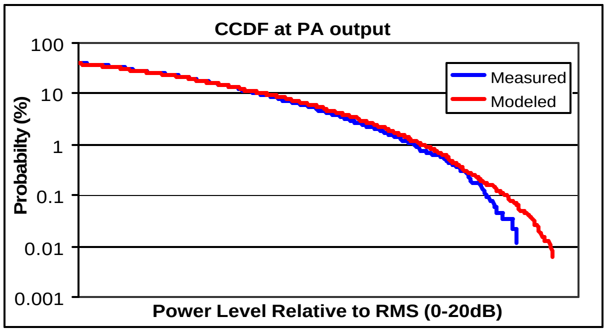

Fig. 5. 5 GHz Measured and Modeled CCDF curves

In Figures 6 and 7 the measured and modeled constellation diagrams are shown for the PA output. From these figures it can be seen that the modeled IQ offsets, phase imbalance and IQ gain imbalance are comparable to the measured results. Table 1 compares the EVM results at each stage of the transmitter.

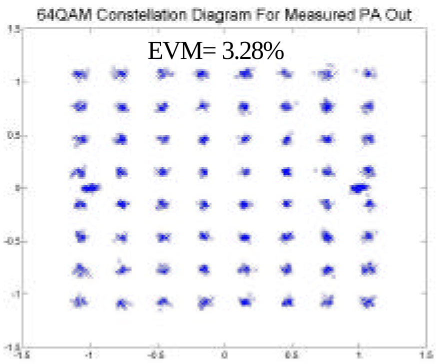

Fig. 6. 64QAM Constellation Diagram for Measured PA Out

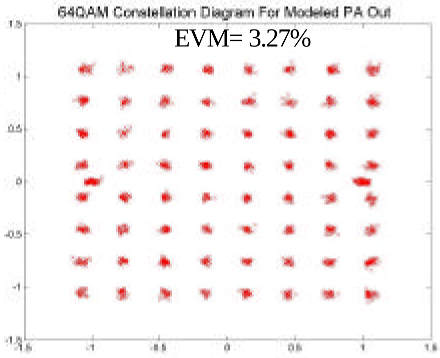

Fig. 7. 64QAM Constellation Diagram for Modeled PA Out

EVM at each stage				
	Baseband output	Filter output	2nd IF output	PA output
Measured	2.19%	2.53%	2.82%	3.28%
Modeled	2.26%	2.45%	2.45%	3.27%

Table 1. EVM Percentage at each stage

In Figure 8 the RMS Error Vector time at the PA output is given. The RMS Error Vector Time looks at the error vector values for each symbol-time and does an RMS average of these values over all of the 52 used sub carriers. The result is a time trace, which shows the average error vector magnitude at each symbol-time [10].

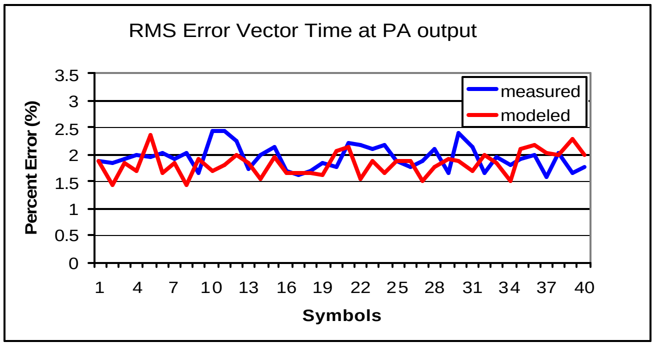

Fig. 8. RMS Error Vector Time at PA output

The results shown above indicate that the transmitter model is accurate; the optimum operating point under normal operating conditions of the system can be found using the model. Figure 9 shows the comparison of the measured and simulated EVM data results versus the input power of the transmitter, using Analog (RF) and Ptolemy (DSP) models. As can be seen from the figure, the Co-Simulated model's accuracy is extended quite further as compared to the simplified DSP model which uses generic RF Blocks to represent the transmitter. By using the RF models in a co-simulation environment, increased accuracy can be gained. However, the Co-Simulation model is only accurate in the linear operation region. The model has to operate in the linear region because the baseband-to-IF and IF-to-RF IMT models are designed for a specific input power, namely -20dBm. Although beyond the current scope, more rigorous power-dependant IMT modeling approaches are possible [16]. The reason the linear range was chosen to be modeled is because PA compression in OFDM systems cause peak to average ratio issues which require the PA to operate in the linear range [17]. To operate in the linear range low input power to the transmitter is required. Since the EVM increases with the increment of input power, it would be nice to use a low input power to get a better EVM result, however a certain Signal to Noise Ratio (SNR) must be maintained for the receiver to detect the signal successfully. Therefore, the engineer must trade-off EVM performance and successful detection of the received signal.

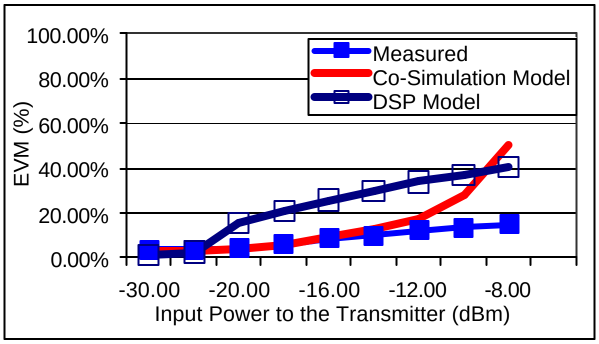

Fig. 9. Modeled EVM versus Transmitter Input Power

VI. CONCLUSION

An accurate model for representing a 5 GHz WLAN transmitter has been presented. By using the VSA to measure both the hardware components and the simulated components, an accurate comparison of the two data sets can be made. Using the file-based approach to represent the RF components helped achieve accurate simulated results of the transmitter. By combining the RF and DSP worlds together an accurate transmitter model has been created and used to find the optimum operating point with quick simulation time.

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