Wireless Connectivity Test

APPLICATION NOTE

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Introduction

Wireless connectivity technologies are used to replace wired installations for communication between electronic devices. In addition, there is a switch from the era of “Internet of People” to the era of “Internet of Things (IoT)”. Many research studies have envisioned that 20 to 50 billion smart devices or “things” will be connected to the internet by 2020. Today, engineers have a variety of wireless solutions to choose from such as Bluetooth, ZigBee, Wi-Fi or others.

The implementation of wireless connectivity requires a range of test and measurement tools to validate and verify the signal integrity through the whole transmit and receive chains, but also the power consumption, its RF emissions, and its immunity to other radio frequency systems. In this application note, we will introduce the RF tests and measurements for wireless connectivity.

Selecting a Wireless Connectivity Technology

Basically, all communication systems that can offer data transmission services can be candidates for IoT communications. For simplification, some of the communication standard names given here will just take a PHY layer name.

There are four key factors to consider when evaluating wireless technologies: cost, range, data rate, and power requirements. The coverage range of a wireless network is limited by technology, transmission power, antenna type, location, and environment. Based on the network range, wireless connectivity standards can be categorized into three big classes:

- Wireless Wide Area Network (WWAN)
  - Low Power Wireless Wide Area Network (LPWWAN)
- Wireless Local Area Network (WLAN)
- Wireless Personal Area Network (WPAN)
  - Low-Rate Wireless Personal Area Network (LR-WPAN)
  - Proximity

Figure 1 shows the major wireless standards divided by these three range categories. The vertical scale presents the difference of transmission speed or data rate.

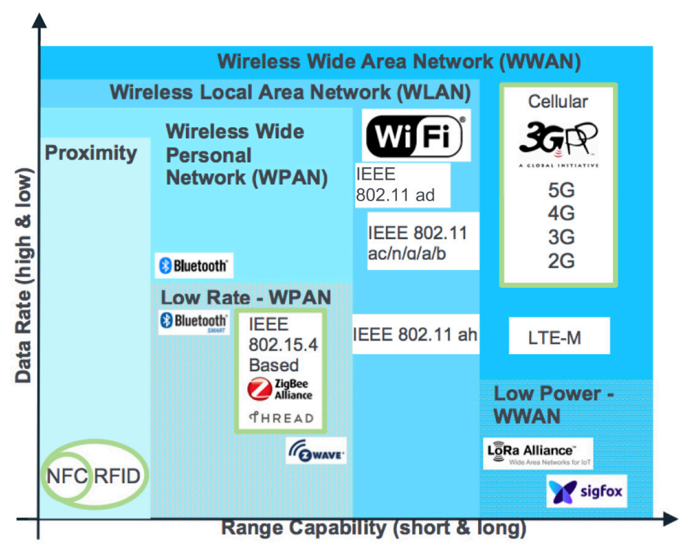

FIGURE 1. Wireless standards (Data rate vs Range).

Standard	Generation	Year	Technology	Bandwidth	Max Data Rate
NMT	1G	1981	FDMA	30 kHz	Na
GSM	2G	1991	TDMA	200 kHz	9.6 kbps
CDMA	2G	1995	CDMA	1.25 MHz	9.6 kbps
W-CDMA	3G	2001	CDMA	3.84 MHz	2 Mbps
CDMA 2000	3G	2002	CDMA	1.25 MHz	2 Mbps
TD-SCDMA	3G	2008	CDMA	1.6 MHz	2 Mbps
LTE	4G	2009	OFDMA	1.4 to 20 MHz	100 Mbps

TABLE 1. Major cellular network PHY standards.

Wireless Wide Area Network (WWAN): Any wireless or IoT application that requires operation over longer distances can take advantage of cellular communication capabilities. Traditionally, those cellular standards are dedicated to voice and data communication with long range coverage (10's of kilometers). From the beginning of cellular standards development, many technologies have been adopted and continue being used today.

Low Power Wireless Wide Area Network (LPWWAN): While the latest cellular standards like 3G and 4G are good at transmitting high quantities of data to help the communication between 'things', the expense and power consumption are too high for many applications, due to the complexity of the standard requirements. For example, smart water or gas meters, do not need high speed transmission but low cost due to the mass adoption and low power consumption due to the battery sizes. LPWWAN technology is perfectly suited for connecting devices that need to send small amounts of data over a long range, while maintaining long battery life. LoRa and Sigfox are two of the most popular emerging technologies in this area.

Wireless Local Area Network (WLAN): The concept of WLAN was initially introduced to provide the "last 100 meters connectivity", which refers to the low-power wireless devices that operate in the short-range of 100 meters. The WLAN communication standards use license free frequency bands (most on 2.4 GHz or 5 GHz). Thus WLAN standards offer free of charge connectivity services.

Improving the data throughput and spectrum efficiency has been a key driver for the wireless communication research for the past 10-20 years. This focus has resulted in more complex channel coding and modulation methods with the higher cost and more power for signal processing. Several WLAN standards have been developed by the IEEE wireless LAN consortium from 802.11 a/b/g to 802.11ad protocols today. Products from every brand name can interoperate at a basic level of service thanks to their products being designated as "Wi-Fi Certified" by the Wi-Fi Alliance.

Standard	Year	Band	Bandwidth	Technology	Data Rate
802.11 b	1999	2.4 GHz ISM	20 MHz	CCK and PBCC	1 to 11 Mbps
802.11 a	1999	5 GHz ISM	20 MHz	OFDM	6 to 54 Mbps
802.11 g	2003	2.4 GHz ISM	20 MHz	OFDM and PBCC	6 to 54 Mbps
802.11 n	2009	2.4/5 GHz ISM	20, 40 MHz	OFDM	7 to 150 Mbps
802.11 p	2010	5 GHz ISM	10, 20 MHz	OFDM	6 to 54 Mbps
802.11 ad	2012	60 GHz ISM	2200 MHz	Single Carrier and OFDM	Up to 6.75 Gbps
802.11 ac	2013	5 GHz ISM	20, 40, 80, 160, 80+80 MHz	OFDM	7 to 867 Mbps
802.11 ah	2016	0.9 GHz ISM	1, 2, 4, 8, or 16 MHz	OFDM	0.15 to 78 Mbps

TABLE 2. IEEE 802.11 PHY standards.

Wireless Personal Area Network (WPAN): WPAN usually covers a shorter range than the WLAN systems. It also has a lower data rate, lower power consumption, and is using smaller batteries. WPAN is widely used to transmit a small amount of data amongst devices such as computers, telephones, tablets and personal digital assistants over a short distance. A common WPAN is a smartphone connected over Bluetooth to a handful of accessories such as a wireless headset, watch or fitness device.

Low-rate Wireless Personal Area Network (LR-WPAN): The classic Bluetooth protocol is not recommended for long duration applications due to power consumption limitations. Therefore, for small gadgets which run on battery or other limited power source, new wireless technologies were needed. To fulfill these requirements, LR-WPAN, a subcategory of WPAN, was introduced that was optimized for low-rate data transmission, low power consumption and often support meshed network architectures. The low power requirement results in battery life cycles of several years or even in permanent operation via small solar cells or induction coils. LR-WPAN is designed for wireless networking among sensors and is more preferred for devices which are smaller in size and consume less energy, like TV remote controls, SCADA system sensor, medical instruments etc.

IEEE 802.15.4 is the most well-known standard which defines the operation of LR-WPAN. It specifies the physical layer and media access control for LR-WPAN.

The most widely deployed enhancement to the IEEE 802.15.4 standard is ZigBee, which is a standard of the ZigBee Alliance. There are many other IEEE 802.15.4 based protocols including Thread, 6LoWPAN, RF4CE, Wireless HART, and MiWi.

With this trend, Bluetooth also introduced a new lower power version of Bluetooth protocol, Bluetooth Low Energy (BLE) or Bluetooth Smart, aimed at novel applications in the healthcare, fitness, beacons, security, and home entertainment industries. The latest Bluetooth protocol, Bluetooth 5, continues to add more features on the BLE to achieve up to 2X wider bandwidth and 4x longer range. Similar to Bluetooth, WLAN added IEEE 802.11ah, and 3GPP added LTE-M to address the low power markets.

Table 3 summaries the major IoT wireless technologies for low power and low rate transmission applications.

	Standard	Band	Modulation Technology	Max Data Rate/ Power	Max Range
Bluetooth	Bluetooth from IEEE 802.15.1	2.4 GHz	FHSS with GFSK, π/4-DQPSK, or 8DPSK	Up to 3 Mbps, 1 W (EDR)	100m
Bluetooth (LE)	Bluetooth	2.4 GHz	FHSS with GFSK	1 Mbps, low to 10mW	100m
ZigBee	IEEE 802.15.4	915 MHz (US) 868 MHz (EU) 2.4 GHz (Worldwide)	DSSS with OQPSK	40 to 250 Kbps, 1mW	10m
Thread	IEEE 802.15.4, 6LoWPAN	2.4 GHz	DSSS with OQPSK	40 to 250 Kbps, 1mW	10m
Z-Wave	Z-Wave	908.42 MHz (US) 868.42 MHz (EU)	GFSK with Manchester encoding	100Kbps, 1 mW	30m
NFC	ISO/IEC 18092	13.56 MHz	ASK with Manchester encoding	424 Kbps,1 to 2 mW	0.1m
RFID	ISO/IEC 18000	120–150 kHz, 13.56 MHz, 433, 860-960 MHz, 2.4, 5.8 GHz, 3.1–10 GHz	ASK, PWM or FSK	640 kbps, up to 4 W	100 m
LTE-M	3GPP CAT 1.4 MHz, CAT 200 kHz (Rel12/13)	LTE band	OFDM	1 Mbps, up to 200 mW	5 km
Sigfox	Sigfox	915 MHz (US) 868 MHz (EU)	DBPSK(uplink), GFSK (downlink)	600 bps, 10 uW to 100 mW	50 km
LoRa	LoRa	433, 868 MHz (EU), 915 MHz (US), 780 MHz (CH)	Chirp Spread Spectrum (CSS)	50kbps, up to 500 mW	15 km

TABLE 3. Major low power & low rate wireless standards.

As there are wireless devices designed using many different wireless standards as shown in table 3, the biggest challenge is interoperability between these devices in the IoT networks. The other challenge is interference among these devices due to crowed frequency bands. Also, the transmit power affects the overall communication between devices and needs to be considered when looking into interference issues. Next we will talk about how to test the RF PHY function of those wireless standards so your products comply and can be released to market as soon as possible.

What does Standard Qualification/ Certification mean?

Wireless protocols or standards are needed to ensure that products can interoperate within the ecosystem where they will be deployed. To adhere to the standard, new products will need to meet qualification as defined per the standard selected. Qualification in this application note is the term used to describe what tests a product is required to pass so it meets a wireless standard. Qualification provides insurance the product will interoperate with other devices using the same wireless standard. Bluetooth products have to be qualified before getting the Bluetooth Logo. Wi-Fi products need to be certified before getting the Wi-Fi logo.

For Wi-Fi certification per the Wi-Fi Alliance, in order to use the "Wi-Fi Certified" logo on the product,

1. Companies must become members of the Wi-Fi Alliance.
2. Members must submit their products for testing at Wi-Fi Alliance's designated certification testing facilities.
3. The tests must ensure the product meets specifications defined by the IEEE 802.11 standard committee.

Failing qualification can mean design turns that will delay the final product release and draw additional development costs. To perform the tests in step 3, the radio is put in direct transmit mode and run the different WLAN 802.11 modes and emitting channels. At the physical layer, the radio output power is measured, and other measurements like specific emission shape and error vector measurements are performed. Table 4 and 5 show the most common tests for RF transmitters and receivers.

	Test Items	Descriptions
In-band	Channel Power	Gives an indication of the total average (and other measures) RF power in a given channel.
	Carrier frequency	Checks the frequency error to prevent the mismatch of transmitters and receivers, and interference in the adjacent frequency channels.
	Bandwidth	Reveals major errors in the design and indicates how much frequency spectrum is covered.
	Modulation	Verifies whether the transmitting signal has a correct modulation function. Typical measurements are Error Vector Magnitude, Frequency Deviation, or others.
	Characteristics	
	Center Frequency Leakage	Checks the DC offset causes the leakage of the center frequency component.
	Phase and frequency errors	Checks the phase or frequency distortion of the components like LOs, amplifiers, filters…
	Timing measurements	Measures the burst characteristics including rise/fall time, on/off power, burst width…
	Spectral Flatness	Tests the power variations for the sub-carriers in an OFDM signal.
Out-of-band	Transmit Spectrum Mask	Measures distortion and interference outside of the transmitter channel, but within the system band.
	Adjacent Channel Power	Similar to Transmit Spectrum Mask, but in different method.
	Spurious	Ensures minimum interference with other frequency channels in the system band.

TABLE 4. Major RF Transmitter tests.

Test Items	Descriptions
Receiver minimum input level sensitivity	Ensures that the wireless device is able to receive data with a defined maximum bit error rate (BER) at a defined minimum input level.
Rejection	Verifies that a receiver is able to work correctly when other channels are occupied by other users.
Receiver maximum input level	Ensures that the transmission can be set up if the distance between transmitter and receiver is very short. The receiver-under-test must be able to receive data with a defined maximum BER at a defined maximum input level.
Received signal strength indication (RSSI)	Measure the power present in a received radio signal.

TABLE 5. Major RF Receiver Tests.

WELL KNOWN IoT STANDARDS

As we discussed above, there are numerous wireless technologies and standards available today, but two stand out from the pack for embedded applications: **WLAN** and **Bluetooth**. RF test solutions for these two standards have been provided by test and instrument companies including Tektronix.

Tektronix RSA306B and RSA600A Series Real Time Spectrum Analyzers: Tektronix RF test products include a combination of hardware and software platforms. The RSA306B and RSA600A Series USB spectrum analyzers offer high bandwidth laboratory spectrum analysis in a small, very transportable package. They are ideal for testing WLAN, Bluetooth, and other wireless technologies.

RSA306B: Compact and Portable	RSA600 Series: Ideal for the Lab
• Up to 6.2 GHz • 40 MHz Real-time Bandwidth • Powered by USB3.0	• Up to 7.5 GHz • 40 MHz Real-time Bandwidth • Optional Tracking Generator

FIGURE 2. Tektronix RSA306B and RSA600A.

Tektronix SignalVu-PC Vector Signal Analysis Software: The RSA300 and RSA600 series operates with SignalVu-PC, a powerful program used as the basis of Tektronix's traditional spectrum analyzers, offering a deep analysis capability previously unavailable in low-cost laboratory solutions.

WLAN Option: With options SV23, 24 and 25 of SignalVu-PC, sophisticated WLAN measurements are easy. In figure 3, the spectrogram of an 802.11ac (20 MHz) signal shows the initial pilot sequence followed by the main signal burst. The modulation is automatically detected as 64 QAM for the packet and displayed as a constellation. The data summary indicates an EVM of -37.02 dB RMS, and burst power is measured at -17.32 dBm. SignalVu-PC applications are available for 802.11a/b/j/g/p, 802.11n, and 802.11ac to 160 MHz bandwidth.

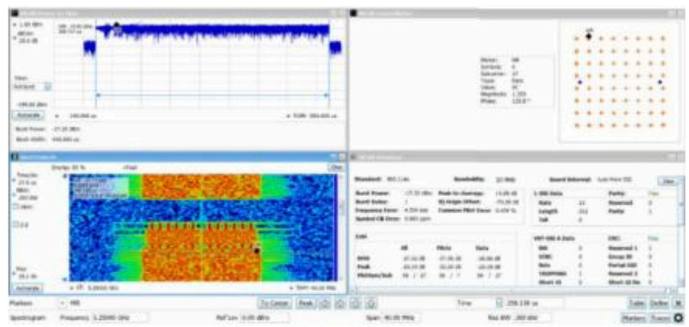

FIGURE 3. WLAN analysis with Tektronix SignalVu-PC.

Bluetooth Option: With application SV27 you can perform Bluetooth SIG standard-based transmitter RF measurements in the time, frequency, and modulation domains. This application supports Basic Rate and Low Energy transmitter measurements defined by Bluetooth SIG test specification RF.TS.4.1.1 for Basic Rate and RF-PHY.TS.4.1.1 for Bluetooth Low Energy. Application SV27 also automatically detects Enhanced Data Rate packets, demodulates them and provides symbol information. Data packet fields are color encoded in the Symbol table for clear identification. Pass/Fail results are provided with customizable limits and the Bluetooth presets make the different test set-ups push-button. The measurement below shows deviation vs. time, frequency offset and drift, and a measurement summary with pass/fail results. A table provides detailed information about frequency drift and offset across the packet.

FIGURE 4. Bluetooth analysis with Tektronix SignalVu-PC.

TSG4100A Series Vector Signal Generators: can generate high-quality Bluetooth signals, which is applicable for the Bluetooth product design, verification test and manufacture, etc. Tektronix TSG4100A series provides midrange RF VSG performance and rich vector signal modulation functions for customers at a low price, making it an ideal solution for IoT receiver testing.

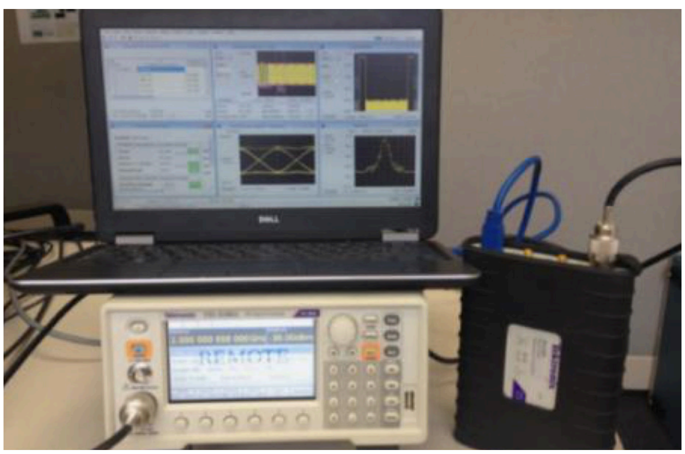

FIGURE 5. Demonstration of Bluetooth Low-energy Signal Transceiving by TSG4100A Vector Signal Generator and RSA306 Real-time Spectrum Analyzer.

EMERGING IoT STANDARDS

IoT is not only about high speed transmission. More and more, new protocols are needed for lower power or long range today. Some protocols use new technologies, and some even use nonstandard modulation methods to meet their goals. These bring new challenges to RF tests and measurements. There are over one hundred wireless connectivity protocols in the world, and there could be even more as the demand of connecting devices to the internet is increased. It is impossible to have the dedicated test and measurement option or solution for each protocol. Fortunately there are some general purpose analysis features can help with this.

ZigBee/Thread Tests: ZigBee and Thread use IEEE 802.15.4 as the low level MAC layer and PHY layer. They are extremely similar in power consumption and usage. The major difference is Thread uses 6LoWPAN to address nodes. Thread enables devices to have IP6 addresses on the internet. ZigBee has done very well for smart lighting and energy. Thread is a younger protocol, but offers IoT advantages. Because of the similarity of the physical layer, we will talk about the RF test of ZigBee and Thread together.

The 2.4 GHz band ZigBee uses offset quadrature phase shift keying (O-QPSK) as the modulation scheme. A half-sine reference filter is used so that the constellation changes from a square to a circle and ideal state circles are moved to the I and Q axes. This makes the O-QPSK signal a constant envelope modulation and allows power amplifiers to operate at or near saturation levels. Figure 6 shows the demodulation analysis of a ZigBee signal in SignalVu-PC.

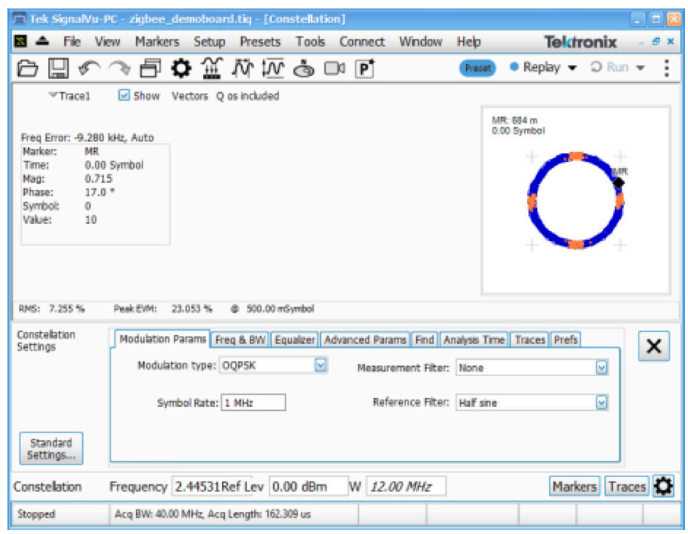

FIGURE 6. O-QPSK demodulation for ZigBee signals.

General Purpose Modulation Analysis Option (SVM): Includes Error Vector Magnitude, Modulation Error Rate, Constellation Diagrams, and more measurements, support 27 different modulation schemes, including 256 QAM, CPM, nFSK, and others to meet the test requirements for most of the emerging IoT protocols including Thread, 6LoWPAN, and ZigBee…

Multiple time correlated displays in SignalVu-PC can be shown simultaneously: the modulation analysis, such as constellation, EVM vs time, eye diagram, summary, symbol tables …, in-band analysis, such as channel power, occupied bandwidth …, out-of-band analysis, such as ACPR, spectrum emission, spurious…, and time domain analysis, such as amplitude/frequency/phase vs time, rise/fall time … Figure 7 shows eight different analyses running at the same time, which are all correlated. This means that markers are linked in the time and frequency domains, as applicable. For example, it is possible to find the worst symbol in the symbol table & see where that falls in the constellation diagram – this is a powerful troubleshooting tool to help to get to the root cause of a SW problem.

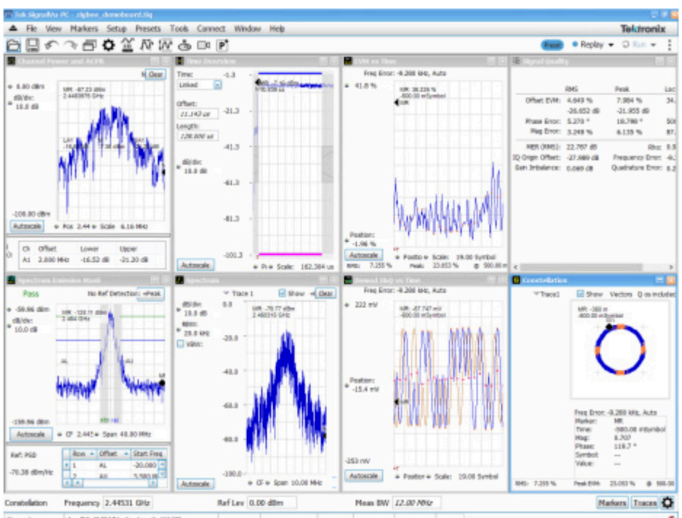

FIGURE 7. Multiple time correlated ZigBee signal analysis.

LoRa Tests: LoRa is one of the most widely used protocols for Low-Rate Wireless Personal Area Network (LR-WPAN) communication. This is the physical layer of Long Range wireless communication created by the LoRa Alliance. The technology is designed to enable a gateway or base station to cover entire cities or hundreds of square kilometers. The most well-known application using LoRa is smart metering for utilities.

LoRa uses a spread spectrum modulation scheme with wideband linear frequency modulated (LFM) pulses, called Chirp Spread Spectrum modulation (CSS). This technology trades transmission data rate with the receiver sensitivity within a fixed channel bandwidth. A variety of bandwidths are available from 7.8 kHz to 500 kHz.

In Figure 8, the frequency vs time display in SignalVu-PC shows how the signal frequency varies with time. At the beginning of each time frame, the preamble consists of ten up-chirps, followed by two and half down-chirps of sync word. This is then followed by the rest of the packet - payload and other fields. For the payload part, the symbols are encoded by “rotating” the chirp waveform by some interval. The chirp is “sliced” at some point, and the part that is sliced off of the end of the waveform is placed at the beginning. This results in a chirp that starts at some mid-frequency, ramps to the end frequency, then jumps to the beginning frequency and ramps to where it started. Symbols are encoded by moving this slicing point, which results in the jump appearing at defined locations within the symbol transmission time.

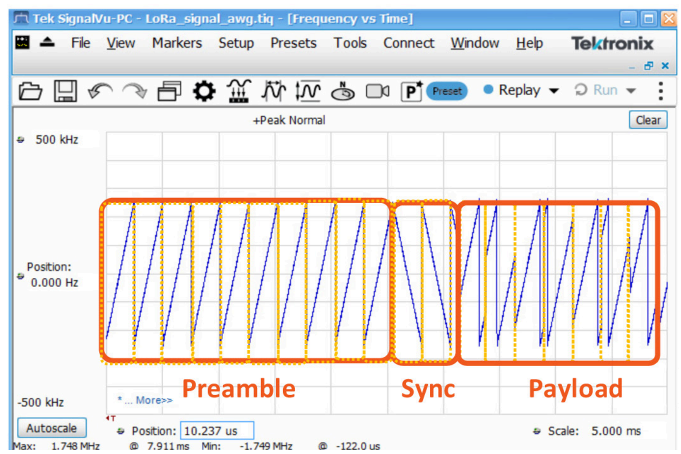

FIGURE 8. LoRa signal presented in frequency vs time display.

Spectrogram is another useful display to analyze the CSS signals. It is a display with the vertical axis (time) composed of successive spectral displays, each having the amplitude represented by color or intensity. The horizontal axis represents frequency. The most recently acquired spectrum results are added to the bottom of the spectrogram. In Figure 9, the upper display shows the spectrogram. When markers are placed, drag one of the markers horizontally through the Spectrogram the CSS or linear FM signal characteristics are able to be observed in the lower Spectrum display.

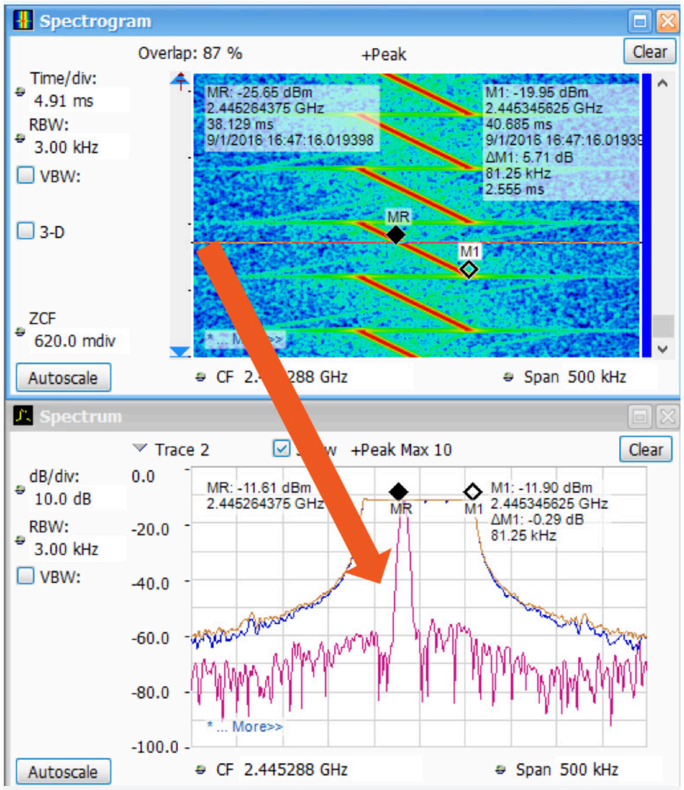

FIGURE 9. LoRa signals in Spectrogram display and playback in spectrum display.

The certification rules are twofold. First general emissions testing rules that nearly every electronic product must meet, secondly intentional radiation testing rules that only products design to transmit data wirelessly must comply with. The rules may vary within a country depending on the frequency range and the type of intentional emission (for ex. hopping or not).

Geographic Area	Approval Regulatory Bodies
United States	Federal Communications Commission (FCC)
Canada	Industry Canada (IC)
Europe	European Telecommunications Standards Institute (ETSI)
Japan	Ministry of Internal Affairs and Communications (MIC)
China	Ministry of Industry and Information Technology (MIIT)

TABLE 6. Regulatory Body List.

What does Regulatory Certification/ Compliance mean?

Some other requirements are not specified by the wireless protocols or standards, and are subject to local geographic regulations. Actually, Operation in countries within defined regulatory domains may create additional requirements. Implementers need to refer to the country regulatory sources for further information. Regulatory certification allows the product to be sold in a particular country, because it meets the country regulatory rules. In most cases regulatory certification is to be obtained in a test house that has been selected by the local authorities.

The rules may differ from countries to countries too. Going through the regulatory emission tests can range from $10,000 to $15,000 per country in a test house assuming you pass the first time.

REGULATORY PRE-COMPLIANCE TEST

Compliance testing is exhaustive and time consuming, and a failure at this stage of product development can cause expensive re-design and product introduction delays. Pre-compliance testing is intended to assure that the product has a high probability of passing the compliance tests; the goal is to uncover potential problems and reduce risk of failure at the compliance test stage.

General-purpose spectrum analyzers that contain general purpose filters and detectors are often employed in Pre-compliance, as they are fast measurement tools that often are already used in the design process so no additional capital expense is required. Figure 10 shows the three basic steps for the regulatory pre-compliance test.

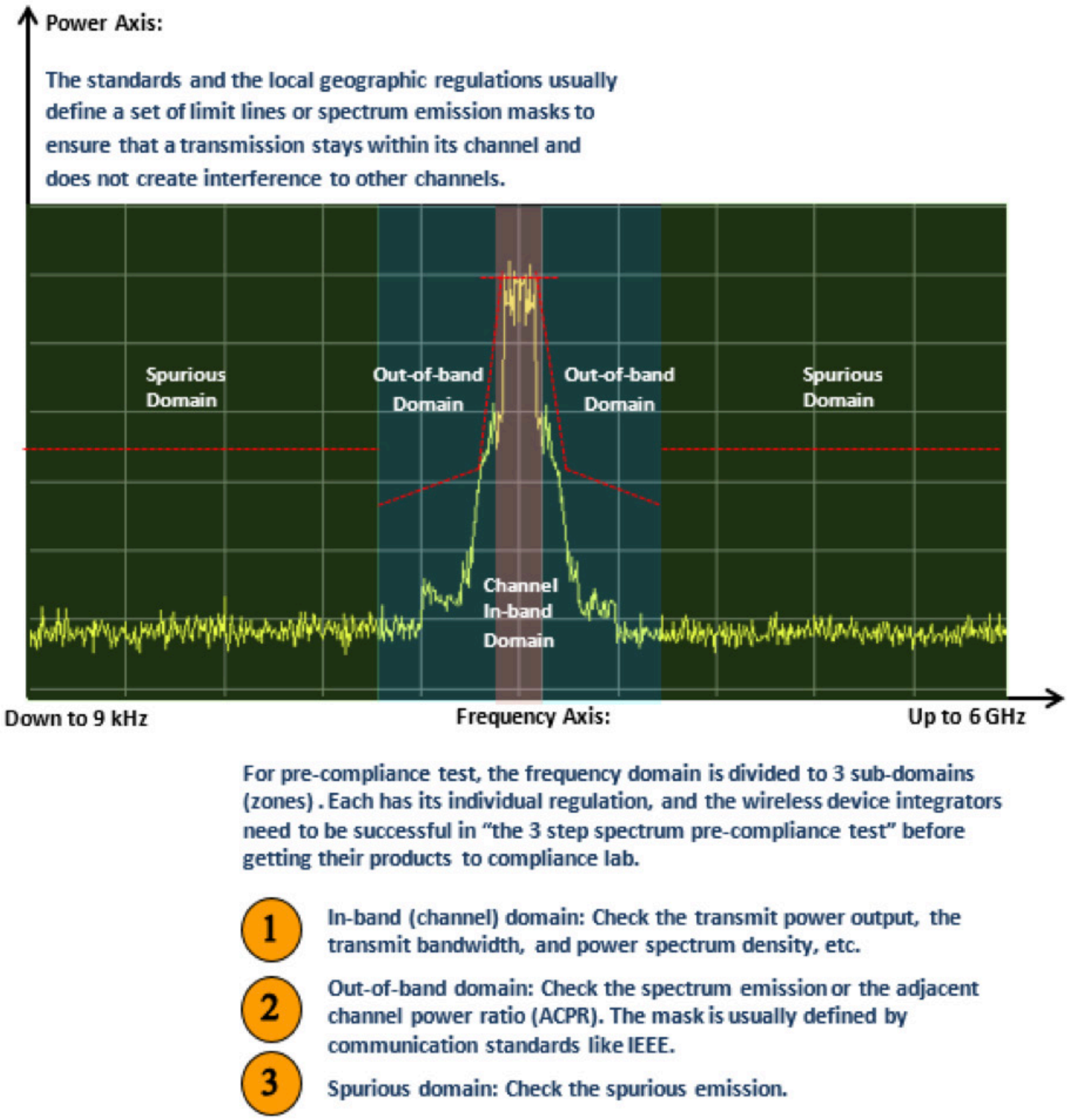

FIGURE 10. The Three Basic Steps for Pre-Compliance Test.

The regulatory compliance tests have both similarity and difference compared to the physical layer standard qualification tests. Frequency domain power measurements, such as channel power, spectrum emission, are the most critical test items, but usually demodulation testing is not required for the regulatory compliance tests. Table 7 and 8 show the WLAN compliance requirements at 2.4 GHz and 5 GHz bands of some major regions and countries.

Regions	US/Canada	Europe	China	Japan
Rules	FCC 15.247/IC RSS 210	ETSI EN 300 328 (V1.8.1)	信部无[2002]353号	MIC/TELEC
Frequency Range	2400-2483.5 MHz	2400-2483.5 MHz	2400-2483.5 MHz	2400-2483.5 MHz 2471 - 2497MHz (CH14)
Bandwidth	>500kHz @ 6dB BW	<20 MHz@ 99 % BW	No requirement	< 26MHz (OFDM+DSSS, and DSSS only) @ 99 % BW < 38MHz (OFDM only) @ 99 % BW
Maximum Output Power	1 W (Antenna Gain<6dBi) Reduced by 1 dB for every 3 dB (Antenna Gain≥6dBi)	100 mW (20 dBm)	100 mW (20 dBm) (Antenna Gain<10dBi) 500 mW (27 dBm) (Antenna Gain≥10dBi)	No requirement
Power Spectrum Density	The peak < 8 dBm/3 kHz	The peak < 10 dBm/MHz	The peak ≤10 dBm/MHz (Antenna Gain<10dBi) The peak ≤17 dBm/MHz (Antenna Gain≥10dBi)	The peak < 10mW/MHz BW< 26MHz (OFDM+DSSS) The peak < 5mW/MHz BW< 38MHz (OFDM only)
Spectral Emissions	No additional requirements. Please refer to the IEEE 802.11 standard.	-10 dBm/MHz (2400 MHz-BW to 2400 MHz and 2483.5 MHz to 2483.5 MHz+BW) -20 dBm/MHz (2400 MHz-2BW to 2400 MHz-BW and 2483.5 MHz+BW to 2483.5 MHz+2BW)	No additional requirements. Please refer to the IEEE 802.11 standard.	No additional requirements. Please refer to the IEEE 802.11 standard.
Spurious Emissions	In any 100 kHz bandwidth outside the frequency band of operation the power shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power. Radiated harmonic and spurious emissions which fall within the restricted bands, as defined in FCC Part 15.205, must comply with the radiated emission limits specified in FCC Part 15.209.	Outside±2.5 time BW: -36 dBm/100 kHz (30 - 47 MHz); -54 dBm/100 kHz (47 - 74 MHz); -36 dBm/100 kHz (74 – 87.5 MHz) -54 dBm/100 kHz (87.5 - 118 MHz) -36 dBm/100 kHz (118 - 174 MHz) -54 dBm/100 kHz (174 - 230 MHz) -36 dBm/100 kHz (230 - 470 MHz) -54 dBm/100 kHz (470 - 862 MHz) -36 dBm/100 kHz (862 MHz - 1 GHz) -30 dBm/1 MHz (1 GHz - 12.75 GHz)	Outside±2.5 time BW: -36 dBm / 100 kHz (30 - 1000 MHz); -33 dBm / 100 kHz (2.4 - 2.4835 GHz); -40 dBm / 1 MHz (3.4 - 3.53 GHz); -40 dBm / 1 MHz (5.725 - 5.85 GHz); -30 dBm / 1 MHz (Other 1 - 12.75 GHz)	2400-2483.5 MHz: 2.5μW/ 1 MHz (Below 2387 MHz); 25μW/ 1 MHz (2387 - 2400 MHz); 25μW/ 1 MHz (2483.5 - 2496.5 MHz); 2.5μW/ 1 MHz (Over 2496.5 MHz) 2471 – 2497 MHz: 2.5μW/ 1 MHz (Below 2458 MHz); 25μW/ 1 MHz (2458 – 2471 MHz); 25μW/ 1 MHz (2497 – 2510 MHz); 2.5μW/ 1 MHz (Over 2510MHz)

TABLE 3. 2.4GHz band WLAN Compliance Requirements.

Regions	US/Canada			Europe	
Rules	FCC 15.407/IC RSS 210	FCC 15.407/IC RSS 210	FCC 15.407/IC RSS 210 or FCC 15.247/IC RSS 210	ETSI EN 301 893 (V1.7.1)	
Frequency Range	5150 - 5250 MHz	5250 - 5350 MHz 5470 - 5725 MHz	5725 - 5825 MHz	5150 - 5350 MHz	5470 - 5725 MHz
Bandwidth	No requirement			99 % BW should be between 80 % and 100 % of the declared Nominal Channel Bandwidth	
Maximum Output Power	50 mW 4 dBm + 10 log BW-26dB	250 mW 11 dBm + 10 log BW-26dB	1 W 17 dBm + 10 log BW-26dB	20 dBm, except for transmissions whose nominal bandwidth falls completely within the band 5 150 MHz to 5 250 MHz, in which case the applicable limit is 23 dBm.	27 dBm
	Reduced by 1 dB for every 3 dB (Antenna Gain≥6dBi)				
Power Spectrum Density	The peak <4 dBm/1 MHz The peak <5 dBm/1 MHz (IC)	The peak < 11 dBm/1 MHz	The peak < 17 dBm/1 MHz	The peak < 7 dBm/1 MHz, except for transmissions whose nominal bandwidth falls completely within the band 5 150 MHz to 5 250 MHz, in which case the applicable limit is 7 dBm/1 MHz.	The peak < 14 dBm/MHz
	Reduced by 1 dB for every 3 dB (Antenna Gain≥6dBi)				
Spectral Emissions	No additional requirements. Please refer to the IEEE 802.11 standard.			Within the 5 GHz RLAN bands (Reference Mask): 0 dB (±0.5BW offset) -20 dB (±0.55BW offset) -28 dB (±BW offset) -40 dB (±1.5BW offset) -42 dB (±9BW offset) -47 dB (±10.8BW offset)	
Spurious Emissions	EIRP of -27 dBm/MHz. (outside of 5.15-5.35 GHz)	Operating 5.25-5.35 GHz: EIRP -27 dBm/MHz (outside of 5.15-5.35 GHz) Operating 5.47-5.725 GHz: EIRP -27 dBm/MHz (outside of 5.47-5.725 GHz)	EIRP -17 dBm/MHz (from the band edge to 10 MHz above or below the band edge) EIRP -27 dBm/MHz (10 MHz or greater above or below the band edge) You can also use FCC 15.247 rule, but not both.	-36 dBm/100 kHz (30 - 47 MHz); -54 dBm/100 kHz (47 - 74 MHz); -36 dBm/100 kHz (74 – 87.5 MHz) -54 dBm/100 kHz (87.5 - 118 MHz) -36 dBm/100 kHz (118 - 174 MHz) -54 dBm/100 kHz (174 - 230 MHz) -36 dBm/100 kHz (230 - 470 MHz) -54 dBm/100 kHz (470 - 862 MHz) -36 dBm/100 kHz (862 MHz - 1 GHz) -30 dBm/1 MHz (1 GHz - 5.15 GHz) -30 dBm/1 MHz (5.35 GHz - 5.47 GHz) -30 dBm/1 MHz (5.725GHz - 26 GHz)	

TABLE 3. 2.4GHz band WLAN Compliance Requirements.

Continued on following page.

Regions	China	Japan	
Rules	信部无[2002]277号	MIC/TELEC	
Frequency Range	5725 - 5825 MHz	5150 - 5350 MHz	5470 - 5725 MHz
Bandwidth	No requirement	OFDM: 99 % BW should be less than (Nominal Channel Bandwidth -2 MHz) Others<18 MHz	OFDM: 99 % BW should be less than (Nominal Channel Bandwidth -2 MHz) Others<19.7 MHz
Maximum Output Power	100 mW (27 dBm)	No requirement	
	EIRP 2 W (33 dBm)		
Power Spectrum Density	≤13 dBm / MHz	<= 10 mW/MHz (20 MHz BW DSSS) <= 10 mW/MHz (20 MHz BW OFDM) <= 5 mW/MHz (40 MHz BW OFDM) <= 2.5 mW/MHz (80 MHz BW OFDM) <= 1.25 mW/MHz (160 MHz BW OFDM)	
	EIRP ≤19 dBm / MHz	Tolerance: +20 % to -80 %	Tolerance: +50 % to -50 %
Spectral Emissions	No additional requirements. Please refer to the IEEE 802.11 standard.	ACPR: 20MHz band (Other than OFDM): • 20MHz offset, within +/-9 MHz band: <= -25 dB • 40MHz offset, within +/-9 MHz band: <= -40 dB 20MHz band (OFDM): • 20MHz offset, within +/-9.5 MHz band: <= -25 dB • 40MHz offset, within +/-9.5 MHz band: <= -40 dB 40MHz band (OFDM): • 40MHz offset, within +/-19 MHz band: <= -25 dB • 80MHz offset, within +/-19 MHz band: <= -40 dB 80 MHz BW(OFDM): • 80MHz offset, within +/-39 MHz band: <= -25 dB	
Spurious Emissions	Outside±2.5 time BW: -36 dBm / 100 kHz (30 - 1000 MHz); -40 dBm / 100 kHz (2.4 - 2.4835 GHz); -40 dBm / 1 MHz (3.4 - 3.53 GHz); -33 dBm / 1 MHz (5.725 - 5.85 GHz); -30 dBm / 1 MHz (Other 1 - 40 GHz)	<= 2.5 μW/MHz (30 MHz to 26 GHz) 20 MHz BW DSSS: <5.140 GHz & > 5.360 GHz 20 MHz BW OFDM: < 5.135 GHz & > 5.365 GHz 40 MHz BW OFDM: < 5.100 GHz & > 5.400 GHz 80 MHz BW OFDM: < 5.020 GHz & > 5.480 GHz 160 MHz BW OFDM: < 4.916 GHz & > 5.584 GHz	<= 2.5 μW/MHz (30 MHz to 26 GHz). 20 MHz BW DSSS: <5.460 GHz & > 5.740 GHz 20 MHz BW OFDM: < 5.455 GHz & > 5.745 GHz 40 MHz BW OFDM: < 5.455 GHz & > 5.745 GHz 80 MHz BW OFDM: < 5.340 GHz & > 5.800 GHz 160 MHz BW OFDM: < 4.236 GHz & > 5.904 GHz

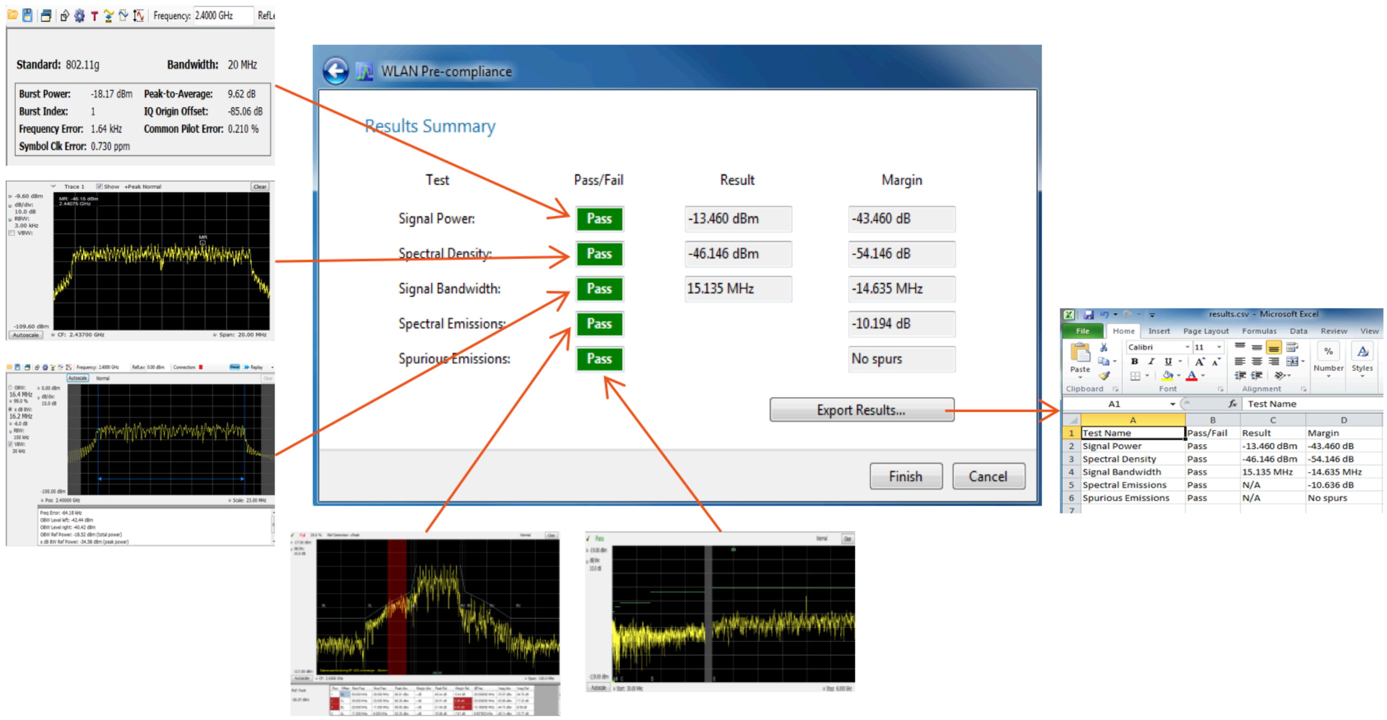

FIGURE 11. All-in-one Tektronix WLAN Pre-Compliance Wizard of MDO4000C+SignalVu-PC.

The test items of regulatory compliance can be done with spectrum analyzers with appropriate filters and detectors. Tektronix also has a free step by step WLAN Pre-Compliance wizard for using SignalVu-PC and the MDO4000B Series Mixed Domain Oscilloscope to conduct the pre-compliance measurement process for your WLAN device. After matching the WLAN standard, bandwidth and channel in the wizard to your DUT and operating your device in continuous mode, the Pre-compliance Wizard can help you make the pre-compliance tests automatically in the touch of a few buttons. The report can be exported to show the pass/fail, the margin to the regulatory requirements.

Summary

The high demand of connecting ‘things’ to the internet results in more and more emerging wireless connectivity protocols, and also drives the classic protocols to develop new versions for low power transmission with low cost. Inexpensive RF test instruments, such as Tektronix RSA300/500/600 USB real time spectrum analyzers, MDO400C mixed domain oscilloscopes, and TSG4100A vector signal generators, provide dedicated test solutions for relatively matured standards, like WLAN, Bluetooth, ZigBee, but also have other general analysis tools help the development of the emerging protocols, like LoRa. This could be helpful for engineers to detect design issues at the early stages of development and reduce the time-to-market of the products.

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