

# Power Measurements of OFDM Signals

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**Abstract**— There are many ways to measure the output power from wireless devices – average, peak envelope power, instantaneous peak power and average peak power being examples. In addition there are multiple instruments and methods available to make these measurements - spectrum analyzers, power meters with peak power sensors, average power sensors and diode detectors.

The dynamic nature of signals that use Orthogonal Frequency Division Multiplexing (OFDM) is such that these various methods can give widely different results depending on the type of measuring instrument used and the power measurement required. The requirements for output power in the regulatory standards can be confusing, leading to incorrect or inaccurate measurements. Problems can also be created when alternative methods of power measurements are used in the production line to set the output power of individual devices to ensure they comply with National restrictions on output power.

This paper reviews the various methods used to make power measurements of OFDM signal for regulatory purposes and recommends suitable methods for production line measurements of 802.11a and 802.11g devices.

**Keywords**—component; OFDM, 802.11a, 802.11g rf power measurements

## I. INTRODUCTION

Wireless devices using Orthogonal Frequency Division Multiplexing (OFDM) can have high peak power to average power ratios, with the peak power being up to N times the average power, where N is the number of carriers [1]. This high peak-to-average ratio can create significantly different results when measuring output power using the various methods described in regulatory standards most widely used for 802.11a and 802.11g devices, namely FCC Part 15 Subpart E, EN 301 893 and EN 300 328.

This paper compares the measurements made on an 802.11g Radio Local Area Network (RLAN) device using a peak envelope power meter, an average power sensor, a spectrum analyzer and a diode detector used with a 500 MHz Oscilloscope. The comparison of results should help identify the best method for making compliance and production-line measurements.

## II. REGULATORY STANDARDS AND MEASUREMENTS

### A. Regulatory Requirements

Regulatory testing for 802.11a devices in the USA is governed by FCC Part 15 Subpart E [2], which requires that the peak transmit power be measured and compared to the applicable limit.

FCC Part 15 Part 15.247 [2] contains the requirements for 802.11g devices and requires that the peak output power be measured, but does not indicate if this is the instantaneous peak power or mean peak power.

In Europe, the applicable standard for 802.11a devices is EN 301 893 [3], and this requires that the mean power be measured, corrected for duty cycle and compared to the applicable limit. This standard is not yet harmonized.

EN 300 328 [4] is the applicable harmonized European standard for 802.11g devices and requires the average output power, corrected for duty cycle, be measured.

The regulatory standards have different requirements for the actual output power measurement – peak transmit power, mean power, average power and peak output power.

### B. Regulatory Measurements – FCC Part 15 E

FCC Part 15 Subpart E [2] defines **peak transmit power** as “the maximum transmit power as measured over an interval of time of at most  $30/B$  (where  $B$  is the 26 dB emission bandwidth of the signal in hertz) or the transmission pulse duration of the device, whichever is less, under all conditions of modulation. The peak transmit power may be averaged across symbols over an interval of time equal to the transmission pulse duration of the device or over successive pulses. The averaging must include only time intervals during which the transmitter is operating at its maximum power and must not include any time intervals during which the transmitter is off or is transmitting at a reduced power level.”

Guidelines issued by the FCC for making the output power measurement [5] allow for three different methods, all using a spectrum analyzer:

1. Spectrum Analyzer – integration over 26dB bandwidth using a sample detector in max-hold mode (note, many analyzers do not allow max-hold in sample mode) provided  
Sweep time < transmission time  
Sweep is gated to transmission
2. Spectrum Analyzer – direct reading (assumes spectrum analyzer measurement bandwidth is greater than the signal bandwidth, which is rare for a 17MHz wide 802.11a or 802.11g signal)
3. Spectrum Analyzer – integration over 26dB bandwidth using video bandwidth averaging and sample detector in max-hold mode (note, many analyzers do not allow max-hold in sample mode).

#### C. Regulatory Measurements – FCC Part 15.247

FCC Part 15.247 [2] does not define peak output power as either average peak output power (as inferred by 15 Subpart E above) or instantaneous peak output power. At this time it is taken that the requirements are for instantaneous peak power.

#### D. Regulatory Measurements – EN 300 328 and EN 301 893

EN 300 328 and EN 301 893 both require the use of a wideband power meter with thermocouple detector (or equivalent) to measure the output power. This power is then corrected for transmitter duty cycle,  $x$ , by the factor  $10 \log(1/x)$ .

### III. POWER MEASUREMENT METHODS

Measurements were made on an 802.11b/g device that was transmitting a signal with a duty cycle of ~95% using four different methods/instruments, as detailed below.

Measurements were primarily made with the device transmitting an OFDM signal (i.e. 802.11g) at a data rate of 6Mb/s. Previous measurements had demonstrated that changing the data rate had little effect on the measured power. Additional measurements were made with the device transmitting using 802.11b; a direct sequence spread spectrum modulation, for further comparison. All measurements were made on three different channels.

#### A. Peak Envelope Power Sensor

The rf port of the device was connected to a peak envelope power (PEP) sensor via a 10dB attenuator. The power sensor was a Rohde and Schwarz NRV-Z32 and it was connected to a Rohde and Schwarz NRVD power meter. The filter setting (measurement time) was altered but had little effect on the measured level.

The measurements were corrected for both the 10dB attenuator between the rf port and the sensor and for the 95% duty cycle.

#### B. Average Power Sensor

The rf port of the device was connected to an average power sensor via a 10dB attenuator. The power sensor was a Rohde and Schwarz NRV-Z51 (thermal power sensor) and it was connected to a Rohde and Schwarz NRVD power meter. The filter setting (measurement time) was altered but had little effect on the measured level.

The measurements were corrected for both the 10dB attenuator between the rf port and the sensor and for the 95% duty cycle.

This test method is equivalent to the method outlined in EN 300 328 and EN 301 893.

#### C. Spectrum Analyzer

The rf port of the device was connected to an Agilent 8564E spectrum analyzer. The center frequency of the analyzer was set to the center frequency of the signal being measured and the span to 30MHz. Resolution and video bandwidths were set to 1MHz and 3MHz respectively and the trace was set to max-hold for 30 seconds. The trace detector was set positive peak.

The power was calculated using the *power over channel* function of the analyzer (an integration function), with channel bandwidth set to 20 MHz.

This test method is the closest equivalent to the method outlined in [5] for FCC Part 15 Subpart E.

#### D. Diode Detector and Oscilloscope

The rf port of the device was connected directly to a diode detector. The detector was connected to a Tektronix TDS 520 500MHz oscilloscope with the input impedance set to 50Ω. A LabView® script was used to process the trace data from the oscilloscope to provide the rms, average and peak values over a transmission. The voltage recorded by the ‘scope was converted to a power level by applying a CW signal to the detector and adjusting the level of the CW signal until the required voltage was read on the ‘scope. The signal level from the generator was then measured using the average power sensor detailed in B.

As these measurements were made over the transmission burst, no additional corrections for duty cycle were required.

As the video bandwidth of the measurement is determined by the termination impedance additional measurements were made with the ‘scope’s input impedance set to 1MΩ to demonstrate the limitations a reduced video bandwidth could set on the measurements.

Table I MEASUREMENT RESULTS – 802.11G (OFDM)

Method	Result (dBm)
Peak Envelope Power Sensor	18.0
Average Power Sensor	10.2
Spectrum Analyzer	18.8
Diode Detector – Instantaneous Peak Power (50Ω)	18.2
Diode Detector – RMS Peak Power(50Ω)	12.4 <sup>a</sup>

<sup>a</sup> On one channel the rms peak power measured using the diode detector was 2.2dB higher than the average power. On the other two channels the rms power measured via the diode detector was within 0.3dB of the average power measured via the average sensor.

#### IV. POWER MEASUREMENT RESULTS – 802.11G

The results, detailed in Table I, highlight the differences between the methods used. The diode detector measurements and time-amplitude plot (Fig. 1 – Diode Detector output into 50 ohms) demonstrate the high peak-to-average ratio of 5.8dB. Other measurement windows on different channels gave ratios as high as 7.8dB.

The use of a high video bandwidth in making instantaneous peak measurements is emphasized by comparing the diode detector plots with the diode detector terminated in 50 ohms (Fig. 1) and 1Mohm (Fig. 2). The peak to average ratio is only a factor of 2:1 in terms of the output voltage with the 1MΩ termination, 6:1 with the 50Ω termination. With the particular device under test, the rms power did not appear to significantly change with the termination impedance.

With the particular product tested the different methods of determining the peak power all produced similar levels (0.8dB of variance between the PEP sensor, spectrum analyzer and diode detector methods). A much larger difference between the average power as measured with the average sensor and rms power as measured with the diode detector is observed in the test data, but this large difference was only observed on one of the three channels tested.

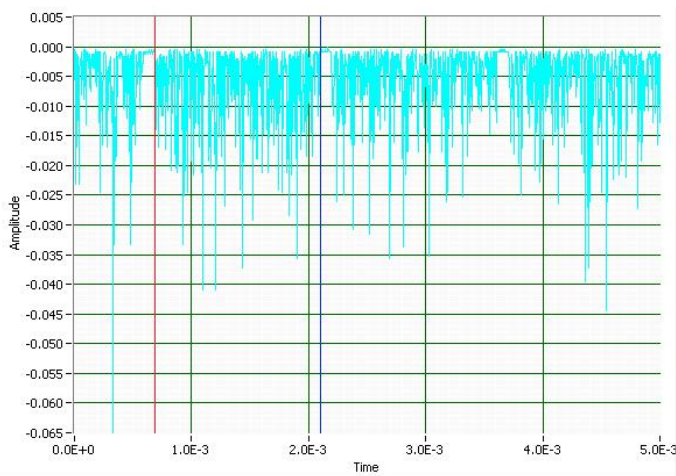


Figure 1. Amplitude-Time Trace from Diode Detector into 50Ω

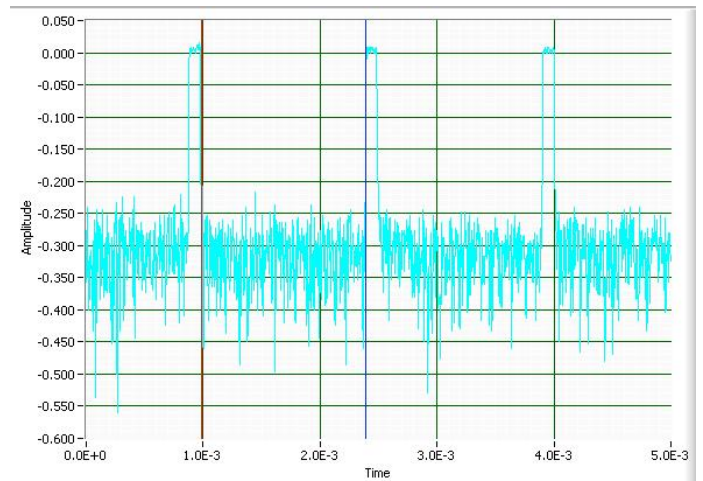


Figure 2. Amplitude-Time Trace from Diode Detector into 1MΩ

As the Spectrum analyzer method uses a much reduced video bandwidth (3MHz) compared to the signal bandwidth, one might be surprised that the output power measured using the integration method is very similar to the measured peak power. With the analyzer placed in a max-hold function, the time varying nature of the signal is ignored. The analyzer is not making a power measurement over a single transmission burst, rather it is capturing the highest power (averaged over a period of 1/video bandwidth, or 0.33μs) in each 1MHz band over a period of 30 seconds. This results in an overly-conservative estimate of a average power.

#### V. POWER MEASUREMENT RESULTS – 802.11B

The results are detailed in Table II. The peak:average power ratio of ~2dB is significantly smaller than the results for OFDM

Table II MEASUREMENT RESULTS – 802.11B

Method	Result (dBm)
Peak Envelope Power Sensor	19.2
Average Power Sensor	17.5
Spectrum Analyzer	20.2
Diode Detector – Instantaneous Peak Power (50Ω)	19.5
Diode Detector – RMS Peak Power(50Ω)	17.4

## VI. IMPLICATIONS FOR PRODUCTION LINE TESTS

Production line output power tests are typically combined with other functional tests, such as receiver sensitivity or protocol evaluation measurements. In these particular tests, the device may be configured to send randomized packets at a low duty cycle. An example of such traffic is given in Fig. 3 that was captured from an Access Point transmitting a streaming video signal. The duty cycle was ~10% with the widest signal only 50mS.

Without a fixed duty cycle the use of an average power sensor is limited as no duty cycle correction factor can be applied and the power cannot be accurately determined. Similar issues may be encountered with a peak envelope power sensor. The combination of meter and PEP sensor used for this evaluation started to give significantly reduced readings when a pulsed waveform with low duty cycle was presented.

The implication is that the production line test must take into consideration the type of transmissions that are used when making power measurements. The use of a diode detector and oscilloscope, with some software control, could easily be used to give accurate readings of instantaneous peak and rms power over any transmission burst. As the power over a single, short burst may not provide a true indication of the devices performance, the software must be able to take the data over a number of such bursts. This would be the only way calibrate the device under test's output power to ensure compliance with the various national regulatory limits.

An approach being implemented by a leading manufacturer of RLAN devices is the use of a peak power analyzer, capable of providing cumulative distribution functions for the peak power over time. This allows the manufacturer to calculate both instantaneous and rms peak power, even for non-periodic transmissions.

Knowledge of the peak and average output power could lead to the identification of products with unexpected peak-to-average power ratios caused by modulation or amplifier response within the radio circuitry. It is also key to identifying the correct operation of any algorithm described by Lawrey and Kikkert [1].

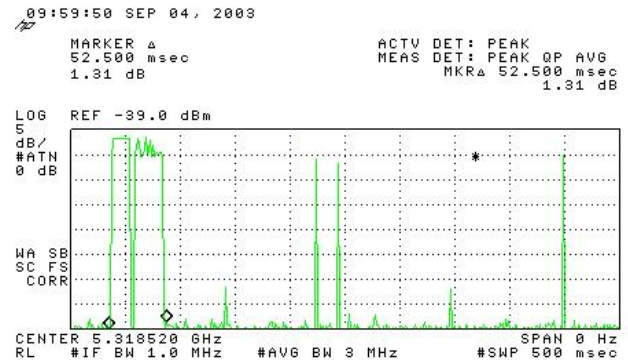


Figure 3. RLAN Traffic For Streaming Video

## VII. SUMMARY

The correct measurement of output power for OFDM signals is essential when making regulatory compliance measurements. These measurements are, however, typically made under controlled conditions of known duty cycle and data pattern which allows for repeatable results with a known correlation between the different test methods.

Production line tests, where the data pattern and duty cycle may not be constant, require more attention to ensure that power measurements made have a practical application in calibrating output power to meet international power limits.

## ACKNOWLEDGMENT

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