Introduction

The internet of things (IoT) affects many aspects of our lives, including home automation, entertainment systems, security and alarm systems, smart watches and wearable health monitors, smart traffic devices, waste management devices, and connected cars. IoT will touch almost every consumer and industrial application.

These IoT devices create unique challenges for designers and manufacturers. For devices such as smart watches and fitness monitors, the designs must be small, cost-effective, and low-power. Designers may find it necessary to use dense, highly-integrated circuits and SoC (systems on chip) devices, which because of the close proximity of power and signal paths may cause signal interference and crosstalk issues due to the capacitive and inductive coupling. New hardware must support multiple wireless platforms with low power consumption. Consumer electronic devices must also support multiple wireless formats to ensure interoperability between different vendors or systems.

Whether you are integrating a new wireless module into your device, testing a new low-power module, or troubleshooting your designs, Keysight Technologies, Inc. has solutions to these IoT design challenges to help you accelerate development and enable faster time-to-market.
Test Challenges and Solutions for Internet of Things-Enabled Devices

The complexity of IoT devices means device designers must address numerous issues to create viable products. As Figure 1 illustrates, each aspect of the device presents its own challenges. Throughout the course of development, engineers need test solutions that can provide the measurements necessary to ensure the proper functioning of the IoT design.

- **Maximizing battery life for IoT smart devices**
  - How long can my battery last?
  - Is my device drawing unnecessary power?

- **Signal and power integrity issues**
  - How do I resolve issues involving interference, cross-talk, excessive losses, impedance mismatch, power rail ripples?

- **EMI compliance and wireless conformance**
  - How confident am I that my design can pass the conformance test?
  - Is my device creating excessive emissions?
  - How well can my device tolerate unwanted emissions?

- **Interference due to multi-format wireless connectivity**
  - Is my device communicating at the right speed and covering the right range?
  - Is my device able to work under dense signal environment with multiple wireless signals operating at the same spectrum?

- **Power Management**
  - How do I control power consumption?
  - How can I optimize power delivery?

- **MCU**
  - How do I ensure the MCU is running efficiently?

- **Battery**
  - How do I monitor and manage battery health?

- **EMI**
  - How do I ensure emissions are within regulatory limits?

- **RF**
  - How do I test wireless communication performance?

Figure 1. Typical IoT module block diagram and associated test challenges
Table 1. Device development challenges, needs, and solutions.

<table>
<thead>
<tr>
<th>Your challenges</th>
<th>Testing needs</th>
<th>Keysight solutions</th>
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</table>
| Low-current measurements over a wide dynamic range for IoT devices | Dynamic power or current waveforms during different operating modes  
- Low-power or low-current measurements (sleep or standby mode)  
- Wide current measurement range from nA to A to cover from sleep mode to active mode  
- Total current drain measurement  
- Battery discharge operation  
- Battery capacity and lifetime  
- Battery emulation  
- Power module efficiency | LI DAQ and shunt resistor  
- Digital multimeter  
- InfiniiVision oscilloscope  
- DC power analyzer and SMU module  
- Device current waveform analyzer |
| Multi-format, cost-effective solutions for IoT wireless connectivity testing | Wireless connectivity testing, including demodulation analysis  
- Multi-radio interference analysis  
- Signal formats covering Bluetooth® LE, ZigBee, Z-Wave, 802.11ah/p, NFC, ASK/FSK, and GFSK  
- Basic power and frequency domain analysis for simple production test | USB power sensor and frequency counter  
- Basic signal generator and spectrum analyzer  
- EXM one-box tester  
- X-Series signal generator and signal analyzer |
| Signal and power integrity analysis | Troubleshoot impedance mismatch between major blocks  
- Debug interference and crosstalk  
- Ripples and noise on power rails | InfiniiVision oscilloscope  
- ENA network analyzer |
| Wireless conformance and EMI/EMC compliance test | Detect any potential failure during early stage of development  
- Prevent costly re-test and delay time-to-market  
- Meet necessary wireless regulatory standards | EMI pre-compliance measurements with N/W6141A EMI measurement application  
- EMC compliance test with N9038A MXE EMI receiver  
- EMI/EMC simulation with Keysight EMPro software  
- Conformance test systems – NFC, Bluetooth, LTE |
Low-power consumption analysis

The biggest challenge (or opportunity) for IoT devices is the life of their small, on-board batteries. IoT devices must work for long times between charges, and wearable medical devices, such as pacemakers and in-ear hearing aids, must not fail. Therefore, it is essential to understand power consumption patterns and battery life.

To maximize battery life, many devices spend the majority of their time in standby or sleep mode and are only active at brief intervals to send or receive data. In active mode, the device may draw up to hundreds of milliamperes, and in the sleep mode, the current will draw only microamperes. Therefore, test equipment must accurately measure over a wide dynamic range and handling a 1,000,000:1 ratio between minimum and maximum current levels becomes the main battery life challenge. Additionally, when the power module is turned on and off frequently to reduce power consumption, high narrow current spikes and quick transient effects will occur. This means that the test equipment must perform fast measurements continuously to capture these single-shot and transient current waveforms.

Design and verification engineers must carefully characterize dynamic current consumption to prevent unnecessary current drain. For high-volume production test, less stringent testing is necessary if dynamic behaviors have been fully characterized. Therefore the selection of test equipment to measure current or power consumption is simpler. A low-cost digital multimeter (DMM) can measure current consumption during active mode and ensure that the current drops below a certain level during sleep mode. Data acquisition (DAQ) devices are low-cost-per-channel solutions for simultaneously testing multiple test points or DUTs in production. For example, you can measure voltage and current at multiple locations on a printed circuit assembly (PCA) or perform parallel testing on a multi-PCA panel. Other products for testing battery life, and their advantages are summarized in Table 2.
Table 2: Keysight offers a wide range of products for low-power consumption test that ranges from the DAQ or DMM for low-cost, high-volume manufacturing to the high-performance DC power analyzer and device current waveform analyzer for comprehensive design and verification tests.

<table>
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<tr>
<th>Low cost per channel</th>
<th>Basic test</th>
<th>Essential tool</th>
<th>High performance</th>
<th>Wide bandwidth</th>
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<tbody>
<tr>
<td>LXI DAQ and shunt resistor</td>
<td>6½ and 7½ digit DMM</td>
<td>InfiniiVision oscilloscope</td>
<td>DC power analyzer and SMU modules</td>
<td>Device current waveform analyzer</td>
</tr>
</tbody>
</table>

- Ideal for multi-point, multi-DUT parallel testing for high-volume production test
- Low-cost per channel solution
- Easy setup with built-in AC/DC current channels (34901A module)
- Flexible and simple production test or basic R&D applications
- 1 μA to 10 A (multiple ranges)
- Low-cost IoT manufacturing tests
- Essential tool for design or manufacturing
- Debug the performance of device down to circuit level
- Ideal to analyze fast changing signals
- Limited dynamic range (> 1 mA)
- N2820A high-sensitive current probe for 50 μA to 5 A measurements
- Design for battery drain analysis and device power consumption test
- High accuracy, wide dynamic range with seamless range transition (nA to A)
- Long term gap-free data logging
- 30 kHz bandwidth
- Act as voltage/current source or electronic load
- Designed for low-power IoT chip design or verification
- High accuracy
- Wide dynamic range (>100 pA)
- Wide 200 MHz bandwidth — ideal for transient current response or spikes

**Keysight CX3300 Series device current waveform analyzer**

The Keysight CX3300 Series device current waveform analyzer is ideal for low-power IoT, chipset, or device measurements. It can perform low-current measurements down to 100 pA to analyze sleep mode abnormalities, and its maximum bandwidth of 200 MHz can capture sharp current spikes.

**Key specifications:**
- Two or four analog channels for current sensors and passive probe interface adapters
- Bandwidth options: 50, 100, and 200 MHz
- 14- or 16-bit wide dynamic range for analog channels
- 1 GSa/s sampling rate
- 100 pA to 10 A current measurement range
- 10 pW to 400 W power measurement range
- Current sensors: CX1101A (basic), CX1102A (wide dynamic range of 100 dB) and CX1103A (low noise floor and 200 MHz wide bandwidth)
Figure 2. The Keysight CX3300 Series offers complete current waveform characterization for power consumption optimization. It captures the periodic low-level current waveforms and sharp current spikes that cannot be captured by other test solutions.

Figure 3. The Keysight CX3300 Series captures a current spike in deep sleep mode for low-power MCU evaluation.
Keysight N6705B DC power analyzer and N6781A/N6785A source measure unit

The Keysight N6705B DC power analyzer and the N6781A/N6785A source measure unit (SMU) perform wide dynamic range current measurements using their patented seamless current ranging feature and gapless measurement sweep and let you visualize current drain from nA to A in one pass (see Figure 4). This enables you to easily measure the deep sleep mode, wake up mode, active mode, pulse transmission, and the return to sleep mode in the same measurement sweep.

This solution also offers glitch-free sourcing when powering dynamic loads and enables battery emulation to simulate the voltage and current waveforms of a real battery.

Key specifications:
- Mainframe holds up to 4 DC power modules
- 36 different modules available (up to 500 W, 60 V, 50 A)
- Built-in arbitrary waveform generator, DVM, ammeter, data logger, and scope-like display
- Digitizing V and I measurements up to 200 kSa/s
- Sub-μA to 3 A for N6781A
- Sub-μA to 8 A for N6785A

Figure 4. The Keysight N6781A SMU offers seamless ranging that enables current measurements for different operating modes from sub-μA to 3 A.

Keysight InfiniiVision oscilloscope

The oscilloscope is an essential tool for design and verification engineers. It supports a broad range of power and non-power measurements with wide bandwidth. It can measure fast changing waveforms of up to GHz bandwidth. Together with a current probe, an oscilloscope can analyze and debug device performance down to the sub-circuit level. However, the oscilloscope’s drift and limited sensitivity mean that it cannot measure the sleep mode current of low-power IoT devices.

The Keysight InfiniiVision 3000, 4000, or 6000 X-Series oscilloscopes with the N2820A high-sensitivity current probe support current measurement down to 50 μA. The N2820A interface uses a make-before-break (MBB) connector, allowing you to quickly probe multiple locations on your DUT without having to solder or unsolder the leads. The MBB header may be mounted on your board. It fits into standard 0.1” spacing for 0.025” square pins (see Figure 6).
Figure 5. The InfiniiVision 3000 or 4000 X-Series oscilloscope and the N2820A current probe provides simultaneous low- and high-gain views for wide dynamic range measurements from 50 μA to 5 A.

Figure 6. Low current probing using Keysight’s ultra-sensitive N2820A current probe with the supplied MBB connector.
Truevolt digital multimeter

The DMM is the go-to current and voltage measurement tool for most engineers and technicians. However, most DMMs lack the dynamic range to measure current from the sleep mode to the full operating mode in low-power IoT devices. The Keysight 34465A/34470A Truevolt DMM features a 1-μA DC current range, which allows picoampere resolution with better than 100-pA accuracy to accurately measure sleep mode current. It also has a 10-A measurement range for current measurements during full operating mode.

The burden voltage created when current flows through the DMM’s shunt resistor is normally not a concern except for very sensitive components.

Another DMM feature to consider is autoranging, which may be slow due to the range changing needed to capture a wide range of dynamic current waveforms. For dynamic current measurements, multiple sweeps with different ranges will be required to capture both sleep mode current and full operating mode current.

Figure 7. Current measurements of the operating mode with the 34465A Truevolt DMM.
Wireless connectivity

Many wireless standards and technologies have emerged to support a wide variety of IoT applications. These range from simple wearable devices connected to a cell phone via Bluetooth, to mission-critical services that require constant, reliable, and secure connections. Wearable and smart home applications centered on the smartphone often use Bluetooth, ZigBee, Z-Wave, and Thread, which offer robust and low-power mesh networks for home automation and smart energy devices. NFC is a very short range system commonly used for mobile payments, ticketing, and access control.

As more wireless technologies arise, smart consumer electronic devices must support multiple standards to ensure interoperability. With many wireless technologies using the same unlicensed spectrum, co-channel and adjacent-channel interferences are likely. This presents challenges to designers as the design and test of devices becomes more complex, time consuming, and expensive. It is important to choose a test solution that enables fast measurements for all necessary wireless standards and supports emerging standards.

No single solution will cover all testing needs throughout the product life cycle. However, Keysight offers a wide range of wireless test solutions, from cost-effective basic frequency and RF power tests to high-performance signal generators and signal analyzers for comprehensive frequency domain, time domain, and modulation analysis. Keysight wireless connectivity solutions cover all your testing needs from design verification, high-volume manufacturing to low-cost production test.
### Table 3. Keysight offers a wide range of products for wireless connectivity testing to address specific application needs

<table>
<thead>
<tr>
<th>Low-cost frequency and power test</th>
<th>Basic RF test</th>
<th>High-volume manufacturing test</th>
<th>High-performance design and verification test</th>
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<tbody>
<tr>
<td>U2001A USB power sensor and 53210A frequency counter</td>
<td>N9310A signal generator with IQ inputs from 33622A function generator and N9320B/N9322C BSA/N9000A CXA</td>
<td>E6640A EXM wireless test set</td>
<td>X-Series signal generators and signal analyzers</td>
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#### X-Series signal generators and signal analyzers

During the design phase, designers prefer a flexible benchtop solution with built-in display and front-panel buttons to easily configure and view measurements. You can use the Keysight X-Series signal generators (MXG, EXG, and PXG) and Signal Studio software to create a broad range of custom and standard-compliant test signals for IoT, including IEEE802.11 variants, Bluetooth, ZigBee, Wi-Sun, and other formats. The benchtop X-Series signal analyzers (CXA, EXA, MXA, PXA, and UXA) offer comprehensive functionalities for signal analysis and troubleshooting. When used with the X-Series measurement applications, they enable one-button testing of various wireless formats, providing standard-compliant measurements of EVM, adjacent channel power (ACPR), spectrum emission mask (SEM), and more. The 89600 VSA software is also compatible with the X-Series signal analyzers (and many other Keysight platforms) for digital demodulation analysis and vector signal analysis of more than 75 signal formats, spanning from the simple BPSK to the complex 4096QAM signals.
E6650A EXM wireless test set
The Keysight E6640A EXM wireless test set offers the broadest multi-format coverage for high-speed and cost-effective tests. It also offers the ultimate in scalability and port density in order to support parallel testing of multiple devices and achieve the highest throughput and yield in the production line. The EXM is a future-proof platform that can adapt to meet new wireless standards or new measurement needs.

N9310 signal generator, N9320B/N9322C basic signal analyzer, and N9000A CXA
The Keysight N9310A signal generator with the IQ inputs from a 33622A waveform generator supports the generation of various analog and digital stimuli for consumer devices. The N9320B/N9322C basic signal analyzer (BSA) enables time domain analysis, spectrum characterization, and demodulation of the ASK and FSK formats. The N9000A CXA, together with X-Series measurement applications, can analyze complex modulation formats such as O-QPSK, Bluetooth, ZigBee, and Z-wave.

U2001A USB power sensor and frequency counter
The Keysight U2001A USB power sensor and 553xx frequency counter enable simple RF output power and frequency accuracy test for low-cost manufacturing such as wearable devices.
Signal integrity and power integrity analysis

With the increased demand for expanded functionalities in a small form factor, there is a need for higher density, higher speed, lower power, and compact circuit design. Signal integrity and power integrity issues are becoming more common as traces become closer and supply voltage is lowered.

Signal integrity is a measure of the electrical performance of the wires or packaging structures used to move signals within an electronic device. In today’s high-speed digital designs, common signal integrity issues include reflections, excessive losses, crosstalk, distortion, and power supply noise that can degrade overall system performance. Techniques using time-domain reflection (TDR) and time-domain transmission (TDT) in both simulations and measurements can help designers troubleshoot and improve signal integrity issues with high confidence.

Power integrity analyzes how effectively power is converted and delivered from the power source to the load within the system. The power is delivered through a power distribution network (PDN). With the drive toward low-power electronics, DC supply voltages and tolerances have been reduced, some from ±5% to ±1%. Ripples, noise, and transients riding on the output power rails can adversely impact the clock and digital data accuracy. Therefore, designers need a power integrity solution that can measure these low DC voltages with high accuracy.

Power integrity solution

The Keysight Infiniium S-Series 10-bit ADC oscilloscope and probes, including the N7020A power rail probe and the N2820A high-sensitivity current probe, provide the best visibility to your power integrity issues.

- The N7020A power rail probe allows you to see the true AC power noise riding on your DC power line and supports up to ±24 V offset.
- The N2820A high-sensitivity current probe supports current measurements down to 50 μA.

The combination of oscilloscope and probes is the ideal power integrity analysis solution for low-power consumer electronics devices and IoT sensors that are generally battery-powered and compact.

Signal integrity solution

Keysight E5071C ENA Option TDR is a software application embedded in the ENA network analyzer that is ideal for signal integrity analysis. It offers real-time measurements simultaneously in time domain (TDR/TDT) and frequency domain (S-parameter), and it provides eye diagram tests without needing an external bit pattern generator.
Figure 8. Keysight E5071C ENA Option TDR provides a one-box solution for high-speed interconnect analysis, including impedance, S-parameter, and eye diagram.
EMI/EMC compliance and wireless conformance test

EMI and EMC compliance test
Meeting electromagnetic interference (EMI) compliance regulations is a critical step in bringing products to market quickly. Failure at the last stage of design will result in expensive re-design and delay product time-to-market. The ability to perform some similar tests before the actual compliance test is very useful to detect potential problems at an early stage. It also helps to save cost to repeat the compliance test after failure. Wherever you are in the product development cycle, Keysight has an EMI measurement solution for you.

Pre-compliance measurements
To avoid costly delays that can result from failed compliance testing, Keysight’s EMI measurement application on X-Series signal analyzers allows you to perform pre-compliance measurements and diagnostic evaluation of your designs. Find and fix problems before they enter the test chamber with the N6141A measurement application on the N9030A PXA, N9020A MXA, or N9010A EXA, or W6141A on the N9000A CXA for a low-cost pre-compliance test solution.

EMC compliance testing
In EMC compliance testing, your success depends on moving products through the test queue quickly and efficiently. Conduct full standards-compliant testing 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 for you to combine the MXE with chambers, antennas, software, value-added integration, probes, and more.

Keysight offers design, simulation and test capability for all of your EMC/EMI design and test needs. After designing your device, you can utilize Keysight test equipment to verify your designs. Keysight products include X-Series signal analyzers, MXE EMI receiver, network analyzers, signal sources, oscilloscopes and more, all for your test requirements.

EMI/EMC simulations
Early in the development cycle, Keysight EMPro software allows engineers to simulate the radiated emissions of electronic circuits and components and then determine whether these emissions are within levels specified by common electromagnetic compatibility (EMC) standards, such as FCC Part 15, CISPR 22 and MIL-STD-461F and ensure that their designs are compliant, even before hardware is developed.

Wireless conformance test
Conformance testing is mandatory for all wireless products including consumer electronics devices. Consumer electronics companies have to confirm that the products comply with supported wireless standards.

Keysight, with more than 75 years of test and measurements experience in wireless communication systems, offers you a wide range of conformance systems that can help you to reliably cover your conformance test requirements in NFC, Bluetooth, and LTE-LTE-A enabled devices.
T3111S NFC conformance test system

The T3111S NFC conformance test system is the Keysight solution for RF analog and digital protocol testing of NFC, EMV, and ISO devices.

Figure 9. NFC test system foundation

1. EMV Analog RF configurations provided by Keysight’s partner, FIME. EMV is a registered trademark in the U.S. and other countries and an unregistered trademark elsewhere. The EMV trademark is owned by EMVCo.
T1111S and T1212S BITE Bluetooth® RF conformance tester

T1111S BITE Bluetooth® RF conformance tester is a modular test system that performs automatically the conformance test cases for Bluetooth® Basic Rate, EDR, enhanced power control and Bluetooth® low energy requirements. The T1111S is officially validated by the Bluetooth® SIG for RF qualification of Bluetooth® devices for all the technologies supported.

T1212S BITE Bluetooth® protocol conformance tester offers complementary protocol conformance test coverage. The system is officially validated by Bluetooth® SIG up to version 4.0 of the standard.

T4010S conformance test system

Keysight T4010S conformance test system is the most efficient test tool available on the market today. The test platform covers conformance testing according to 3GPP TS 36.521-1 LTE RF and 3GPP TS 36.521-3 LTE RRM for FDD and TDD, 1CC, 2CC, and 3CC, as well as LTE device acceptance test plans from major network operators. LTE Advanced features, such as Release 10, 11 and 12 carrier aggregation are also available on the T4010S. Engineers can use the T4010S system for R&D design verification with the same hardware that is used for conformance testing. T4010S offers the ability to execute test cases with different parameters other than those required by 3GPP. This platform also allows testing for all LTE frequency bands at no additional cost.

The T4010S is built around the Keysight Technologies, Inc. E7515A UXM wireless test set, extending the UXM functionality to pre-conformance and conformance testing.

Figure 10. Keysight EMI/EMC compliance and wireless conformance test solutions.
Summary

IoT presents many design and test challenges to consumer electronics designers or manufacturers. Battery life is a critical specification for many IoT devices. Complete characterization of the current consumption patterns during the different operating modes are crucial to optimize and guarantee the battery life of the device. Radio or transceiver design also needs to be fully tested for various supported wireless formats to ensure interoperability and prevent interference issues. Signal integrity and power integrity issues are becoming more common due to the compact circuit design with closer components or traces and lower DC supply voltages and tolerances. Potential issues for EMI or EMC should be detected at early stage of design phase to avoid costly re-test and delay time-to-market. All these design and test challenges can be minimized with the right test solutions.

Keysight offers a wide range of test solutions to address many of these consumer electronics test challenges. With continuous innovation and investment in developing new technologies and Keysight participation in industry-standard bodies, you can be assured that Keysight test solutions are able to keep up with the emerging technologies via upgrade or retrofits.

For more information on power consumption test solutions, visit:
  - LXI data acquisition unit: www.keysight.com/find/34972a
  - TrueVolt DMM: www.keysight.com/find/truevolt
  - N2820A high sensitivity current probe: www.keysight.com/find/n2820a
  - InfiniiVision oscilloscope: www.keysight.com/find/infiniivision
  - DC power analyzer: www.keysight.com/find/dcpoweranalyzer
  - Device current waveform analyzer: www.keysight.com/find/cx3300

For more information on wireless test solutions, visit:
  - Internet of Things: www.keysight.com/find/iot

For more information on signal and power integrity solutions, visit:
  - Signal integrity analysis: www.keysight.com/find/e5071c
  - Power integrity analysis: www.keysight.com/find/s-series

For more information on EMI compliance and wireless conformance test solutions, visit:
  - EMI/EMC tests: www.keysight.com/find/emc
  - Wireless conformance test: www.keysight.com/find/system
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