ETSI Standards and the Measurement of RF Conducted Output Power of Wi-Fi 802.11ac Signals

Introduction

The European Telecommunications Standards Institute (ETSI) have recently introduced a revised set of compliance standards for wideband data transmission equipment, examples of which are IEEE 802.11™, RLANs, Bluetooth®, Zigbee™ and other related technologies. The updated ETSI standards address equipment operating in the 2.4GHz ISM band, and 5GHz RLAN band, are harmonized European standards under the new Radio Equipment Directive (RED), which has superseded the R&TTE Directive. The directive demands that equipment meets certain essential requirements before they can be placed onto the market in the European Union in order to ensure that their presence within the spectrum does not create harmful interference. A key requirement of the standards is the measurement of RF conducted output power, which brings with it certain challenges. The wide bandwidth, high throughput nature of 802.11ac signals generates far more testing challenges than the legacy 802.11a/g/n/b signals. These challenges drive new measurement and instrument requirements which can be properly handled by wideband RF power sensors such as the Boonton RTP5006 real-time peak power sensor.

The Wi-Fi 802.11ac Signal

Bandwidth Requirements

The 802.11ac Wi-Fi protocol is driving the next generation of high throughput wireless systems. Raising data rates up to a maximum of 6.93 Gbps, it transmits at 5GHz, and enables devices to support channels with bandwidths of 20, 40 and 80MHz. It also includes wider channel bandwidths of non-contiguous 80+80MHz and contiguous 160MHz configurations. These wide bandwidths present measurement challenges to the compliance laboratories whose job it is to verify that the equipment under test performs according to the specifications outlined in the ETSI standards. Peak power sensors with at least as much bandwidth as the signal they are measuring must be used in order to ensure accurate power measurements. Many power sensors have less than the required bandwidth to capture the entire 160 MHz band limiting their ability to capture short bursts or fast transitions.

Modulation

The 802.11ac standard uses Orthogonal Frequency Division Multiplexing (OFDM), which employs a large number of closely spaced subcarriers modulated at a low data rate. The orthogonality of the subcarriers means that there is no mutual interference, and the transmitted data is shared amongst the carriers in order to give high immunity against selective fading from multipath effects. The sub-carriers are spaced 312.5kHz apart, so a 20MHz channel has 64 sub-carriers and a 160MHz channel has 512 sub-carriers. Each sub-carrier is individually modulated using a standard scheme such as Quadrature Phase Shift Keying (QPSK), Binary Phase Shift Keying (BPSK), 16 Quadrature Amplitude Modulation (QAM), 64 QAM or 256 QAM.

As well as digitally modulated signals already having higher crest factors than analogue signals, higher orders of modulation such as 256 QAM bring more technical challenges with them for design engineers, including the need for more processing power to decode the symbols, and ADCs with increased dynamic range due to the fact that smaller changes in amplitude must be detected. In order to properly capture signals with these modulation schemes, a power sensor must have a wide dynamic range and be able to measure both peak and average power for crest factor measurements.

MIMO Technology

MIMO processing (Multiple Input Multiple Output), is employed in 802.11ac utilizing up to eight antennas at both the transmitter and the receiver in order to increase both its data throughput and its spectral efficiency. This technology exploits the phenomenon known as multipath fading, which normally has a detrimental effect on the received signal. However, with multiple data streams transmitted on the same channel, and powerful digital signal processing at the receiver, MIMO offers a greatly increased data capacity, as well as immunity against fade conditions. Figure 1 shows a typical MIMO configuration.

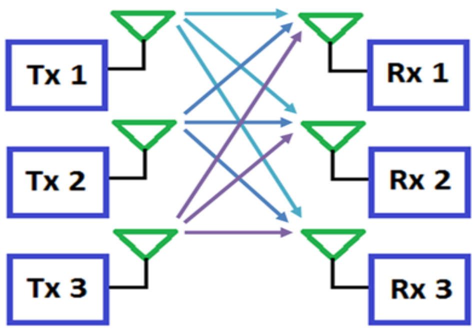

Figure 1. 802.11ac MIMO configuration.

The ETSI standards state that when measuring MIMO signals the power of each channel must be monitored. This means that a wideband power sensor should be connected to each transmit port and, most importantly, they must be synchronized in order to accurately assess the combined power of each individual burst of the Wi-Fi signal. Synchronized measurements add complications to a test system and power sensors deployed to make these measurements support simultaneous trigger, capture and measure through a single controller or software interface.

The ETSI EN 301 893 v2.0.7 Standard – Measurement of Transmit Power

Section 5.4.4.2 of the standard is concerned with the measurement of RF output power. In summary, the measurement procedure should be as follows:

- **Step 1:** A fast power sensor should be used, meaning that it should be capable of measuring wideband peak power. It should be suitable for 6GHz RF, and its sample rate should be 1 Msamples/second or more. At least 10 bursts should be captured.
- **Step 2:** For devices with one transmit chain, a power sensor should be connected to the transmit port. For devices with multiple transmit chains, a sensor should be connected to each transmit port in order to carry out a synchronous measurement on all ports. The sensors should be triggered so that they start sampling at the same time, making sure that the time difference between the samples of all sensors is less than 500ns. The power of the individual samples of all ports should be summed, and the resulting data should be used to calculate the following:
- **Step 3:** Find and store the start and stop times of each burst. The start and stop times are defined as the points where the power is at least 30 dB below the highest value of the samples acquired in step 2.
- **Step 4:** Store the average power between the start and stop times of each burst.
- **Step 5:** Record the highest average power value found in point 2 above. This value will be used for maximum EIRP (Equivalent Isotropically Radiated Power) values.

Figure 2 shows a typical Wi-Fi 802.11ac signal measured by the Boonton RTP5006 Peak Power Sensor and Power Analyzer Software:

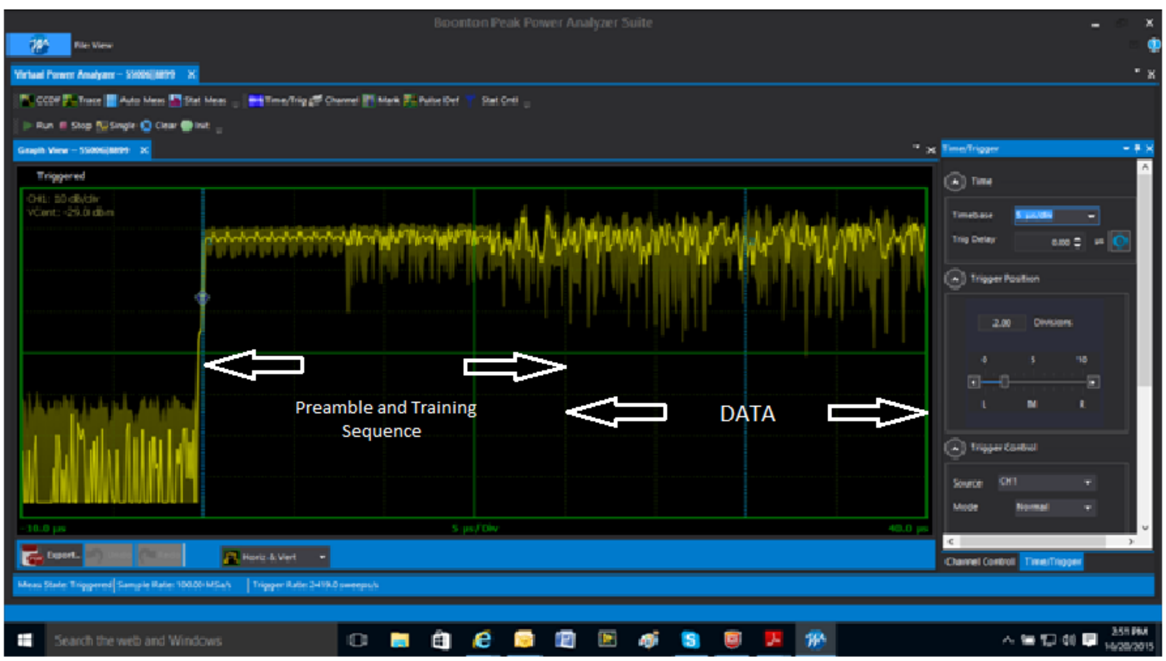

Figure 2. The beginning of a frame, including the preamble and training sequence, followed by the beginning of the OFDM signal captured with a Boonton RTP5006.

Measurement Solution Using a USB Peak Power Sensor

USB Peak power sensors function as fast, calibrated power measurement tools which acquire and compute the instantaneous, average and peak power of wideband modulated RF signals. Figure 3 shows a block diagram of a typical sensor.

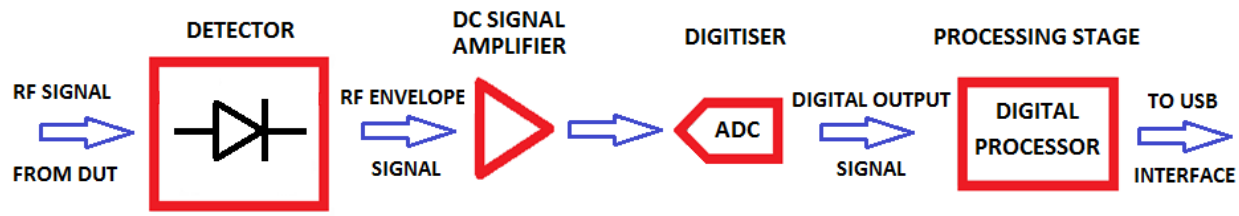

Figure 3. The stages of a typical USB Peak Power Sensor.

The Detector

The first and most critical stage of a peak power sensor is the detector, which removes the RF carrier signal and outputs the amplitude of the modulating signal. The video bandwidth of the detector dictates the sensor's ability to track the power envelope of the signal, so in the case of Wi-Fi 802.11ac the bandwidth of the detector must be at least 160MHz wide. The RTP5006 Real-Time Peak Power Sensor from Boonton provides 195 MHz of video bandwidth and is able to easily handle the wideband requirements of 802.11ac signals. The picture on the left in Figure 4 shows how a detector with insufficient bandwidth is unable to closely track the signal's envelope, therefore affecting the accuracy of the power measurement, while the detector on the right has sufficient video bandwidth.

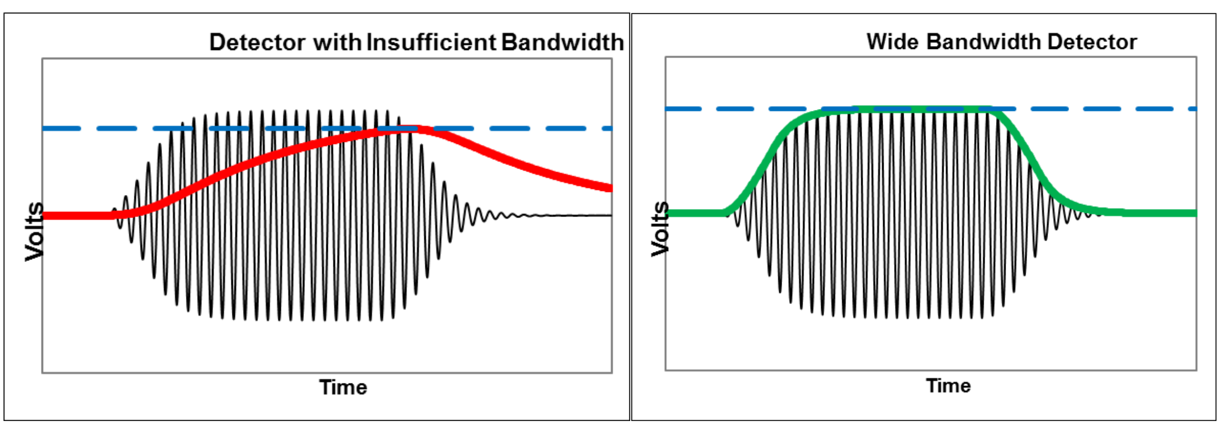

Figure 4. A wide video bandwidth enables the analysis of very short bursts, fast transition times and very broadband signals. Boonton's RTP5006 has a video bandwidth of 195MHz.

Detector video bandwidth is directly proportional to the rise times which the sensor is able to measure, so the wider the bandwidth of the detector the more closely it can track any fast transients which are present during a Wi-Fi burst.

The dynamic range of the detector is also important, especially with regard to the higher peak to average ratios of modern digital wireless communication technologies. Also, as mentioned earlier in step 3 of the stipulated measurement steps, the start and stop times of each burst are defined with reference to a power level at least 30dB down from the highest value. So a sensor with sufficient dynamic range should be selected. With a wide dynamic range from -60 dBm to +20dBm not only does the RTP50006 sensor handle the wide bandwidth requirements it also handles the wide dynamic range challenge.

The DC Signal Amplifier and Digitizer

The signal amplifier must have at least as much bandwidth as the detector in order to pass the amplified signal to the digitizer. Its importance should not be overlooked, as it is a key component when determining response speed. When measuring instantaneous peak power the digitizer's high sample rate is important in order to ensure that no information is lost between samples, and also that power versus time waveforms can be analyzed in high resolution, even when viewing the signal at the fastest time base setting. RTP5000 peak power sensors sample at 100 Msamples/second, one hundred times faster than the minimum requirement of the ETSI standard ensuring every detail of the signal is captured. Short Wi-Fi bursts can last 30us or less, which means that only 30 samples will be captured when sampling at 1 Msamples/second, therefore giving a high level of uncertainty. If none of these samples hits the peaks then the average power measurement could be out by perhaps 0.5dB, with the problem worsening as channel bandwidth is increased. So 3000 samples collected over the same time period using a sensor with a 100 Msamples/second sample rate will give a much more reliable result.

The Digital Processor

The processor takes the raw samples from the digitizer and carries out an analysis on them in order to produce statistics about the signal's power distribution, and then either assembles them into a power versus time trace to be viewed on a conventional display, or uses them to calculate the relevant burst information as required by the ETSI standards. Boonton uses a buffered measurement mode to quickly calculate the burst measurements with a patent pending technique called Real Time Power Processing™ (RTPP). Most USB sensors collect samples until they have enough to construct one complete sweep on the graphical display. Acquisition is then halted to allow these samples to be processed and displayed, after which time acquisition is resumed in order to repeat the process. This means that there will be times when important information could be lost. Boonton's RTPP™ technology enables sensors to constantly collect samples without any gaps in their acquisition at the full rate of 100 Msamples/second, ensuring that accurate data for every burst is captured.

Collecting Wi-Fi Burst Data

The ETSI specifications state that burst average power must be recorded, as well as start and stop times. Figure 5 illustrates the measurements which can be made by the Boonton RTP5006 sensor using the buffered measurement technique.

Figure 5. Specifc measurements that can be made on each consecutive burst of the Wi-Fi signal.

Real Time Power Processing™ in the Boonton sensor provides all the burst information required by the ETSI specification. Immediately upon acquisition, the raw samples are processed and analyzed to yield all the appropriate measurements, so only the relevant information is stored for each burst. This means that there is no need to store raw samples for post-analysis. In fact, maximum and minimum power levels are also recorded, which, although not a requirement of the standards, can also be useful to carry out a more in depth analysis. For example, the crest factor of each burst can be obtained by calculating Peak/Average power.

All of the above measurements are generated and stored in an on-board buffer, and by processing the samples in real time and keeping only the relevant burst information, a large number of data points, corresponding to up to 2048 bursts, can be analyzed. Additionally, these points can be immediately extracted and stored elsewhere in order to allow space for continuous data collection for as long as is required. This is useful when carrying out adaptivity measurements as stipulated in the ETSI standards, which define the conditions under which the equipment may transmit. A continuous measurement of 60 seconds or more is necessary in order to ensure that the UUT is not resuming normal transmissions as long as an interference signal is present.

Table 1 shows an example of data from the measurement buffer.

Entry Count	Interval Start	Interval Duration	Interval Average	Interval Minimum	Interval Peak
0	0.00 us	5.01 us	-0.043 dBm	-39.042 dBm	8.826 dBm
1	9.99 us	5.00 us	-0.006 dBm	-38.431 dBm	8.827 dBm
2	19.99 us	5.01 us	0.039 dBm	-41.549 dBm	9.742 dBm
3	30.00 us	5.00 us	0.017 dBm	-38.551 dBm	9.802 dBm
4	40.01 us	5.00 us	0.022 dBm	-40.699 dBm	9.477 dBm
5	49.99 us	5.00 us	-0.020 dBm	-39.706 dBm	8.102 dBm
6	60.00 us	5.00 us	0.036 dBm	-37.803 dBm	9.750 dBm

Table 1: Readout of measurement buffer containing 7 entries.

Conclusion

USB peak power sensors can provide an effective solution to the measurement challenges presented by the ETSI standards for wideband transmission equipment. The advanced specifications of the Boonton's RTP5000 Real-Time Peak Power Sensors enable the sensors to handle the challenging RF conducted power measurements stipulated in ETSI standards. Real Time Power Processing™ ensures that no data is lost, which therefore means that the measurement buffer can be utilized to capture data for every burst, and a sample rate of 100 Msamples/second, exceeding the requirements by 100 times, guarantees a greater accuracy. A video bandwidth of 195MHz ensures that even wideband signals are accurately tracked, and a dynamic range of -60 to +20dBm means that all samples for each burst will be processed. Boonton sensors are ideal for compliance testing, R&D, manufacturing and field testing of wideband communications signals such as Wi-Fi 802.11ac.