Effects of High Peak-to-Average Ratio on Power Amplifiers

PA evaluation is essential for efficient design of systems that must be compliant with the WLAN standard.

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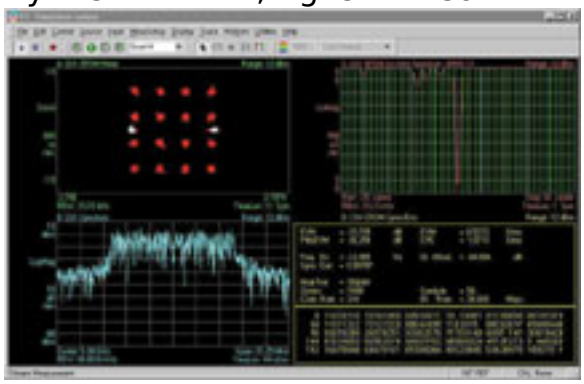

Wireless Local Area Network (WLAN) systems are rapidly growing in popularity as users around the world look for the convenience of wireless connectivity in a computing environment. Many design efforts are focused on 5 GHz WLAN systems based on the IEEE 802.11a standard. These systems are capable of delivering higher data rates with better spectral efficiency and less interference than earlier systems. Their improved performance will be welcomed by current WLAN users, and provides an opportunity to reach new markets that need higher data rates.

To support high-rate data transmission in 5-GHz WLAN systems, IEEE 802.11a proposes multi-carrier modulation, orthogonal frequency division multiplex (OFDM). The basic concept of OFDM [1] is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over several subcarriers. With lower data rates in the parallel subcarriers there is increased symbol duration, which decreases the relative amount of dispersion in time (delay spread) caused by multipath propagation. Intersymbol interference (ISI) is almost completely eliminated because an adequate guard interval can be inserted between successive OFDM symbols.

One of the most difficult design issues with OFDM is its high peak-to-average power ratio, which greatly affects power amplifier (PA) performance. To simulate PA nonlinear behavior under OFDM stimulus, models must have improved accuracy in order to determine the output RF spectral content and Error Vector Magnitude (EVM) [2].

This article discusses the simulation environment for 5-GHz high data rate WLAN systems and Power Amplifier selection.

The OFDM Signal

In a simplified block diagram of an OFDM transmitter and receiver, input data is converted from serial to parallel, allocated to a subcarrier, then modulated using linear modulation such as BPSK, QPSK, 16-QAM or 64-QAM. The OFDM signal is generated as the IFFT of modulated subsymbols. In the receiver, after downconversion, the signal is recovered by frequency synchronization, followed by a FFT and the appropriate QAM demapping.
In the WLAN system, packetized burst signals are transmitted without scheduling. Therefore, synchronization must be established burst by burst.
The composite OFDM signal is a collection of all the independent modulated subcarriers (52 in the case of IEEE802.11a and Hiperlan2). This complex signal exhibits a higher peak-to-average power ratio (PAPR) than a single carrier system. A large PAPR brings disadvantages such as increased complexity of the analog-to-digital and digital-to-analog converters and reduced efficiency of the RF power amplifier [1]. Normally, operation at an average power level much lower than the PA saturation point is required to alleviate the PAPR, which is the cause of the reduced power efficiency. The process of evaluating a Power Amplifier with respect to the RF requirements of IEEE802.11a is mentioned in this article.

Power Amplifier Behavioral Model

For testing and verifying any power amplifier design, the basic WLAN schematic from Agilent EEsof Advance Design Systems (ADS) [5] WLAN library is shown in Figure 1. Let's take the 36 Mb/s data rate example. The data is first coded by 64 QAM modulator, the pilot signal coded by BPSK. After OFDM modulation and upconversion to RF carrier, the framed WLAN signal is routed through a power amplifier and sent to a receiver.
We can test and verify an actual WLAN power amplifier selected for the system design, to see if it can meet the requirements given by IEEE 802.11a. A recommended candidate is the MGA-82563 [3], an economical low noise 0.1 to 6 GHz GaAs PA from Agilent.
In the example, we will consider a design using two cascaded MGA-82563 components with ideal drive.
There are two modeling approaches for the PA. First, as a circuit model, RF/DSP co-simulation can be performed using the Circuit Envelope simulation for the PA circuit. This approach is referenced later; another method is based on a behavior timed RF_Gain model, where the simulation can be performed at the system-level.
For the RF power amplifier, the complex input signal $V_1(t)$ is represented by the in-phase and quadrature components about its carrier frequency. The output signal is given by

$$V_1(t) = \mathrm{Re}\{v_1(t)e^{j2\pi f_{c1}t}\},\ v_1(t) = V_{11}(t) + jv_{Q1}(t)$$
$$V_2(t) = \mathrm{Re}\{a\&\#215\ g_{comp}v_1(t)e^{j2\pi f_{c1}t}\}$$

where *a* denotes the gain of the component as set by the component parameter Gain. If the input is a baseband timed signal, then only the real part of the Gain is used. g_{comp} denotes the gain compression factor as determined by the gain compression parameters, such as GCType, TOIout, dBc1out, PSat, GCSat and Gcomp. In this example, we will discuss the dbc1out (1 dB gain compression output) case.

Power Amplifier Circuit and P2D Model

In many cases, it is not sufficient to model the PA using only a simple behavioral model based upon parameters such as P1dB and IP3. To improve modeling accuracy, ADS design environment employs a unique approach using both a circuit simulator (Agilent EEsof Circuit Envelope) to model the power amplifier cascade with a data-flow simulator (Agilent EEsof Ptolemy) to carry out DSP behavioral simulation [4]. We combine a detailed circuit-level model of the power amplifier with the DSP simulation of a coded IEEE802.11a signal stimulus. The MGA-82563 MMIC circuit is the candidate PA.

An alternative to the detailed circuit model is the power-dependent S-parameter or P2D model. It is derived from a Harmonic Balance circuit simulation which generates power-dependent S-parameters, assuming the use of 50-ohm terminations. A power sweep template enables the user to enter the power levels with specified start and stop points [5]. In this scheme, the circuit simulation engine runs using the P2D file-based model, co-simulating with the DSP behavioral model simulator. This setup is faster than the detailed circuit model co-simulation (Figure 3).

Test and Verification Environment

The test results are taken from the non-linear behavioral model PA in the verification ADS system as shown in Figure 1. We will also demonstrate a unique simulation methodology in Agilent EEsof &#151 ADS simulation with 89600 Vector Signal Analyzer software [6].

As noted earlier, the power envelope of the OFDM burst is not constant. Due to the large peaks that are characteristic of the OFDM signal, a single peak-to-average power ratio is not very useful [7]. It would be more meaningful to associate a percentage probability with a power level.

The Complementary Cumulative Distribution Function (CCDF) is the common CDF subtracted from 1. The lower picture Figure 3b shows CCDF captured with ADS software. The axis shows dB above average power on the horizontal axis and percent probability on the vertical axis. The point at which the signal is clipped is shown at 5.5 dB above the average, which will be exceeded 0.3% of the time. If an amplifier with 5.5 dB headroom is used in the system it will go into saturation 0.3% of the time. The waterfall curve shown in the top picture of Figure 3b represents the statistics for Gaussian noise. Most OFDM signals will follow this statistic closely.

Output RF Spectrum

The Output RF Spectrum (ORFS) with Mask measurement in ADS shows the relationship between the frequency offset from the carrier and the power, measured in a specified bandwidth and time. The measurement provides information about distribution of the transmitter's channel spectral energy due to modulation. The test is passed if the RF spectrum does not exceed the limits defined by a Mask appropriated by IEEE802.1a. The test is failed if energy is present above the Mask limits.

The results from ADS simulator with MGA-82563 PA behavioral model shows the ORFS with Mask for Channel 36, corresponding to a channel center frequency of 5180 MHz. The RF spectrum (red line) does not exceed the mask (blue line), indicating a successful test result. The IEEE802.11a standard requires testing at channel 56 (5280 MHz) and channel 161 (5805 MHz). The results are shown in Figure 3a. The results of mid and high band indicate a high level of RF spectrum, exceeding the mask spectrum.

We checked these results against the same set of tests with the P2D power profile

using Circuit Envelope simulator and they agreed with the behavioral model. We conclude from these tests that the MGA-82563 power amplifier does not meet the overall power spectrum profile required by IEEE802.11a.

Error Vector Magnitude (EVM)

EVM is very important, being the primary measure of modulation accuracy. High value of EVM can be the effect of I/Q inbalance, phase noise, DC offset, channel impairments and other degradations in the circuitry. In our case we are interested to measure the effect of PA on EVM. At 36 Mbps we need to achieve 11.2% EVM according to IEEE802.11a standard.

The results of EVM measurements using the MGA-82563 PA indicated an unacceptable value of EVM, exceeding 11.2% in the middle and upper bands &#151 28% and 56% respectively. The lower band measured a 7.5% EVM. This is the golden measurement that indicates that MGA 82563 PA will not suffice the power level requirement of 802.11a signal transmission. The result of three EVM measurements for three frequency bands are captured in the table shown in the lower part of Figure 4.

Test and Measurements Using Vector Signal Analyzer Software

Design verification using 89600 Vector Signal Analyzer (VSA) software in ADS provides a unique capability [6]. Using the same measurement algorithms used in the VSA instrument, designers can test a particular design on the desktop in an early stage. VSA software is represented as a model in ADS. When ADS simulation is launched, VSA software acts as a sink &#151 it gathers the stream of data from ADS simulation then processes and displays the measurements.

Figure 1 shows the VSA model. It can be used in conjunction with the signal measurements provided in ADS. Figure 4 shows the VSA display. The measurements from MGA-PA are captured. The lower display in Figure 4 shows the measurement for the low 5085 MHz band. EVM in percentage is in the lower right quadrant &#151 6.5%.

The top display of Figure 4 is the measurement for the higher band at 5805 MHz. EVM &#151 54%. This value agrees with ADS measured value of 56%. Also shown in the VSA display is the signal constellation.

This is a valuable measurement for designers who will repeat the same test with their hardware PA, using the same instrument algorithm.

Summary

5-GHz WLAN systems are growing rapidly in popularity and are being marketed all over the world. The use of OFDM gives these WLAN systems their high data rate performance, but OFDM signal's high peak-to-average power ratio requires a high performance power amplifier. To illustrate the effects on system performance, we examined a non-linear power amplifier using the test and measurements required by IEEE802.11a standard.

To illustrate the design of practical WLAN systems, the ADS 2001 5 GHz WLAN Design Library was used to simulate non-linear components. Key measurements such as Error Vector Magnitude (EVM) and Output RF Spectrum with Mask (ORFS) were measured to test and verify the example PA to see if it could meet the IEEE 802.11a specification. The test results showed that this amplifier could be used in a WLAN system for Channel 36, but that performance was marginal at Channel 56 and insufficient at Channel 161. This type of component evaluation is essential for efficient design of systems that must be compliant with the WLAN standard. Furthermore, 89600 Vector Signal Analyzer software was also utilized to validate

the simulation results. The combination of VSA software and ADS simulation environment offers extensive capabilities for the design, test and verification of components for 5 GHz WLAN. Once the PA hardware is ready, designers can reuse the same signal from ADS and same measurement from VSA to test their hardware. For more information on ADS 2001, the 5 GHz WLAN Design Library and to access the references used in this article, please visit www.agilent.com /eesof-eda.
References

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