Abstract
The wireless Internet of Things is growing rapidly, with about 30 billion devices on the air, and more being added all the time. Electronic products of many types are adding wireless capabilities, from healthcare devices to outdoor grills. But some designers may be new to the wireless world, and unfamiliar with regulatory testing required in most geographies. Most wireless devices must pass this testing before they can be marketed.

This paper covers background of wireless operations, regulations affecting those devices, and testing required to enable market access.

Understanding Spectrum Uses
Across the wireless spectrum, many forms of communications are available. Parts of the spectrum are dedicated to certain services such as aircraft, personal radio, broadcasting, public safety, and land mobile. For example in the United States, many bands are available for individual licensing, in which dedicated channels are allocated to certain services for licensed users in a certain area. This licensed method requires application to national regulatory agencies such as the Federal Communications Commission (FCC) in the US. While the frequency assigned may be shared with other users, the number and identity of the users are available in databases, so frequency coordination is usually a viable way to resolve interference problems.
Significant quantity of this spectrum is available in desirable parts of the spectrum, such as VHF and UHF bands at about 30 to 800 MHz. These bands have radio characteristics that allow longer range operation, making these channels attractive to certain applications such as remote monitoring of oil wells, natural resources conservation, and large agricultural enterprises. In these licensed services, the assigned frequency, bandwidth, and modulation types are well defined, and some channels are narrower than those in some other wireless services, but some level of interference protection is usually available. At higher frequencies up into microwave bands, wider frequency allocations are used for higher bandwidth services, and point-to-point links are common.

![Figure 1. US Frequency Allocations around the 5 GHz ISM Bands](image)

One exceptional service among licensed uses is cellular phone. Cellular spectrum is purchased in areas, and vast infrastructure is available to subscribers to the cellular service companies. These service providers purchase dedicated spectrum at certain frequencies in certain geographies, and customers of these providers pay subscription fees for use of the systems. Text messaging, voice calls, and data services are available, so some IoT devices use cellular data services for their communications.

There is another form of spectrum access available which does not require users of equipment to be licensed in the same way. Across the entire wireless spectrum are certain frequency bands that are available for license-free, low power use. These Industrial, Scientific, and Medical (ISM) bands are available for unlicensed use, which makes it convenient for consumer applications without the complications of licensing each installation. These bands are located at frequencies from hundreds of kilohertz to hundreds of gigahertz in about two dozen frequency allocations. These ISM bands are dominated by services such as Near Field Communications (NFC), Wi-Fi®, and Bluetooth® but are also intended for innovation, so many types of modulation are active in there, and variations in semi-standard modulations and protocols abound.

The lower ISM bands are used for NFC applications such as card access security systems, wireless payment services, and Radio Frequency Identification (RFID) systems for asset tracking and inventory. Some short-range analog services such as some wireless phones and remote-control toys use these lower frequency bands as well.
However, for wireless IoT devices, the ISM Bands at 900, 2400, and 5500 MHz are most important and widely used for digital communications including ZigBee®, Bluetooth, and Wi-Fi among many others. These frequencies have become very popular and now accommodate higher bandwidth digital signals. The exact size and frequency of ISM bands vary between geographies, but much of this spectrum is common across most of the world. This also has encouraged widespread use of similar equipment which have therefore become inexpensive. One advantage of using these major standards is interoperability making it possible for a wireless device to operate almost anywhere. Unlike some licensed services, the IoT device only needs to provide one end of a communications link. The other end may be a cell phone or wireless access point already installed in a facility, and the IoT device can use that to connect to Internet infrastructure. This means favorable economics for the IoT device manufacturer.

The Regulatory Agencies

While licensing is not required for users of these ISM bands, that does not mean that there are no rules for use of these radio frequencies. With the standardization of protocols, interoperability is possible, but for reliability, commercial alliances and special interest groups have defined suites of tests to confirm that a device operates correctly in a certain type of network. This ensures robust protocol design, compatible operation of devices from different manufacturers, and avoids interference from improper implementations of these protocols. This type of industry-based standard testing is often called “interoperability certification” testing, though that term is sometimes used for other types of testing. One example of this interoperability testing is defined by the Wi-Fi Alliance® for Wi-Fi devices, and another by the Bluetooth SIG for Bluetooth devices. Without passing these test suites, you will not be able to claim or label the device as having a certain capability defined by the commercial bodies.

This interoperability testing measures some lower-level signal characteristics including type of modulation and channel frequency, but much also tests the ability of a device to understand control signals and protocols such as establishing a connection, transferring and acknowledgment of data, and cooperation among devices to ensure smooth flow of data and reduce interference.

Another form of regulation comes from governmental bodies, which in various geographies define certain performance standards to which the device behavior must be tested before a device can be certified and marketed in the region managed by that governing body. These are “Regulatory Compliance” testing, which have the force of law in most of the world.
The regulatory agencies include the FCC in the US, European Telecommunications Standards Institute (ETSI) in the European Union, Ministry of Internal Affairs and Communications (MIC) in Japan, and many others throughout the world. Some standards are written by organizations such as ANSI in the US, but when adopted by governments, will assume legal status.

**ETSI EN 301 893 V2.1.1 (2017-05)**

![ETSI EN 301 893](image)

Figure 3. ETSI Regulatory Standard EN 301 893 is an example of Regulatory Standards

These agencies’ intent is to facilitate effective and efficient use of the radio spectrum, so much of the regulation is aimed at avoiding interference between devices in the same or different services. This takes the form of both clean RF transmissions and reducing susceptibility to interference. More recent tests are aimed at enforcing cooperative behaviors between devices using the frequencies, avoiding the interference, and the inefficiencies of spectrum use that result from interference.
Regulatory Compliance Tests

Early regulatory compliance tests were written to control both intentional emissions (from devices using wireless communications) and unintended or incidental emissions from circuitry generating or using high frequencies, but not intended to be radiated. These early intentional emissions tests focused on quality of emissions from a transmitter. These tests measured power, frequency control and stability, signal bandwidth, and spurious emissions. These are relatively simple characteristics to measure, and test times tend to be shorter than some newer test requirements.

However, some devices creates wireless signals incidental to the device operation and not related to wireless communications functions. Digital circuitry in personal computers creates signals that interfered with other nearby wireless devices, including licensed services. For example, a common clock frequency for personal computers is 14.318 MHz, and multiples of this frequency are used for clocking various circuitry in the PC. In other cases, display hardware uses much lower frequencies, which affected services on lower bands. Development of switching power supplies created signals on power cords and other wires emerging from the device, and not only radiated interference, but also introduced vulnerabilities of a device to strong external fields.

These devices radiated not only the fundamental, but also many harmonics, far above the clock frequency, disrupting existing licensed users of those harmonic frequencies including broadcast radio and television. Regulatory agencies issued test requirements to measure unintended emissions and signal strength limits were established to reduce this interference. From these issues were born the Electromagnetic Interference (EMI) and EMC (Electromagnetic Compatibility) tests, which measure not only emissions, but also susceptibility of the equipment to strong electromagnetic fields.

These tests for unintended emissions have served to reduce the noise present on the radio spectrum when the devices had no intention of using wireless communications. As for devices designed to use wireless communications, regulatory testing continues to evolve in response to new modulation types and the problems caused by crowding on the ISM bands.
Modern Trends in Wireless Regulatory Tests

With the growth of digital modulation techniques, new performance, and test requirements have been added to measure other characteristics of signals from these devices and how (and even where) the devices are used. Some of these measurements include Power Spectral Density (PSD) which is appropriate for wide bandwidth digitally modulated signals. Since Wi-Fi channels are getting wider (20, 40, 80, 160 MHz, and so forth) and since this increases the noise energy in this wider bandwidth, regulators are allowing wider channels to use more transmit power to maintain the Signal-to-Noise Ratio (SNR) in the receivers. Contrast this with EIRP which measures total power regardless of bandwidth.

Since these unlicensed bands allow many varieties of modulation, regulators want to ensure that any signal type will use the spectrum in a fair and compliant manner. Hence, wider channels are allowed greater total power to maintain constant SNR, and in any given bandwidth the signal will have the same power as if it only occupies the narrowest channel selection.

Since the proliferation of devices on the ISM bands, interference has become a serious problem as both the transmitter and the receiver may contribute to degraded channel operation. Regulators also focused on receiver performance, and defined tests for receiver blocking, for example. These tests measure how much receiver performance is degraded by strong signals on nearby frequencies. Also, recognizing the potential for receivers to emit signals related to the RF circuitry, tests were defined to measure receiver spurious emissions via antenna connections. So, in compliance with these two tests, receivers will be better able to operate in busy radio spectrum and will not accidentally radiate unnecessary signals, either.

Some protocols such as the 802.11 family of Wi-Fi signals can demodulate signals from similar nearby networks. This allows them to cooperate in using the spectrum, avoiding collisions and interference. This helps in an all-Wi-Fi installation. But there are many different types of modulation on the ISM bands, and devices cannot decode extrinsic modulations and protocols, and therefore cannot intelligently share the channels, which results in collisions between transmissions. Each time two signals collide, time is wasted not only during the collision, but both transmitting units will then need to handle non-acknowledged transmissions, and must retransmit the lost messages, wasting many message times recovering from the collision. It is far better to avoid collisions and increase likelihood of success for the first transmission.
Due to the many incompatible modulations on the ISM bands, this cooperation is difficult to achieve. To counter this, some regulatory tests now include what you might call “behavioral” testing to reduce interference between different RF signals regardless of their modulation and protocol. These new tests are necessary to increase efficient use of spectrum.

An example of this type of behavior test is the ETSI “Adaptivity” test of the Channel Access Mechanism (CAM) in the wireless subsystem. (Similar tests are also defined by the FCC in Wi-Fi 6E test suite, which are called Contention Based Protocol (CBP) tests).

New wireless communication chips and subsystems must contain a mechanism called “Channel Access Engine” to sense and avoid other signals and share the spectrum over time. This mechanism will sense RF energy of whatever sort in the active channel prior to making a transmission. When the test system detects a signal, it will delay the listening device transmission until after the sensed signal ends. But more than that, the listening device must extend the delay for a semi-random duration beyond the end of the sensed signal. This random delay increases the chance that, if multiple devices are waiting to transmit, only one device will be first to initiate the next “conversation” on the air, and other devices will detect that signal and again pause. This avoids the collisions that would result if all waiting devices had the same timing. The channel access engine includes calculations based on priority class and pause duration to allow fair sharing of the spectrum over time.

The ETSI EN 301 893 Adaptivity tests are designed to measure behavior of this channel access mechanism. It should reduce likelihood of collisions between different signal types and increase tolerance of extrinsic signals. The Adaptivity test simulates three different signal types using standard RF test waveforms of Orthogonal Frequency Division Multiplex (OFDM), Additive White Gaussian Noise (AWGN), and LTE.
A New Challenge in New Bands: Interference to Incumbent Users

As the radio LAN (RLAN) bands grow to include new adjacent frequencies, the existing services using those new frequencies require protection from the new unlicensed users. For example, the incumbent users of the radar services in the 5 GHz range required protection from interference when the ISM expands on these radar frequencies. For example, radar services operate in the 5 GHz range, and when the ISM band was expanded to allow operation on these radar frequencies, the incumbent users (radar) required some protection from interference. Regulatory agencies responded by defining a test in which a wireless device must sense radar signals and vacate any channels in which the radar was present. This is the Dynamic Frequency Selection (DFS) function and the regulatory compliance tests for DFS measure compliance with the regulations. DFS is not the same as Adaptivity though there are a few similarities.

Figure 6. DFS is intended to protect weather radar, an incumbent user of bands now allocated to Wi-Fi.

Hence, wireless IoT devices may use the radar frequencies without interfering radar installations. But as an incumbent and important service, radar needs protection from the many unlicensed devices which may move into the area and begin using radar frequencies.

The DFS function only applies to the frequency ranges that may interfere with radar services and not all the 5 GHz RLAN channels. Hence, the RLAN device must listen for radar before beginning transmissions. Depending upon the operating frequency, the device must show certain probability of detecting a radar signal, and then show that it can either cease operating or rapidly move its network to another channel, staying off the radar frequency for 30 minutes.

The regulatory tests for DFS are rather challenging because they require significant behavior sequences and timing in the RLAN device. But more than that, the radar signals themselves may be present on different channels, and many different types of radar signals are in use and each signal type must be tested. Automated test systems can significantly reduce both the overall test time and the tedium for test engineers in these repetitive DFS testing tasks.
A Second Incumbent Challenge from Wi-Fi 6E

Wi-Fi 6E is another expansion of the 5 GHz ISM band up to 7.2 GHz in the US (less in some regions), 1.2 GHz of additional spectrum above the present allocation. But again, there are already services active in the additional spectrum, and the FCC in the US has defined a new set of tests for devices used in the Wi-Fi 6E bands. Some of these tests are intended for protection of incumbent services. The incumbent users on the new band are primarily terrestrial microwave links and satellite services. Therefore, some new test requirements address antenna pattern to avoid radiating signals more than 30 degrees above the horizon. Another new operation requirement is a mechanism to use a database to identify available channels based upon geographical location of the Wi-Fi 6E device. In locations of known incumbent users, unoccupied frequencies will be available, but occupied frequencies will not be allowed for use.

Figure 7. Satellite RF links are incumbent users of the new Wi-Fi 6E Bands

Figure 8. Terrestrial Microwave links are incumbent users of the new Wi-Fi 6E bands.

The Wi-Fi 6E test requirements also include a function named Contention Based Protocol (CBP) which is very similar to the ETSI Adaptivity test. This function will cause a device to detect activity on the active channels and cause it to delay transmissions until after the detected signal is gone. Again, a semi-random delay will help determine transmission timing, avoid collisions, and increase the likelihood of success on the first transmission.
Solutions for IoT Regulatory Device Test

These new, more complicated regulatory compliance tests have significantly increased the complexity of the test process. In the past, simple tests for power, bandwidth, and frequency were all that was needed to attain regulatory compliance. New tests such as DFS, Adaptivity, and CBP now require collection of very large volumes of data at high speed, and precise timing or DUT behavior. While it is a time-consuming process, the test systems must now collect these data, process, and analyze the data sets.

The Keysight IOT0047A Regulatory Test Solution is a complete, automated test system which can perform these difficult tests with speed and accuracy. It comprises of test and measurement instruments and software and is flexible enough to perform ETSI, FCC and DFS tests. Since regulatory agencies are now frequently changing regulations, a software update can keep the test system compliant with new test requirements.

The hardware of the IOT0047A includes several standard benchtop instruments serving in a complete system solution. The Keysight N9020B MXA series signal analyzer is a key element of this test system. It serves as a spectrum analyzer for most tests of frequency, bandwidth, PSD, and timing. With the licensed options, it can support dozens of specialized applications. The X-Series Signal Analyzers allow a test lab to repurpose capital equipment into other applications as the demands on the test lab vary with time.

Another benchtop instrument in the test system is the RF signal generator. The IOT0047A solution can include both the N5172B EXG and the N5182B MXG, offering high performance signal generation in a compact format. They can generate signals at frequencies and bandwidths sufficient to simulate the desired communications and radar waveforms for the many new regulatory tests required for IoT devices.

Two other specialized instruments comprise the test system hardware: The X8749A Signal Conditioning Test Set includes switching, attenuation, and other RF signal conditioning for the system in an integrated package. The X8750A 4-Channel MIMO Power Test Set is used for MIMO testing, and you can use up to two units to perform simultaneous measurements of devices up to 8x MIMO capability.

The test system uses Signal Studio software to create the signal files used by the signal generators for the various communications and radar signals required for device testing. Over 30 different versions are available for 5G, LTE, Bluetooth and many other radio standards, as well as custom signal generation packages.

The complete solution comes with three versions of software that you could run on the system PC. XA5001A is used for the ETSI 300 328/301 893 European regulatory tests, the XA5002A is used for FCC Part 15.247/407 US certification tests, and the XA5003A DFS Test Software controls the DFS radar tests. The software is designed with the test engineer in mind and provides several configuration and parameter setups which allow very flexible operation. The system can run a whole sequence of tests or be configured for only certain tests or frequency ranges for retest and fault diagnosis. There is no need to re-run a whole test suite to identify root cause of a small number of test failures.
How It Works

Data collection itself is a challenge in some of these regulatory tests. For the ETSI Adaptivity test, the engineer usually must collect several minutes of data at one microsecond sample rate. The duration depends upon the class of device being tested, but it results in a very large volume of data.

The IOT0047A regulatory test solution from Keysight Technologies executes the Adaptivity test in one continuous process. During the test, the software will load the RF channel with data transmissions and record the RF transmissions based on the set duration. The X8749A instrument can collect these data in a continuous stream, speeding up data collection compared to historical methods. In the past, data could be collected by successive zero-span sweeps using a spectrum analyzer, and the present ETSI standard allows for this, even though it is a discontinuous process. But the limited number of points per sweep on most spectrum analyzers means that many sweeps must be collected and read out in alternating series, a comparatively slow process. Then these sweeps must be combined into a long record for processing. Automation of the data acquisition into a single step saves a lot of work and time.

The IOT0047A software processes these data into Channel Occupancy Times (COTs) and Idle Periods in the one microsecond data record. The software will then process these COT tables to determine the statistical distribution of idle periods and whether the Channel Access Engine is compliant with the timing requirements of the compliance test.

The test results are presented in both graphical and tabular forms, and you can select to generate reports in any of six file formats. Compared to the older manual or semi-automated methods, this test automation saves significant time and work, increases lab efficiency, and reduces time to market for new devices.

DFS is another test in which an automated test system has a similar story of time savings. The IOT0047A regulatory test solution includes a signal generator to create simulated radar signals from files generated by the Keysight Signal Studio software. These include many different radar types, from several various countries’ radar systems. The test system communicates with the device under test and applies the selected radar signal at the selected frequency and power level and waits for the DUT to acknowledge detection of the radar.

The required number of repetitions, the many radar signal types, and the many test frequencies multiply to create a very large number of combinations and test iterations. In the IOT0047A, the DFS test in each signal/frequency combinations are applied the required number of times, and the test system moves the radar signal to the next frequency and repeats the process. The test system records thousands of repetitions and immediately display the results as the test progresses. The complete test results are also available as a report in several file formats.
Conclusion

The Keysight IOT0047A Regulatory Test Solution is a valuable addition to IoT device test labs and can reduce test times and get products to market faster, even with the complex new tests now required for regulatory certification.