Keysight Technologies
IoT – With Great Power Comes Great Challenges

Application Note

Rising challenges for IoT device designers and developers – component, circuit and system levels. What are the tools and solutions available? What are the test considerations that might help save time and cost?

KEYSIGHT TECHNOLOGIES
Unlocking Measurement Insights

HARDWARE + SOFTWARE + PEOPLE = IOT/M2M INSIGHTS

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There is a storm coming – the explosion of the Internet of Things (IoT)[1]. It is estimated there will be more than 30 billion 'Things' or smart objects, the building blocks for IoT, everywhere and always connected. IoT applications, like smart homes and healthcare, are already gaining popularity in the consumer market. There is even a smart city near completion in Korea, with more planned elsewhere. Ongoing advances in the technologies enabling the IoT are giving way to a wave of new and unimaginable applications for both the consumer and enterprise markets. At the same time, software and services, hardware and connectivity are evolving rapidly. To fully leverage these advances, IoT device designers and developers need tools and solutions to help them overcome the complex design and integration challenges, thus enabling their fast and successful development and deployment of IoT devices.

1. Introduction

Kevin Ashton first coined the phrase “The Internet of Things” in 1999 when discussing applications for RFID tags. From the simple tracking and counting of RFID objects, the Internet of Things has taken off with Machine-to-Machine (M2M), Big Data and Machine Learning, enabling applications such as the smart building, smart grid and intelligent transport systems.

IoT devices at the end nodes connect to the cloud or server for intelligence and analytics. Some connect directly and some via gateways, as shown in Figure 1. Gateways aggregate traffic from lower power networks onto higher capacity LANs and WANs. They typically include greater power supply and computing resources than end-nodes. Edge or fog applications running in gateways offload processing from both cloud and end-node sensors and actuators. End-nodes are often designed to have a long battery life, necessitating the efficient use of embedded computers and radio transmission. Intelligent threshold triggers in gateway applications make traffic more efficient by passing actionable information to central cloud servers. Gateways interface with the cloud and end-nodes via a heterogeneous mix of wireless technologies, both cellular and non-cellular. Radio interfaces address varying application needs depending on coverage, latency, throughput, energy efficiency, and cost.

Massively scaling a heterogeneous mix of wireless communication technologies introduces challenges like interoperability and interference, which have to be addressed during the design and development of IoT devices. Besides conforming to network requirements and wireless regulatory standards, design aspects such as energy consumption and battery lifetime must also be considered. IoT devices are often expected to operate for many years in deployment.

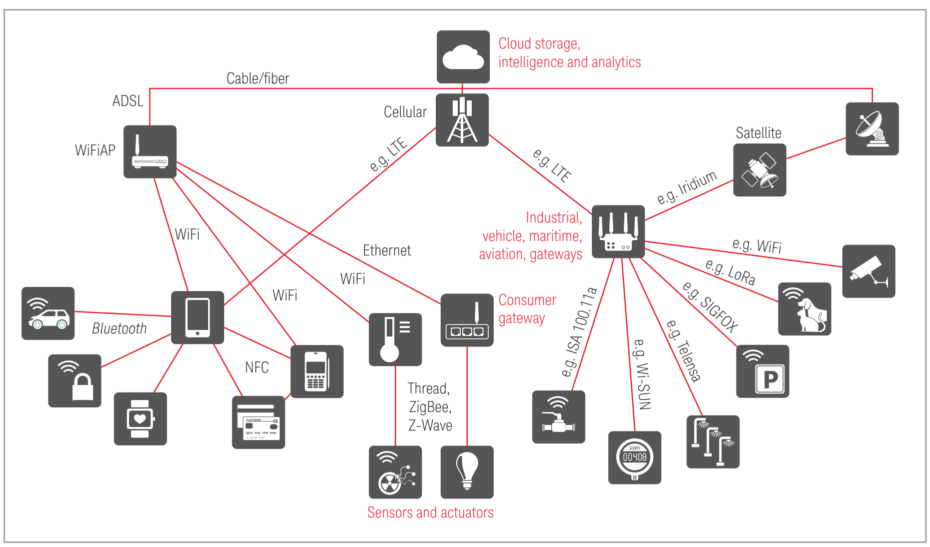

Figure 1. Myriad pathways and gateways provide access to the cloud.[1]

2. Challenges in IoT

The massive increase in the number and density of devices deployed for IoT applications and services is giving rise to an array of challenges that must be addressed to ensure successful implementation. In this section, we will discuss some of the specific challenges facing IoT device designers and developers.

a) Higher Level Integration of Circuits and Components

Advances in mixed signal integrated circuit (IC) technology have been a key enabler of IoT devices. By reducing part-counts, for example, smaller footprints can be achieved. And, with greater integration comes lower cost, lower energy consumption and better performance. However, mixed signal integration may also introduce new design complexities. Current mixed signal ICs integrate digital, analog and RF functionalities into a single chip. Systems on chip (SoCs) integrate previously discrete system components onto a single substrate. Low-power wireless microcontroller SoCs with integrated wireless connectivity, sensing and actuating interfaces are being deployed in many IoT applications.

PCB integrated antenna are often used to replace chip or external antennas for wearable and compact low-cost devices such as smartwatches.[2] With devices increasingly using printed antennas, multiple antennas and multiple radios, it becomes ever more important to model and measure antenna performance and self-interference in a variety of real-world conditions. Antenna match, efficiency, radiation, and reception patterns need to be evaluated, often with consideration to walls, mounting structures or, in the case of wearable devices, clothing and the human body.

With increasing complexity, electrical, thermal and mechanical behaviors need to be fully evaluated. These effects can impact the performance and reliability of other device subsystems. To address this challenge, design and simulation tools that support an accurate and seamless flow of co-simulation across multiple realms and technologies—from component to system level—are necessary to help realize success and provide in-depth design insight into a device's real-world operation.

b) Energy Efficiency and Battery Life

Simple devices like sensors are often battery driven and have limited energy storage. For networks with a large-scale deployment of sensor-nodes or medical implants, these devices should have lifetimes of months or years. Frequent battery replacement is costly and not practical in some operating environments. To save energy, devices usually operate with a very low duty-cycle and reside mostly in idle or sleep mode, activating only when necessary.

In higher performance devices and gateways, the processor, display and wireless modules account for a large part of the total energy consumption. These devices are equipped with multiple wireless interfaces and are more often required to be in active-mode for heavier processing tasks. To understand the energy consumption of these devices, the power management and complex interaction of the different components and modules must be adequately considered, as shown in Figure 2.

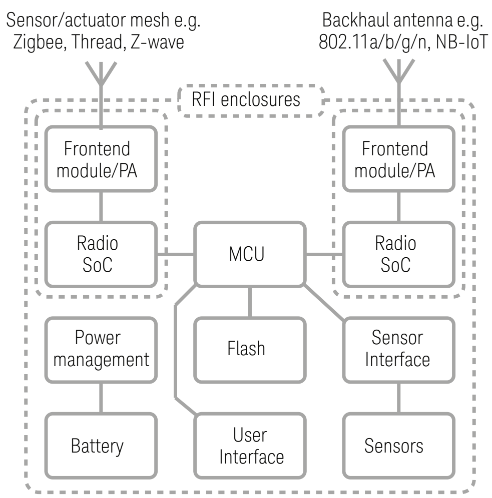

Figure 2. Typical components of an IoT gateway/sensor (e.g., a heating thermostat, smoke alarm, security alarm, or utility meter gateway).

To optimize battery life, it is important to know the current use and duration of each operating mode. The duration and amount of current consumed determine the effectiveness and efficiency of each activity. Current drain may be the only good way of determining the time duration of a certain processing event or activity. A key challenge is to measure current drain that spans a wide dynamic range; from sub µA in sleep mode to hundreds of mA in active mode. Battery drain analysis with seamless current ranging (to capture high peak, low duty cycle and low average values) and simulated network conditions is desired. Whether using an actual battery or power supply, the designer must ensure the device is properly powered so that battery drain results are representative of the device when it's in actual use.

With advances such as energy harvesting, new battery technology and low power design, battery life is being prolonged. Utilization of smaller cell size, narrower bandwidths low power communication networks also helps to alleviate energy constraints. To achieve lifetime and thermal requirements, it is necessary to conduct systematic energy analysis. Doing so helps maintain good control of the device's hardware and software performance. This is especially important in real-life operation where environmental and network conditions may significantly decrease a device's operating lifetime.

c) Signal Integrity (SI) and Power Integrity (PI)

SI can be categorized into four groups: issues related to one net, coupling between multiple nets, power and ground paths in power distribution network (PDN), and electromagnetic interference (EMI).[4] Methods to minimize SI issues include maintaining controlled impedances through interconnects, attention to trace spacing to minimize mutual inductance or capacitance, correcting longer than ideal return paths, minimizing PDN impedance, and ensuring good grounding and shielding. Even so, as semiconductor technology advances with smaller gate or channel length and faster switching, rise-times are decreasing and clock frequencies are increasing, making SI issues inevitable. In low power circuits, there is less tolerance for SI issues like crosstalk.

PI is the analysis of how effectively power is converted and delivered from the source to the load within a system. The power is delivered through a PDN that consists of passive components and interconnects from the source to the load. With the drive towards low power electronics, DC supply voltages and tolerances have been reduced. In some cases, supply tolerances have dropped from +/-5% to +/-1%. Ripple, noise and transients riding on these low-voltage rails can adversely affect clocks and digital data. To ensure clean power rails, supply lines need to be examined for quality and integrity. The challenge is to measure ever smaller and faster AC signals riding on top of DC supplies.

With increased functionality, higher density, higher speed and lower power electronics, SI and PI issues are becoming more common. Using system modeling and simulation tools to predict performance, complemented by measurement tools to evaluate implementations, enables design teams to reduce both project risk and time-to-market.

d) Heterogeneous Mix of Wireless Technologies and Multi-Standard Devices

To serve the diverse nature and needs of IoT applications, numerous wireless technologies and standards have emerged.[1] Varied networks are able to support applications ranging from simple battery-powered sensors to the high-bandwidth, mission-critical services for autonomous cars. Figure 1 shows devices like a smartphone supporting cellular and non-cellular radio interfaces like NFC, WiFi, *Bluetooth*®, and LTE. The fact that there are so many standards available for IoT presents a measurement challenge. These standards have many different physical layers, each of which has its own unique RF test requirements. Further complicating matters, each physical layer can potentially support multiple modulation schemes.

As an ever growing number of devices support multiple standards, testing these devices becomes all the more complex. Each standard has its own set of test requirements and challenges. Developers also need to verify that devices interoperate well together and can handle multiple standards concurrently. Nevertheless, test equipment can become expensive when a separate instrument is needed for each individual standard. A more cost-effective approach is to have a single instrument that is capable of testing all of the necessary standards, and supports the addition of new standards as they emerge.

e) Interference, Compliance and Conformance

With the high density of IoT connected devices, wireless technologies that share similar frequency bands can cause co-channel and adjacent channel interference with one another. As an example, an increasingly large number of IoT devices use the unlicensed Industrial, Scientific and Medical (ISM) frequency band. As a result, the 2.4-GHz ISM band, which is used by cordless phones, wireless video cameras, microwave ovens, and wearable devices, is getting quite crowded. It is critical that devices be thoroughly tested to ensure they meet network requirements and regulatory standards, as well as have the ability to operate in this dense signal environment. This includes meeting conformance and compliance standards. In addition, real-time spectrum analysis which allows detection and capture of spectral environment is a valuable way to identify time-varying sources of interference.

Another concern with the large number of IoT devices operating simultaneously in close proximity to one other is electromagnetic interference (EMI). There are four broad types of electromagnetic compatibility (EMC) testing: radiated and conducted emissions testing, and radiated and conducted immunity testing. One party wants to avoid creating unwanted emission and the other works towards robustness against unwanted emission. To make compliance certification measurements, solutions that comply with the requirements of the respective standard are required.

3. Solutions and Test Considerations - Software and Hardware

Keysight Technologies provides a broad range of integrated solutions for design, validation, conformance, and manufacturing test. In this section, a number of them are proposed for designers and developers working at the component, circuit and system level to address the challenges previously described.

(i) Design and Simulation (a-e)

Design and simulation tools provide designers with an understanding of the underlying physics of complex systems. Complex, sensitive and high-performance mixed signal circuits can be modelled and integrated without significant compromises in performance. Keysight EEsof's Electronic Design Automation (EDA) software addresses the inherent challenges in system, circuit and physical-level design by providing solutions for the complete design-flow as shown in Figure 3. Using design-flows built on these system, component and physics-level design tools, design engineers can create better products faster. Moreover, Keysight's EDA software is fully compatible with Keysight's test and measurement equipment, offering designers a complete solution from design to validation test.

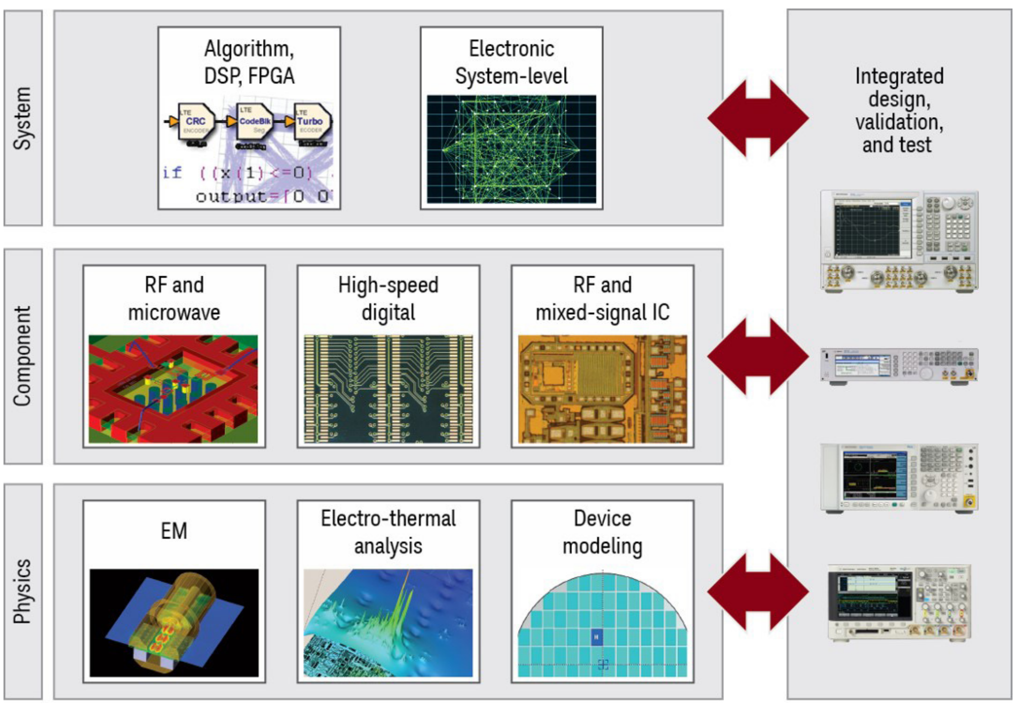

Figure 3. Keysight's design software provides designers with complete design-flows from design to validation and test.

Early in the development process, a new product can be simulated using SystemVue, a focused EDA environment for electronic system level (ESL) design. As seen in Figure 4, SystemVue enables system architects and algorithm developers to innovate the PHY layer of wireless communications systems, and provides unique value to RF, DSP and FPGA/ASIC implementers. SystemVue also includes virtual measurement tools that can be attached to nodes in the simulation to predict system performance.

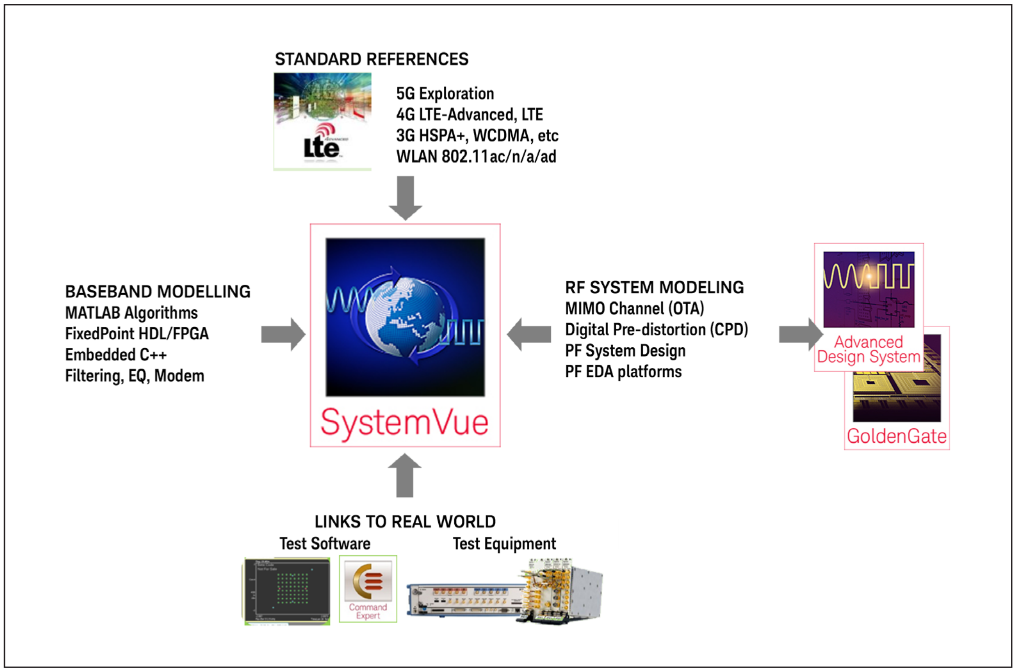

Figure 4. SystemVue is the nucleus for cross-domain development environment.

Advanced Design System (ADS) is the tool for RF, microwave and high-speed digital applications. It includes a design simulation environment that enables co-design of the IC, package and board to help save time and reduce errors introduced when using multiple tools. Tradeoffs can be made interactively on the IC, package and board while they are being co-designed. Circuits designed in multiple technologies can be combined and simulated at both the circuit and full 3D EM level.

ADS features a complete schematic capture and layout environment, circuit and system simulator, native access to 3D planar and full 3D EM field solvers, accurate and efficient electro-thermal analysis, and the largest number of process design kits (PDKs). It also offers EDA and design flow integration with companies such as Cadence, Mentor and Zuken. Moreover, an optimization cockpit allows for real-time feedback and control, while up-to-date wireless libraries allows designers to work with the latest emerging wireless standards. X-parameters* model generation is also possible for nonlinear high-frequency design.

With low power circuit design, noise calculation may be important, especially as signal levels get closer to the noise floor. ADS provides linear noise simulation with AC and S-parameter simulators. The noise simulation computes the noise generated by each element and then determines how it affects the noise properties of the overall network. In most cases, noise generated by circuit elements is calculated automatically. For example, lossy passive elements contribute noise according to their ability to deliver thermal noise power. The noise contributions from nonlinear devices are computed by models that include temperature and bias dependence, similar to those models used by SPICE.

1. X-parameters is a trademark and registered trademark of Keysight Technologies in the US, EU, JP, and elsewhere. The Xparameters format and underlying equations are open and documented. For more information, visit **http://www.Keysight.com/find/eesof-x-parameters-info.**

ADS also offers SI and PI analysis with SIPro and PIPro.[1] SIPro provides speed and accuracy for the EM characterization of high-speed links on densely-routed, highly complex PCBs. Compared to gold-standard Finite-Element-Method (FEM) simulation, SIPro demonstrates very good agreement at a small-fraction of the time and memory consumption. PIPro provides PI analysis of PDN and includes DC IR drop analysis, AC impedance analysis and power-plane resonance analysis. The DC IR drop simulator provides a table of DC voltages and currents for each PCB-via, pin, sink, and voltage regulator module in the PDN, enabling SI and PI engineers to predict DC voltage at the pins of the ICs sinking the current. With the visualization of voltages, current-density and power dissipation on power and ground nets, trouble spots can be easily identified.

With one common environment for both SI and PI analyses, a single setup can be easily copied from one analysis type to another. Resulting EM models transfer seamlessly back to the schematic for further simulation. The integrated schematic capture, layout and data analysis environment with multiple simulators including IBIS-AMI channel, transient, S-parameter, and physical layer EM, ensure designs comply with the latest standards. In support of channel simulation within the ADS environment, designers can use EMPro software for full 3D EM simulation of complex channel component models, and SystemVue software to generate custom IBIS-AMI transmitter (Tx) and receiver (Rx) behavioral models for fast channel simulation. This flow eliminates the need to switch between different tools, enabling better engineering collaboration and time saving.

Keysight EDA offers a broad selection of EM simulation technologies covering Method of Moments (MoM), FEM and Finite Difference Time Domain (FDTD). The Momentum simulator employs MoM for passive circuit modeling and analysis to accurately simulate coupling and parasitic effects of complex multi-layer designs. The FEM simulator based on FEM, accurately simulates 3D structures such as packaging, bond-wires, connectors, and other components. EMPro with its FDTD solver, is the most efficient solution for antenna, EMI/EMC, radar cross section, and biomedical applications.

GoldenGate is an advanced simulation, analysis and verification solution for integrated mixed signal RFIC designs. It is fully integrated into the Cadence ADE and includes Momentum for 3D planar electromagnetic simulation, SystemVue and Ptolemy wireless test benches for system-level verification, and the ADS Data Display for advanced data analysis. GoldenGate links system, subsystem and component-level design and analysis as part of a comprehensive design-flow for complete IoT design.

As the design moves from simulation to realization, actual device modules can be substituted into the simulation. Real measurements or hardware-in-the-loop replace virtual tools and enable developers to compare simulated versus measured performance. For greater visibility, simulation can be used to interpolate and extrapolate waveforms in locations inaccessible by measurement probes. For continuity from design to prototype validation, Keysight offers an unparalleled range of lab-grade test equipment—from benchtop to modular and handheld.

(ii) Battery Current Drain Analysis (b)

Keysight's N6781A and N6786A 2-quadrant Source Measure Units (SMUs) are specifically developed for battery drain analysis of wireless devices.[5-7] The N6781A offers high accuracy for low current measurements with specifications up to 20 V, 3 A and 20 W. The N6786A is good for higher power devices like the latest smart phones/phablets, tablets and notebooks, with up to 20 V, 8 A and 80 W of output power.

The most important feature of the SMUs is their seamless measurement ranging, which spans over 7 decades for accurate measurement of dynamic current drain signals (Figure 5). They also feature settable battery emulation characteristics to provide results comparable to an actual battery, as well as a zero-burden ammeter and voltmeter logging operation mode for performing run-down testing with an actual battery when necessary. A fast transient response minimizes the transient voltage drop for pulsed currents drawn by wireless devices, while a 200-kHz sampling rate provides detailed measurement insight.

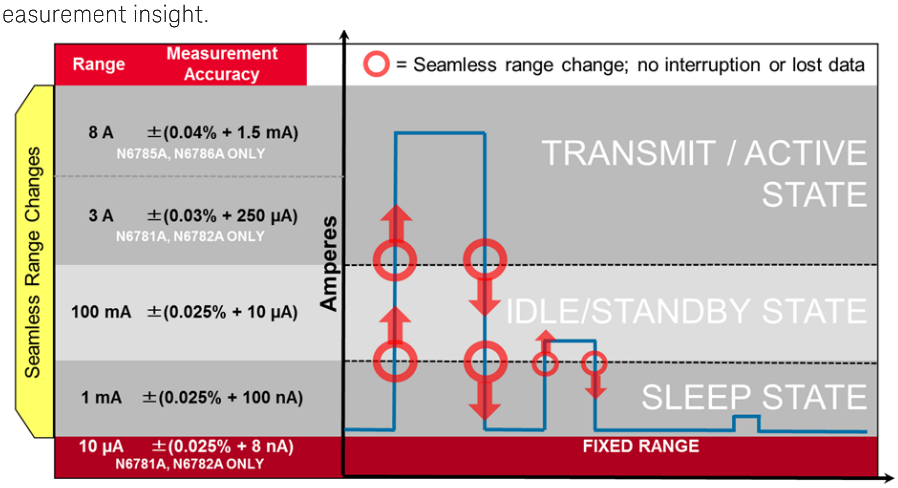

Figure 5. Seamless measurement ranging allows Keysight's SMUs to track the level of the dynamic signal in real time and use the most optimum measurement range for the given signal level.

Both SMUs operate within the mainframe of the N6705B DC power analyzer. The N6705B provides a platform for power, waveform capture, long-term current drain data-logging and display, plus analysis of results. The 14585A software compliments the solution by adding advanced battery drain functionalities such as statistical analysis and energy measurements.

An example of insight provided by greater time-resolution when optimizing the battery run-time of a GPRS device is shown in Figure 6. On the left, a good portion of current drain for the DRX standby operation is captured. The exploded view on the right shows details of each Rx current burst, which provides insight into the baseband and receiver activities during this period.

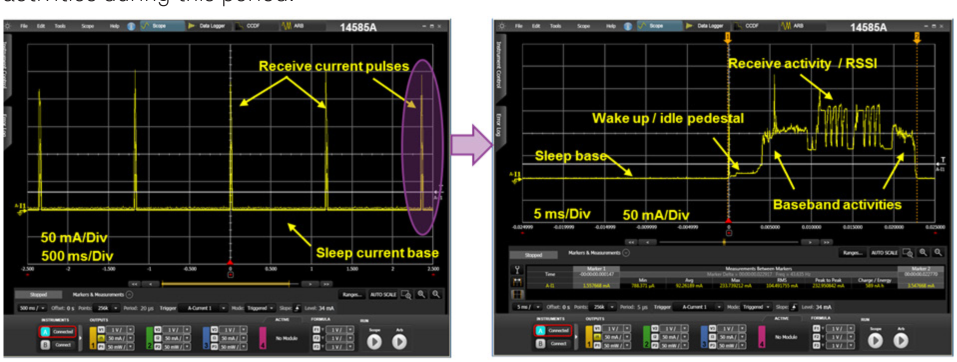

Figure 6. Better insight for optimizing the battery run-time with the zoom-in view.

It is often useful to evaluate a device powered by a battery-emulator power supply that delivers a constant DC source to the device. At other times, it is useful to use the device's actual battery, such as when conducting an actual battery run-down test. This test setup reveals additional insight into the device when it's operated with its battery. The N6705B coupled with the E7515A UXM Wireless Test Set's flexible network emulation and configurable sleep mode capabilities enable characterization of device battery life and current drain under realistic operating conditions (Figure 7). Besides evaluating the resulting impact of different operating modes over various settings, the user equipment's applications and network conditions on battery consumption, users can analyze the impact from design changes, firmware updates and the addition of complex transmission and reception capabilities such as carrier aggregation and higher-order MIMO.

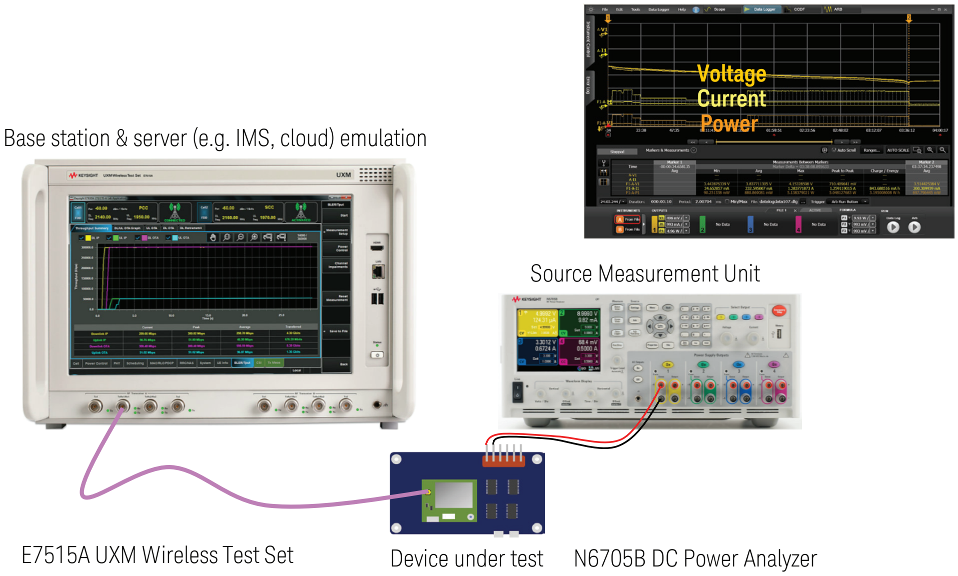

Figure 7. Designers can characterize battery and current drain with the UXM and DC power analyzer.

Other applications offered by the N6705B DC power analyzer and tips to optimize device's battery life can be found in reference 5 and 6, respectively. For even lower current and higher bandwidth measurements, the CX3300A Device Current Waveform Analyzer can be used. It measures current down to 150 pA and bandwidth up to 200 MHz.

(iii) Signal Integrity and Power Integrity Tools (c)

There is a wide range of measurement tools available to validate and correlate SI and PI simulation with actual measurement. For example, the ENA Option TDR addresses interconnect test, the Infiniium oscilloscopes support transmitter test, and the Bit Error Ratio Test (BERT) solutions can be used for receiver test. Supporting software serves to enhance the measurement value of these tools.

The E5071C ENA Option TDR[8] is a one-box solution for analyzing high-speed serial interconnects. It enables time-domain (TDR/TDT), frequency-domain (S-parameters, which can be used to describe crosstalk) and eye-diagram analysis, as shown in Figure 8. The ENA replaces traditional solutions such as vector network analyzers and TDR oscilloscopes. It incorporates a setup wizard that automatically adjusts skew and makes measurements with just a few clicks. Moreover, it allows fast and accurate measurement of small discontinuities. The superior noise performance enables real-time measurements without the averaging traditionally needed with TDR oscilloscopes. Another advantage is ESD robustness; ESD protection circuits are difficult to implement on a TDR oscilloscope. The ENA supports compliance test and is certified for major communication standards. Together with differential and single-ended TDR/TDT probes, the ENA can also be used for PCB quality control and failure analysis.

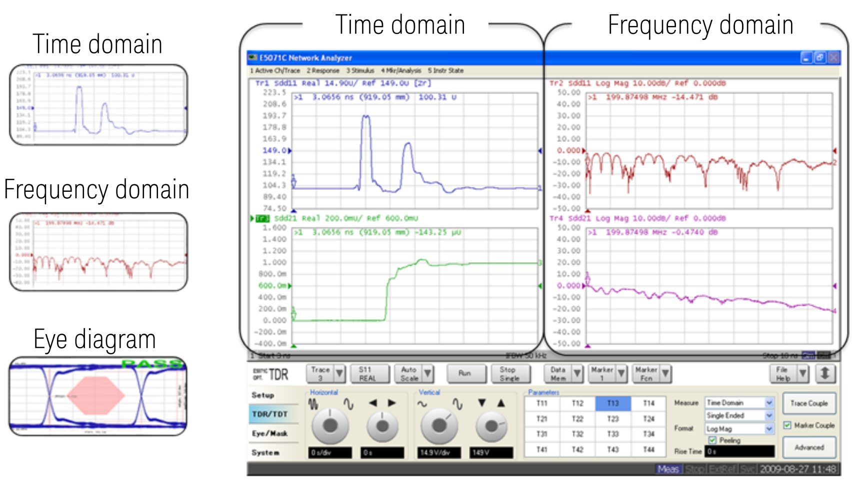

Figure 8. The E5071C ENA Option TDR is used for real-time measurement of the time and frequency domains.

Figure 9. Real-world jitter measurements with the Infiniium S-Series oscilloscopes.

The Physical Layer Test System (PLTS) software[9] is specifically designed for SI in interconnects. It works with the PNA, ENA, and PXI vector network analyzers, as well as TDR oscilloscopes. The PLTS guides users through hardware setup and calibration, and controls the data acquisition. It also provides de-embedded model creation for automatic fixture removal that allows engineers to examine only the component of interest. The system is easy-to-use with one-button compliance tests.

To measure jitter and observe waveforms, high bandwidth measurement solutions are required. The Infiniium S-Series oscilloscopes[10] offer the industry's best SI with 10-bit ADC, a low-noise front end (90 µV RMS noise at 1-GHz bandwidth), up to 8-GHz bandwidth, a 20 GSa/s sample rate, and less than 200 fs RMS intrinsic noise. Figure 9 shows actual jitter measurements using these oscilloscopes. All models in the family utilize the same time-base technology block and a low horizontal component of jitter that measures less than 130 fs over short record lengths. The S-Series supports compliance applications like DDR, eMMC, MIPI, USB, and many more.

Software applications that enable better measurement insight are available for the S-Series. The InfiniiScan rapidly triggers on complex events that can be seen but may be impossible to specify using hardware triggers. It quickly scans through thousands of acquired waveform cycles and isolates anomalous signal behavior. The Serial Data Analysis provides quick SI validation for high-speed serial interfaces with embedded clocks. The EZJIT, EZJIT-Plus, and EZJIT-Complete help to characterize and evaluate most commonly needed jitter measurements. The N8833A crosstalk analysis application[11] assists in the diagnosis of crosstalk by detecting and quantifying sources of crosstalk. The N8833A also enables users to visualize expected improvements to help quantify the amount of design margin recovered when specified aggressors are removed from victims (Figure 10).

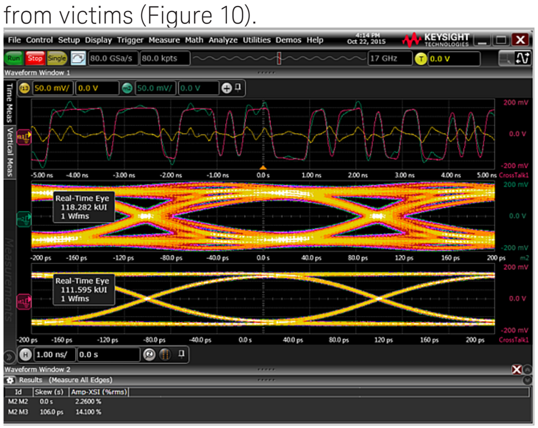

Figure 10. Before and after view of a victim waveform with FEXT. The top plot shows the victim waveform in green, the aggressor in orange, and the crosstalk removed waveform in red. The middle plot is the eye diagram of the victim with the bulging indicative of FEXT. The bottom plot is the eye diagram of the victim after removing crosstalk.

An important thing to consider is that oscilloscopes themselves are subject to SI challenges like distortion, noise and loss.[12] Scopes with superior SI attributes provide a better representation of signals under test and vice-versa. Table 1 shows seven critical oscilloscope attributes that are important to obtaining an accurate representation of measured signals under test.

Table 1. Important oscilloscope attributes in providing accurate representation of a signal under test.

Signal Intergrity Metric	**Scope Technology Block**	**Where can you find the answer?**
Resolution	ADC bits	Product data sheet
Noise	Front-end	Most vendors include in product data sheet.
Vertical scaling supported in HW	ADC/front-end	Datasheets don't always specify when SW maginification starts. Some vendors BW limit at small sensitivities.
Frequency response flatness	Analog filters and correction filters	Not typically included in product datasheets. You will need to ask the vendor to see a magnitude and phase response for the model you are evaluating.
Time scale accuracy	Time base	Product data sheet
Amount of intrinsic jitter	Time base	Some vendors include, others don't. If not in the data sheet, ask the vendor.
ENOB (Effective Number of Bits)	Combination of both vertical and horizontal scope system	Some vendors include, others don't. If not in the data sheet, ask the vendor.

For receiver test, Keysight's BERT solutions cover affordable manufacturing test and high-performance characterization, and compliance testing up to 32 Gb/s. For example, the J-BERT M8020A[13] is designed for R&D and test engineers who characterize and verify compliance of chips, devices, boards, and systems with serial I/O ports. It has all the needed receiver test capabilities built-in and can be used to test popular serial bus standards such as USB Super Speed, and MIPI™ M-PHY.

To measure small AC signals riding on top of DC supplies and capture transients created by high frequency loading, PI solutions with low noise, support of popular rail voltages, low loading, and high bandwidth are desired. Together with the Infiniium S-Series, the N7020A power rail probe and N2820A high-sensitivity current probes present the PI analyzer reference solution.[14] This solution enables complete visibility into the signals hiding on DC power rails (Figure 11). The N7020A has a 1:1 attenuation ratio, ± 24-V offset, and 2-GHz bandwidth to capture high-frequency noise and transients that can cause clock and data jitter. It can be bandwidth-limited to reduce noise. The N2820A enables current probing down to the 50-µA range for low power measurements.

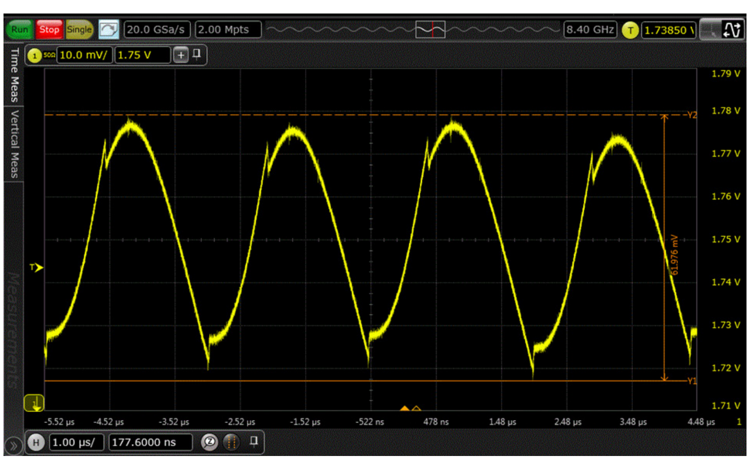

Figure 11. Zoom-in view of the ripple, noise and transients on top of a typical 1.8-V DC supply.

(iv) Wireless Test Solutions (d)

For those developing IoT devices and looking for solutions to support the wireless formats of today and tomorrow, Keysight offers a range of hardware platforms; benchtop, modular and one-box testers (Figure 12). These products are complemented with software that provide greater features and measurement insight. The advantage of using Keysight's solutions is the common measurement science ensures consistent and comparable measurement results for the entire product lifecycle from R&D to manufacturing.

In the design and prototype evaluation phase, benchtop instruments like the X-Series Signal Analyzers and Signal Generators are ideal as they provide the benefits of high performance and front panel capabilities. Later in the product lifecycle, where criteria like test speed, flexibility, and footprint are of greater importance, modular and one-box tester solutions like the M9420A VXT PXIe vector transceiver and the E6640A EXM wireless test set, respectively are better candidates. For example, the EXM[15] provides the broadest multi-format coverage of any one-box tester in its class, with regular updates that add new formats. Current supporting formats include 2G/3G/4G cellular formats, WLAN, ZigBee, *Bluetooth*®, and Wi-SUN. It can also be scaled up to four TRX channels. Each TRX is a complete vector signal analyzer (VSA), vector signal generator (VSG) and four-port RFIO, with up to 6 GHz frequency coverage and 160MHz bandwidth. Ports can be configured as two half-duplex and two full-duplex or 4 full-duplex.

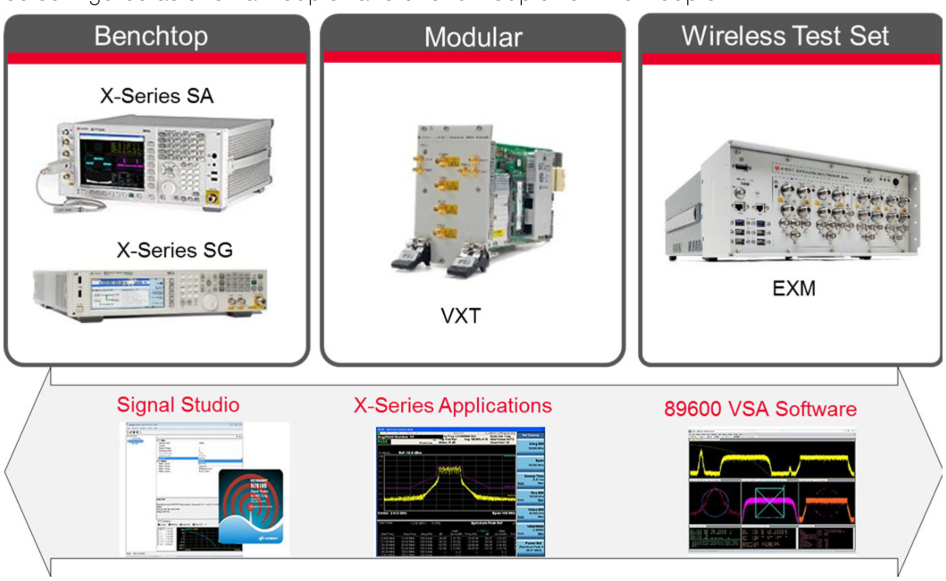

Figure 12. Keysight's measurement science across benchtop, modular and wireless test set. The software below, complement these hardware to provide greater features and measurement insight.

To accelerate design and test, Keysight offers three popular software applications to be used with the benchtop, modular and one-box tester platforms. Signal Studio software enables the creation of custom and standards-compliant waveforms, while the X-Series measurement applications enable one-button testing for the various IoT wireless formats. Aside from the signal generation software and measurement applications, the 89600 VSA software is the industry-leading tool for digital modulation analysis and is useful for deeper troubleshooting of wireless formats.

As an alternative to integrated test-sets, some small to medium-sized manufacturers may select cost-effective solutions[16-19] for implementations such as ASK/FSK and the lowest-cost *Bluetooth*® and ZigBee. The N9320B/N9322C Basic Spectrum Analyzer (BSA) can be used as a cost-effective solution for testing low-cost devices and modules. The BSA is ideal for the research, development and manufacture of consumer electronics, as well as for bench-repair, universities and colleges, and general-purpose spectrum monitoring.

The T3111S RIDER NFC Conformance Test System in Figure 13 is a one-box solution for RF analog and digital protocol testing of NFC, EMV and ISO devices. The test system is based on the T1141A NFC Test Set and is complemented by either the Keysight or FIME robots for accurate and repeatable RF testing. The T3111S is an officially validated test platform for the NFC Forum Certification program. It is also recognized for EMV Level 1 Card and Terminal type approvals. In addition, Keysight offers a solution for NFC R&D

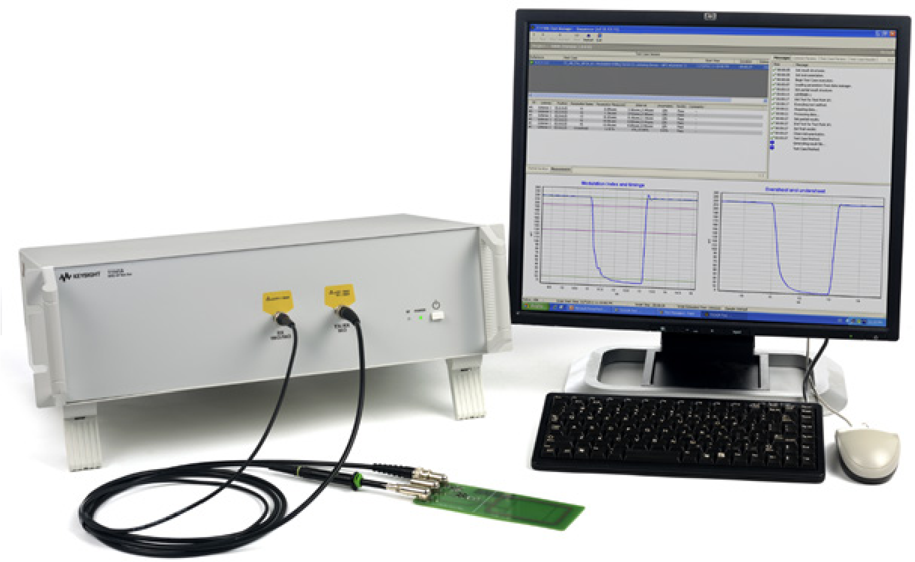

Figure 13. The T3111S RIDER NFC Conformance Test System for RF analog and digital protocol testing of NFC, EMV and ISO devices.

(v) Real-Time Spectrum Analysis (d, e)

Real-time spectrum analysis can be used to address a number of challenges, including troubleshooting performance problems in real-world environments and capturing interfering signals (intentional or unintentional) that may be present and impacting performance—even if they are transient and very short in duration. This capability can be upgraded as an option on the UXA, PXA and MXA signal analyzers. The Real-Time Spectrum Analyzer (RTSA)[20,21] option enables detection of signals as short as 3.33 ns and scanning up to 510-MHz real-time bandwidth, with real-time signal analysis for frequencies up to THz using external mixing. Effective triggering allows users to focus on the signal of interest in complex signal environments and even see small signals in the presence of large ones.

The 89600A VSA software complements the RTSA, enabling deeper analysis of captured complex signals. The N9077A WLAN measurement application and RTSA capability enable the signal analyzer to pinpoint interference caused by many signals in the ISM and UNII (2.4 GHz or 5 GHz) bands. Figure 14 depicts real-time spectrum analysis results in different formats to reveal agile, elusive or unexpected signals. The density display provides a detailed view of ongoing changes in the content of the spectral environment. Here, the color scale shows the frequency of occurrence. The spectrogram presents frequency spectra versus time and uses color to indicate magnitude. Information is updated in real-time, displaying signal changes in the spectrum domain, time domain and spectrogram views.

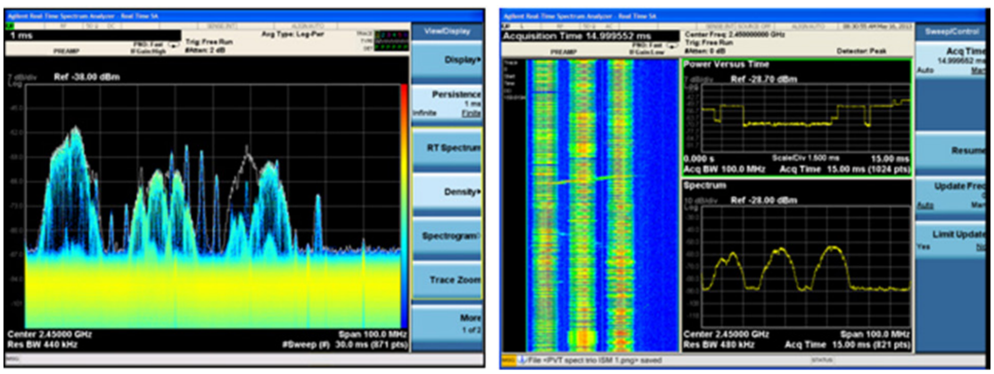

Figure 14. Real-time spectrum analysis results are displayed in (a) density format, (b) spectrogram and power versus time.

(vi) EMI /EMC (e)

Early in the development cycle, Keysight's EDA EMPro software can be used to simulate the radiated emissions of electronic circuits and components. Calculated results help to determine whether emissions are within levels specified by common EMC standards, such as CISPR, FCC Part 15 and MIL-STD-461G. Modeling can help designers estimate emissions levels before the hardware is developed.

To avoid costly project delays due to EMC compliance failures, development teams perform early pre-compliance testing on their new designs to help identify EMI problems. The N/W6141A EMI measurement application, running on the X-Series spectrum analyzers (PXA/MXA/EXA/CXA), facilitates pre-compliance testing with a broad suite of EMC-focused data collection and analysis tools.

The success of EMC compliance testing depends on moving products through the test queue quickly and efficiently. Full standards-compliant testing can be conducted in accordance with CISPR and MIL-STD with the upgradeable N9038A MXE EMI receiver. For a complete EMI test solution, Keysight Solutions Partners provide a single point-of-contact to combine the MXE with chambers, antennas, software, value-added integration, probes, and more. Figure 15 shows the test setup for radiated EMI measurements.

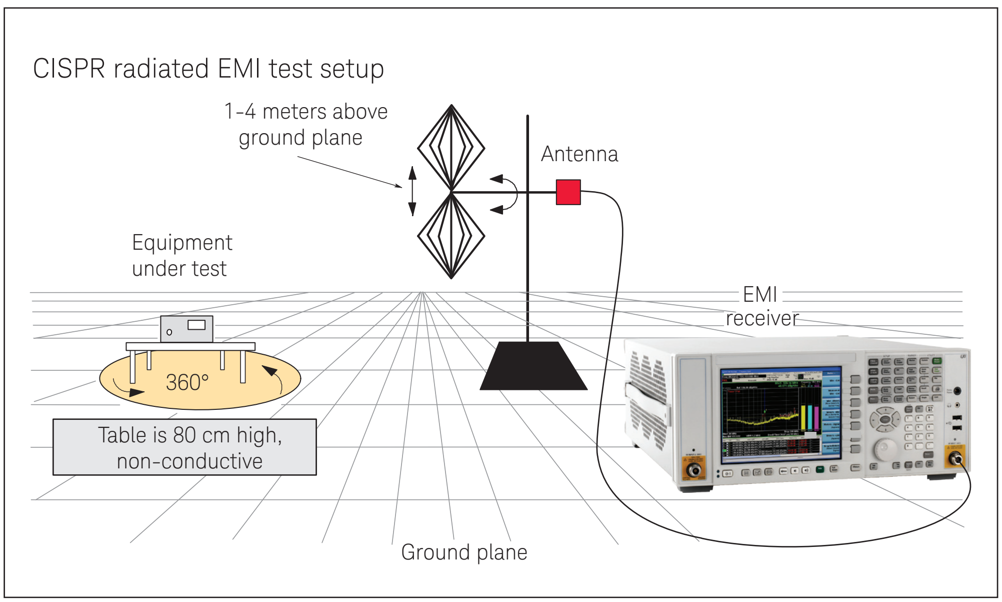

Figure 15. This test setup is used to perform radiated EMI measurements.

4. Conclusion

Addressing the rising challenges faced by IoT device designers and developers requires reliable and accurate test and measurement solutions. Using Keysight solutions, engineers can not only gain a faster time-to-market advantage, but also the increased likelihood that their devices will be successfully implemented in the market.

Keysight offers an array of solutions covering all phases of the product lifecycle to help device designers and developers address their challenges head on. Each solution is bolstered by Keysight's continuous innovation and investment in developing new technologies to support evolving standards and meet new and emerging test and measurement needs. To ensure it provides today's device designers and developers access to leading-edge solutions, Keysight sits on many industry committees and works closely with customers. By doing so, it is able to keep up with technology via upgrades, updates and retrofits.

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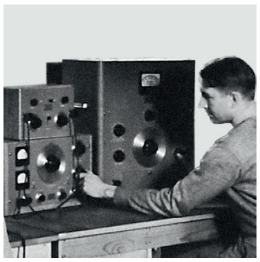

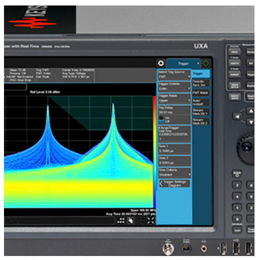

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