Making RF Magic

Insights to get the most out of your RF transceiver

eBook

KEYSIGHT

Wireless Is Here to Stay

As an engineer, you make RF magic happen. User experience is key and user expectations are high. So, how do you make the magic happen?

The demand for wireless data is increasing and the number of data users is growing. But the available spectrum is fixed. You're adapting by employing complex protocols and physical layers to maximize spectrum efficiency and handle the increasing number of users. Unfortunately, as an increasing number of devices become wireless, interference — an RF engineer's constant companion—becomes an increasing challenge.

Between interference of all kinds, battery-power constraints, standards compliance and varying regulatory compliance, delivering the bits of data is a full-time job. But you do it. It sometimes seems downright magical to the user.

> Any sufficiently advanced technology is indistinguishable from MAGIC.
>
> Arthur C. Clarke

RF Test Keeps it Real

So how do you know your transceiver is working properly? To verify that today's complex modulation schemes work correctly and coexist with others, you have to test. Wireless test is essential to the abundant and growing number of technologies that are keeping us connected. It's no surprise, then, that testing is complex. Testing must be accurate, reliable, efficient, consistent and repeatable in different locations, at different stages of development and at different stages in the block diagram of your transceiver. Your test set up and test algorithms matter. And finding out about issues early is critical to meeting development cost targets and hitting market windows.

Many commercial wireless physical layers are tied to a standard that specifies performance to ensure interoperability across vendors. These wireless standards are complex and evolving. It's challenging, but essential to keep current with reasonable effort. Ensuring that your test tools are built on trusted measurement IP helps you focus on engineering, so you can make the magic happen.

Wireless test is essential to the abundant and growing number of technologies that are keeping us connected.

Contents

There are many different tests an RF engineer will make in the process of transceiver development, but they fall into some general categories: RF spectrum and power, interference, modulation and power consumption, which we will discuss in more detail.

INSIGHT 1

RF Spectrum and Power

You don't want to have too much RF power or too little or have it at the wrong time because it can render your transceiver inefficient. Learn the key steps to ensure that you are making judicious use of RF power in your device.

GO TO INSIGHT 1 >

INSIGHT 2

RF Interference

Understanding interference of all kinds is critical to successfully delivering data. Make sure you are taking advantage of all the right tools to sleuth sources of interference.

GO TO INSIGHT 2 >

INSIGHT 3

Modulation

Modulation techniques are getting better at reliably delivering lots of data in the presence of interference and band crowding. Get insights on measuring and troubleshooting modulation quality.

GO TO INSIGHT 3 >

INSIGHT 4

Power Consumption

Many RF devices are portable and users always want the longest battery life possible. The challenge of optimizing power consumption, is multi-faceted. Learn the key steps to maximizing battery life in RF transceivers.

GO TO INSIGHT 4 >

INSIGHT 1

RF Spectrum and Power

Just the right amount at just the right time

RF power is critical. If you have too much, too little or have it at the wrong time then your transceiver is inefficient or ineffective or inoperable. RF power determines the distance you can transmit and has a strong effect on battery life. So, judicious use of RF power is key.

Regulatory and standards requirements set limits for the maximum amount of power you can transmit, but there is plenty of room for magic while working inside the limits.

RF Spectrum and Power

To efficiently share limited spectrum, most digitally-modulated signals are pulsed or framed in some way. In addition, power often changes within an individual burst or frame to support receiver synchronization and equalization.

Examples include preambles or training sequences, or when using time division multiplexing. So, when you make your RF power measurement matters. In addition, many RF signals in wireless systems are noise-like, so power must be averaged to some degree and measured across a band or channel.

> **When** you make your RF power measurements matters.

Figure 1.1. A TDMA format signal (in this case, GSM) with 8 time slots; time slot zero is "Off."

Figure 1.2. Time gating is used to look at the spectrum of the GSM time slot 3.

With the complex structure of the signals, it is no surprise that RF power measurements are highly specific to the wireless standard. Standards may define an RF power measurement in a specific way, possibly for carrier groups, modulation types or triggered on a training sequence. In some RF power measurements, it is important that time gates be aligned with specific symbols in the preamble or symbols in the data portion of a frame. Gated spectrum measurements are important here because the gate markers can select only the desired portion of the frame for analysis and exclude the rest. Likewise, band-power markers can isolate signals in the frequency domain, typically the power of a single signal among others, a portion of a signal or the power in a specific frequency band. In terms of both frequency span and measurement method, it can be very complex and increasingly challenging to set up manually.

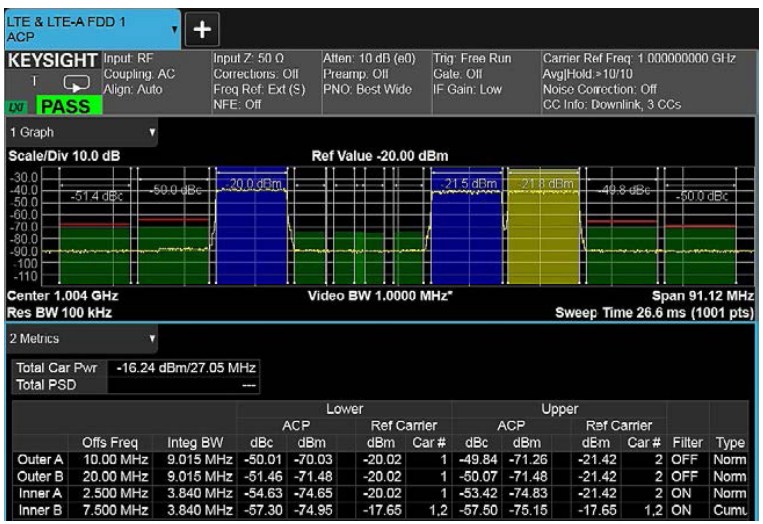


Figure 1.3. ACPR/ACLR measurements on modern wireless systems may be complex to set up when the configuration includes cumulative ACLR due to the use of non-contiguous carrier aggregation.

Using a standard-compliant measurement application is a reliable and consistent way to conform to a standard or convention and make sure you are getting the job done.

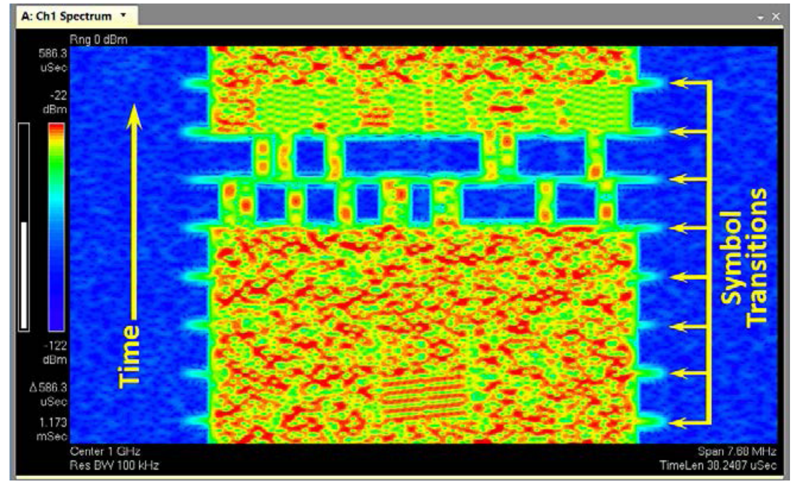


Figure 1.4. Spectrogram of an LTE signal, produced from post-processing a gap-free signal capture with overlap. The spectral spreading at the transitions between symbols allows symbol timing and subcarrier changes to be seen without demodulation.

Despite the complexity, we are ultimately still working with RF signals. A tried and true power meter might be the first tool you use to see if individual signals inside your system, such as the LO, are correct. A signal analyzer is where you'll go next for making a combination of fundamental RF power measurements such as distortion measurements and channel power, in addition to the more complex, standards-specific RF power measurements. Signal analyzers are also useful as you make measurements on very small signals in the presence of other signals in your RF system. A number of factors can create this type of situation. You might be trying to make a measurement on your signal in the presence of interference or noise. A common example is to measure one channel among many. By tuning out other signals and broadband noise, a signal analyzer allows you to see signals closer to the noise floor. Any time you are trying to measure a signal smaller than others in the same frequency range, you need a signal analyzer.

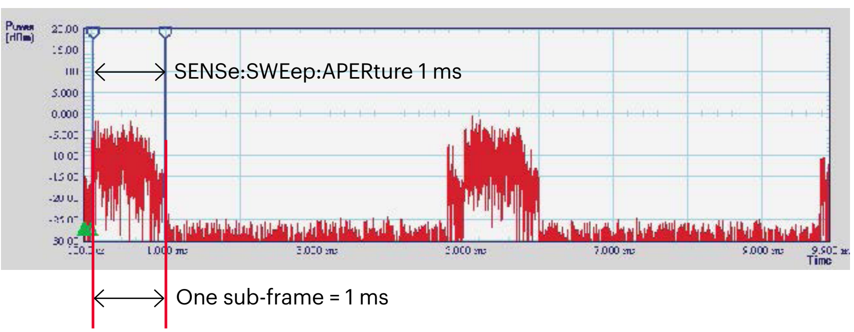


Figure 1.5. Many power meters can measure power versus time, with selectable timing parameters. This is a measurement of one sub-frame of an LTE signal, using a burst average power setting.

Key steps to making the right RF power measurements

1. Start with a power meter for maximum accuracy, excellent frequency range and source match. Use interchangeable power sensors which allow power meters to have exceptionally broad frequency coverage while maintaining good impedance match that contributes to measurement accuracy. Choose a power meter and power sensor combination with peak-power capability to measure the behavior of time-varying signals, dynamic elements, thermal phenomena or power-supply-related effects.

2. Use a signal analyzer for frequency-selective measurements. Start with fundamental RF measurements such as distortion measurements and channel power. Move to standards-specific RF power measurements for gated spectrum and band-power measurements. Choose a signal analyzer that offers built-in capability for these measurements, either a general RF-power application or a standard-specific one.

In addition, transient effects and drift can be a problem with pulsed signals and are often seen in high-frequency RF and microwave systems, where physical device geometries are small and, consequently, thermal time constants are short. Transient effects are also significant for systems using digital predistortion techniques. In those cases, vector, demodulation, and signal recording/playback tools can be helpful.

Want to Learn More?

- **App Note:** *Transmitter Test: Overcoming Five Fundamental Challenges*
- **App Note:** *Receiver Test: Overcoming Five Fundamental Challenges*
- **Blog Post:** *Sneaky Little RF Power Errors*

INSIGHT 2

RF Interference

Interference is everywhere

Interference is a constant companion for today's wireless transceivers. Reliably delivering data keeps users smiling; understanding interference of all kinds is critical to delivering data.

RF Interference

Interference is unavoidable. Especially in unlicensed spectrum, such as industrial, scientific and medical (ISM) bands, you will encounter interference. With multiple radios in one device, the possibilities of self-interference are a notable concern. Your job as an engineer is to develop a transceiver that is robust and resilient in the face of this universal foe. To do this, you need to understand interference and deal with it. That might mean finding interference and remedying it. Or it might mean choosing a modulation scheme and associated protocol that tolerates the most common types of interference you will encounter.

Due to the ubiquity of interference, many approaches have been devised to enable RF transceivers to be robust and resilient to various types of interference. Retransmission channel-switching and collision avoidance are examples of techniques that support data throughput when interference disrupts transmission. OFDM and frequency hopping spread spectrum are examples of modulation schemes designed to function well in a noisy spectral environment because they have good resistance to narrowband interference. Magic tricks, such as these, to manage interference are essential to the RF engineer's toolkit.

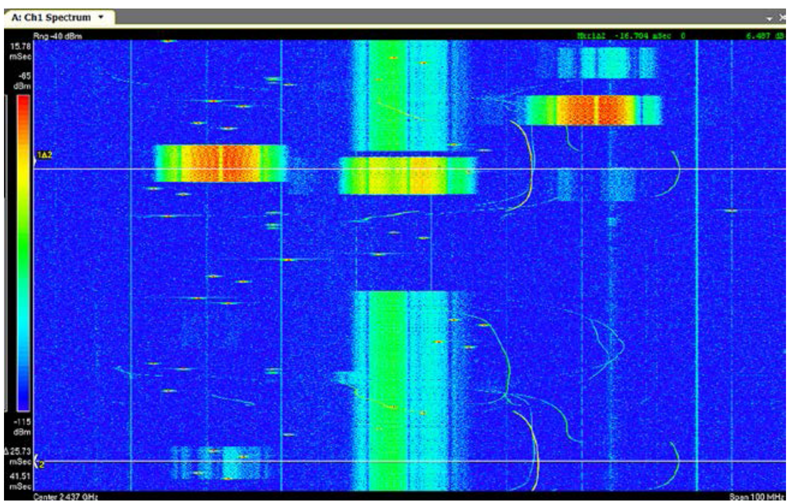


Figure 2.1. This spectrogram display provides an overview of signals and behavior in the 2.45 GHz ISM band over an interval of about 26 ms. The highly-overlapped real time measurement produces a detailed view of WLAN bursts, *Bluetooth®* hops and microwave oven leakage.

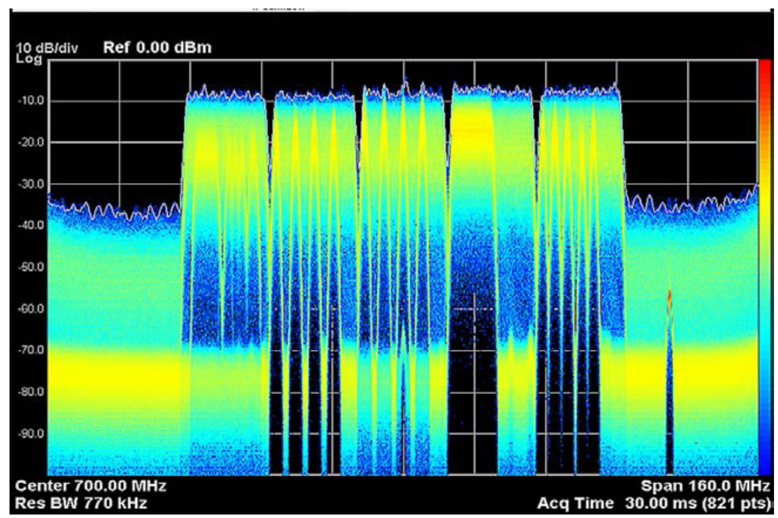


Figure 2.2. A real-time spectrum measurement of this five-carrier LTE-Advanced signal reveals both in-band and out-of-band interference.

To keep the data flowing, you will need to understand both your transmitter's resistance to interference and your receiver's response to it. Generating interfering signals is a key aspect of developing transceivers that operate well in real-world situations. You will want to consider both continuous and time-varying interference to ensure that you are producing a robust transceiver.

Sleuthing how different types of interference will impact you requires a full complement of tools. You need a comprehensive view of the interference — and your transceiver's performance — so you don't encounter surprises and end up with disappointed users. Some types of interference are elusive or intermittent. In those cases, utilizing a spectrogram display, fast sweeps, real-time spectrum analysis (RTSA) and record / playback functionality are extremely insightful.

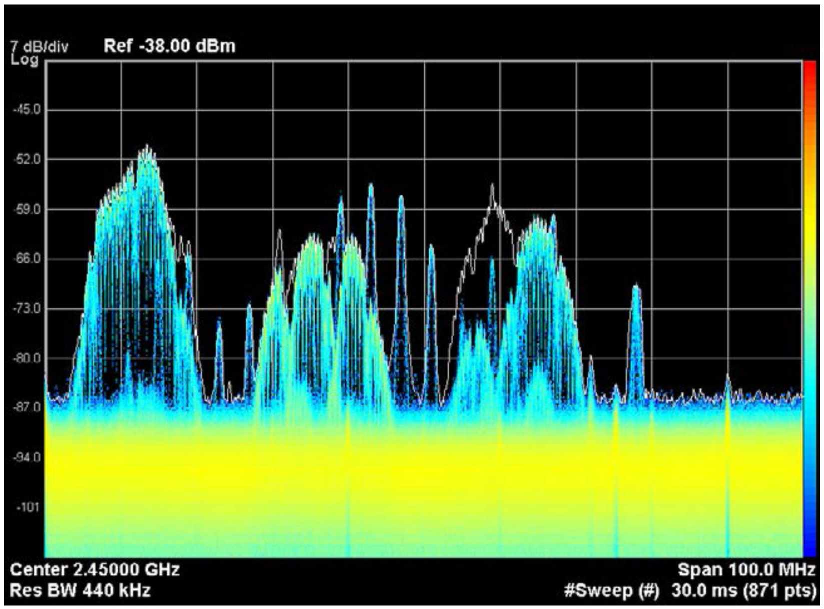


Figure 2.3. With a similar setup to the swept spectrum analysis approach the real-time density display quickly reveals detail about the spectral occupancy of this band.

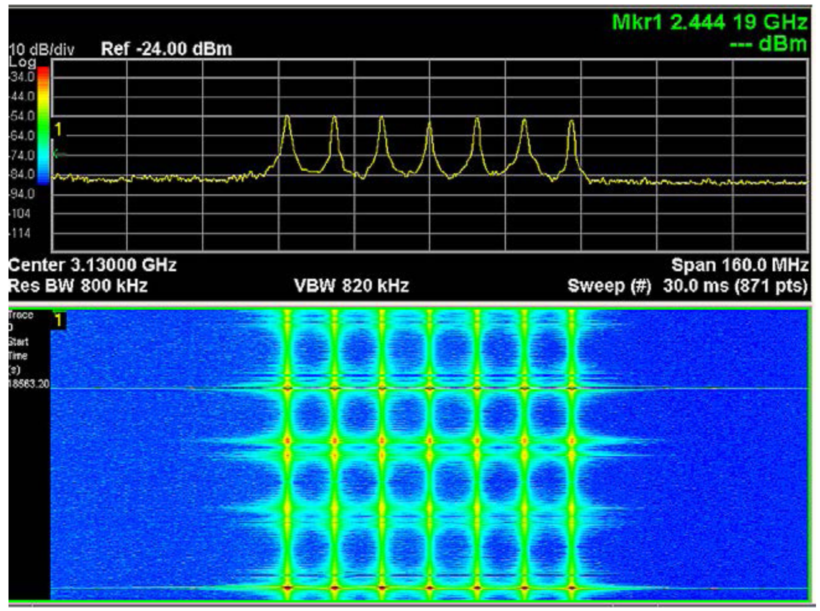


Figure 2.4. The spectrogram view of real-time data displays time information instead of density, providing a clear indication of signal behavior over time.

Key steps to sleuthing interference

1. Generate realistic signals with complex modulation and complex protocols — both standard-compliant signals and interfering signals. An RF signal generator can substitute for oscillators and synthesizers, and it can produce a variety of CW and modulated interference and blocking signals. Choose a signal generator with standard-compliant signal creation, built-in vector arbitrary waveform generators, deep memory, and wide modulation bandwidth.

2. Analyze interfering signals — both your own, internally-generated interference and interference from outside your DUT. Improve your probability of discovering the interfering signals by choosing a signal analyzer with fast sweeps, spectrogram display and RTSA. If your signal analyzer is upgradeable, you can add functionality when you need it.

3. Utilize signal recording/playback. Signal measurements can be made on a continuously-updated basis or they can be made in a post-processing mode on gap-free recorded data from a time capture operation. One advantage of capture and post-processing is the ability to re-analyze the signal using different measurements including vector and demodulation, and to re-measure the captured data using different center frequencies and spans without rerecording.

Bring the data you gather together with your own system knowledge to get a more complete picture of the interference your DUT will need to withstand.

Want to Learn More?

- **Blog Post:** *RF Interference Will Hobble Us Before the Spectrum Apocalypse Arrives*
- **App Note:** *Transmitter Test: Overcoming Five Fundamental Challenges*

EMI pre-compliance: test early and test often

One specific type of interference, electromagnetic interference (EMI), is a category unto itself. The best practice is to understand EMI early so that you have a clear picture of what is going on while you are troubleshooting and optimizing. Frequent testing maximizes the chance you'll discover a wide variety of possible issues, and test tools today allow you to make EMI pre-compliance tests earlier and better. Electromagnetic compatibility (EMC) certification is a part of your process, but the results of certification testing should never be a surprise.

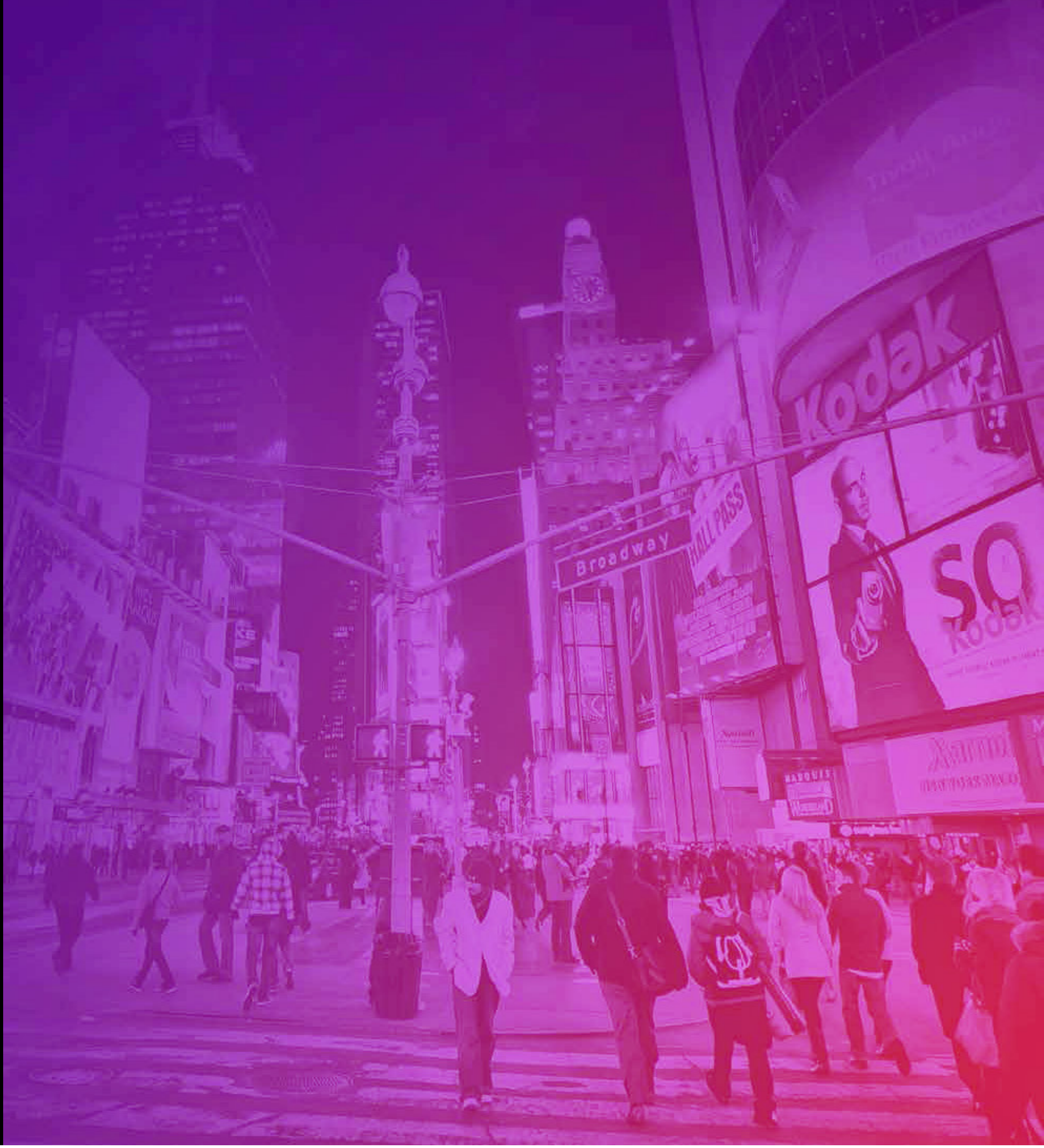
Figure 2.5. When making EMI measurements, you often want to scan and search for signals above the limit.

INSIGHT 3

Modulation

More data, delivered faster

In a connected world, the name of the game is: more data, delivered faster. There is a constant need for increased channel capacity to supply an increasing number of data-hungry users with the content they demand. And a lot of magic is happening in this space. In some cases, you can move to higher frequencies where contiguous spectrum is more readily available. But in most cases, you have to do more with the spectrum you have available. Modulation techniques are getting better at reliably delivering lots of data in the presence of interference and band crowding. Denser constellations, closer carrier spacing, more complex modulation or multiplexing schemes and capacity enhancements (such as MIMO) are some of the increasingly pervasive — and creative — ways we are doing more with a fixed set of channels. Orthogonal frequency division multiple access (OFDMA) is an example of a technique that's compatible with all these elements and is becoming increasingly pervasive in 802.11 WLAN and cellular communication standards.



Modulation

Increased data throughput is an important benefit of sophisticated modulation schemes. But it's not the only one. Moving more data in each transmission burst has implications for power consumption and spectrum efficiency as well. Ultimately, the more data you can send in one burst, the less time your transmitter needs to be active. This means you spend less time occupying the channel and draining the battery.

The advantages of more complex modulation schemes are clear; the tradeoffs extend into design considerations and optimization. It takes some mathematics and a capable processor to make this magic happen. Thankfully, modern processors are sufficiently compact, powerful and power-efficient to enable enormous processing in handheld devices.

Modulation quality is a key metric of a transceiver; it characterizes how well the transceiver can be understood and can understand. As modulation schemes are getting more dense and complex, it is no surprise that assessing the modulation quality of your device is also getting more complex. Many modulation quality measurements are now also time-specific, potentially requiring measurement only during specific times, such as only during data transmission or perhaps a training sequence. Understanding the modulation quality measurements required by the wireless standard you are implementing is crucial. But set up of those measurements is often nontrivial. In many cases, the wireless standards have gotten to a level of complexity where reliable, manual set-up of these modulation quality measurements is cumbersome or even unrealistic. Measurement applications that are preconfigured and validated for these measurements are a huge asset.

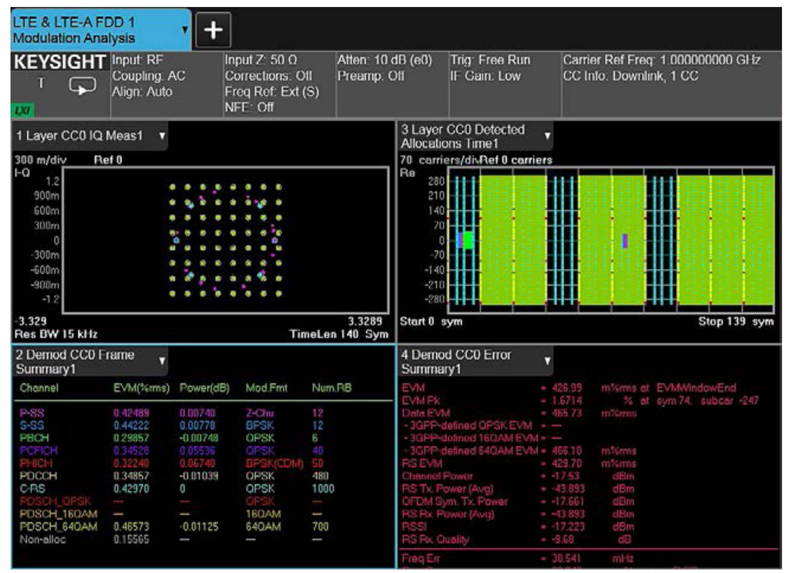


Figure 3.1. Measurement applications provide composite and multi-measurement displays for a more complete understanding of signal quality and behavior. This LTE measurement screen includes the constellation, detected allocations, a frame summary and an overall error summary. For optimization and troubleshooting, measurements are color-coded based on channel type.

With all multi-carrier modulation types, error vector spectrum and error vector time measurements are valuable and complimentary. Marker coupling is a powerful feature for troubleshooting and is often overlooked. A common way to use marker coupling is to identify a signal with an unusual amount of error, place a marker on it, and couple markers in other measurement traces to it. This way, error peaks can be linked to constellation points, amplitude values, specific subcarriers or particular symbol times.

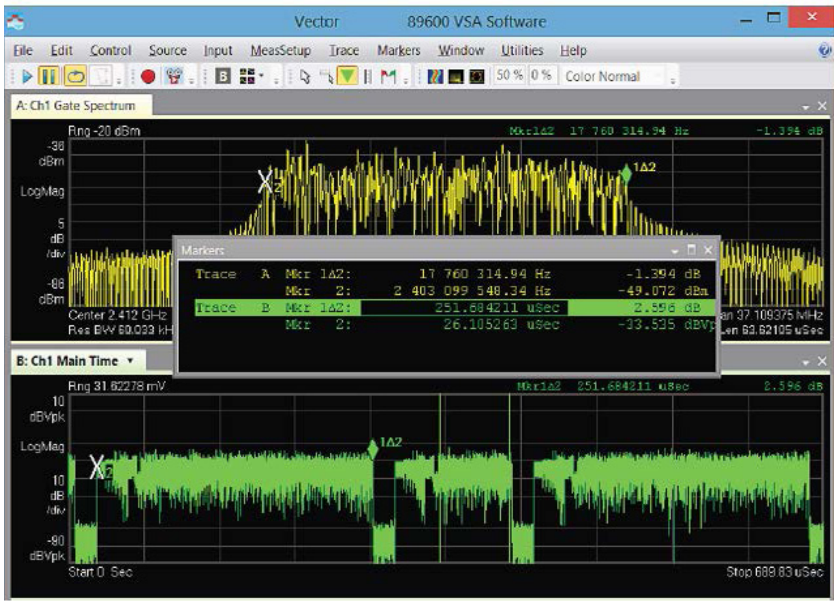
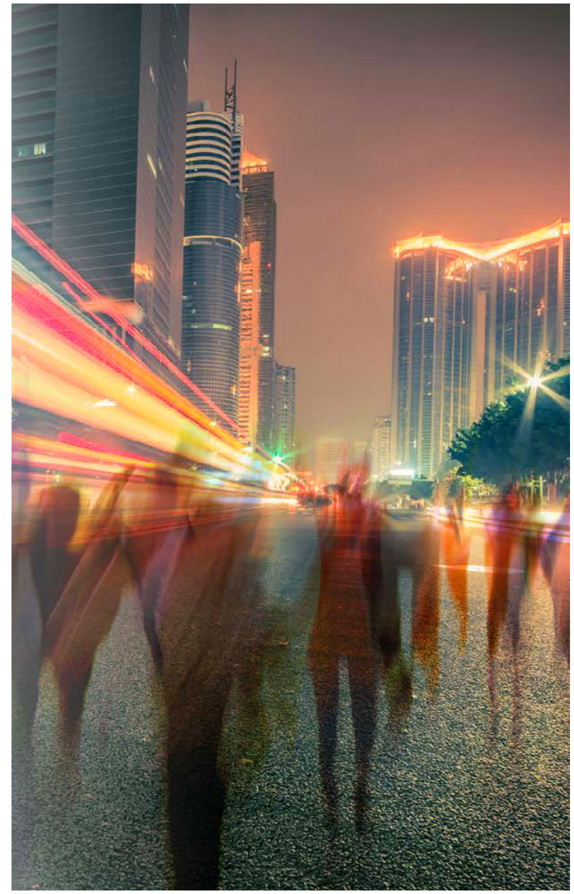


Figure 3.2. A combined frequency and time domain measurement display from the Keysight 89600 VSA software with markers for bandwidth and burst length. The lower trace is the signal's log-scaled magnitude, or RF envelope, with vertical gate markers to select the portion of the time record used to calculate the spectrum in the upper trace. The time domain trace also shows that the frame being measured is shorter than the others.



Modulation quality is a key metric; it characterizes how well the transceiver can be understood and can understand.

Key steps to modulation quality

1. Get the basics right by starting with frequency and time measurements. Most signal analyzers will not reliably demodulate signals that have an incorrect symbol rate or bandwidth, have major frequency errors, have poor signal-tonoise ratio, or have improper framing/timing. As tempting as it sometimes is to jump straight to the modulation quality measurements, it is important to begin with spectrum and RF envelope analysis. Verify signal center frequency, bandwidth and signal-to-noise ratio, along with any other time- and frequency-domain parameters for your wireless standard.
2. Basic digital modulation analysis allows you to see the modulation quality of your component or system and confirm that you are meeting the standard. The most commonly used displays in basic digital demodulation are: constellation diagrams, a table summarizing modulation quality, a list of transmitted symbols, and one or more traces indicating modulation error. This information can be combined with your own knowledge of your system to point more clearly to error mechanisms or potential causes.
3. Advanced digital modulation analysis is an essential aspect of troubleshooting. In many cases, these advanced techniques are aimed at focusing analysis on specific portions of signals or aspects of them, and linking different measurement results to determine the cause of problems. For example, focusing on specific carriers, or groups of carriers, can isolate frequency specific problems at the band edge and facilitate comparison of the pilot carriers to data carriers. Symbol-specific analysis helps isolate possible errors with intentional changes in modulation types between symbols and impulsive, intermittent or periodic error sources. Other culprits could be RF on/off switching, power supply, settling or thermal effects.

Digital demodulation/modulation analysis depends on algorithms, and different algorithms may produce different results on impaired signals. Using consistent algorithms throughout the product development process can reduce aggravation and prevent lost time.

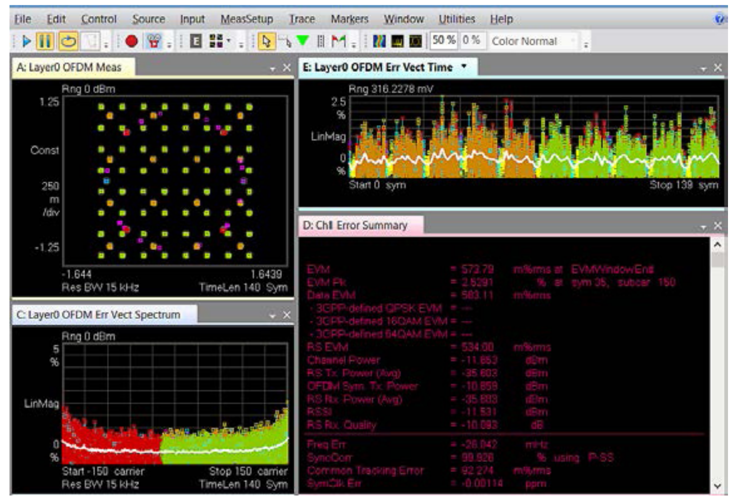


Figure 3.3. A typical 4-trace display of basic demodulation results includes a constellation diagram, a table summarizing errors and traces plotting errors versus time and/or frequency. This constellation diagram is a composite that layers multiple symbols, subcarriers, and modulation type.

Want to Learn More?

App Note: *Transmitter Test: Overcoming Five Fundamental Challenges*

App Note: *Successful Analysis of Modulated Signals in Three Steps*

INSIGHT 4

Power Consumption

The longest battery life you can get

Many RF devices are portable — and that means battery-powered. Modern portable devices are generally powered by rechargeable batteries, but some specialized devices, such as many IoT products, may use traditional primary batteries. Users expect their devices to operate with reasonable charging intervals. The user always wants the longest battery life possible. The challenge of optimizing power consumption, efficiency and signal quality for low-power and ultra-low power devices is multifaceted. These battery, power supply, or power converter limitations create tradeoffs in the form of instantaneous and total power versus RF performance. In the fickle consumer market, these tradeoffs are important from both a functional and competitive standpoint.

INSIGHT 4

Power Consumption

Low power consumption during active operation is essential, which is already true with other battery-powered devices. However, for RF engineers, especially those designing IoT and similar devices, there are additional challenges due to the implementation of ultra-low power quiescent modes to further extend battery life. Understanding quiescent power consumption is essential to achieving long life between recharge or replacement intervals, along with managing the transitions between sleep states and active operation.

> Understanding **quiescent power consumption** is essential to achieving long life between recharge intervals.

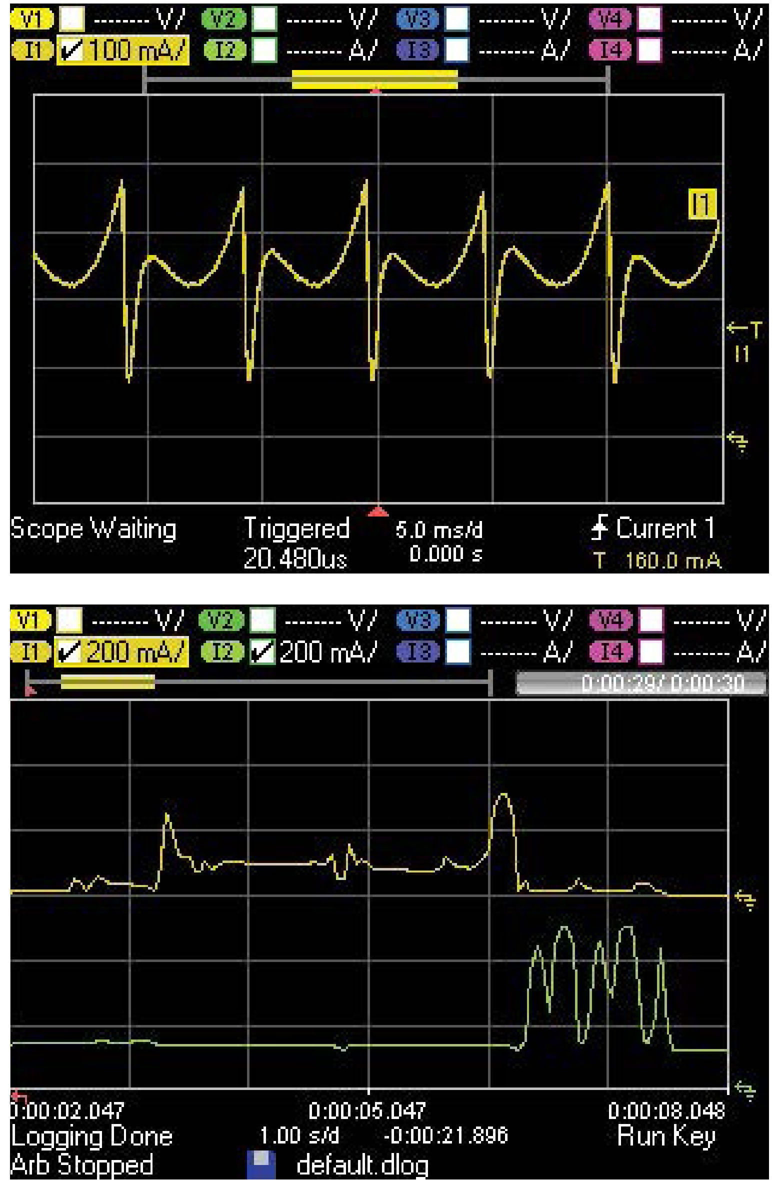


Figure 4.1. The dynamics of current consumption are shown over 30 ms in scope view (top) and over 30 seconds in data logger view (bottom). Measurements such as these provide a more complete understanding of the real-world power demands of a device or subsystem.

Understanding early on how the limitations of your battery affect your device is essential to avoid performance issues down the road—when they are much harder to correct. Power supply capacity, battery life and size are all important considerations. Late-stage discovery of subtle or transient problems can have serious consequences in real world operation. The consequences of RF issues stemming from battery power include regulatory non-compliance, poor user experience and competitive failure.

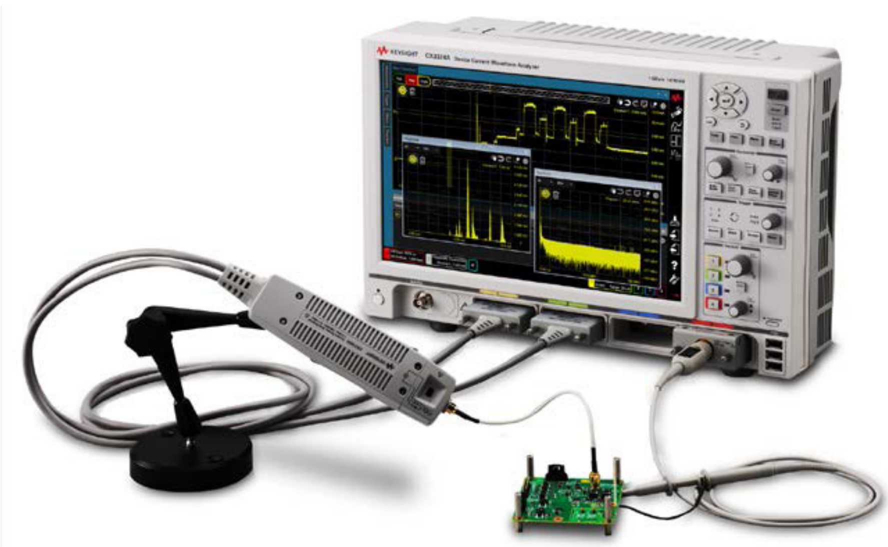


Figure 4.2. The Keysight CX3300 Series device current waveform analyzers' dedicated current sensors greatly suppress high frequency current noise without losing their low-burden current sensing capability. The dual-channel sensor enables almost 5-decade dynamic range using the simultaneous dual-range view technology.

> Late-state discovery of subtle or transient problems can have **serious consequences** in real-world operation.

Key steps to maximizing battery life

1. Choose power supplies that have the ability to match their output characteristics to the limits of real-world power sources. This helps you anticipate the behavior of your devices with the batteries they will actually be using and avoid any unanticipated issues. Use these tools to verify proper operation, track down problems and find constraints that may influence fundamental design decisions — as early as possible.
2. Make realistic measurements of power draw by using tools such as device current waveform analyzers. Pay special attention to dynamics, very low current states and current transitions.
3. Make the four main categories of measurements — frequency, timing, power, modulation quality — on your subsystems or DUTs under the worst-case conditions of realistic supplied power.

Depending on your transceiver and use case, you might additionally need to employ real-time signal analysis or signal capture and playback to isolate issues that may be transient. In many cases you can correlate across these domains by using triggers to link the power waveforms with digital signals and signal analyzer measurements.

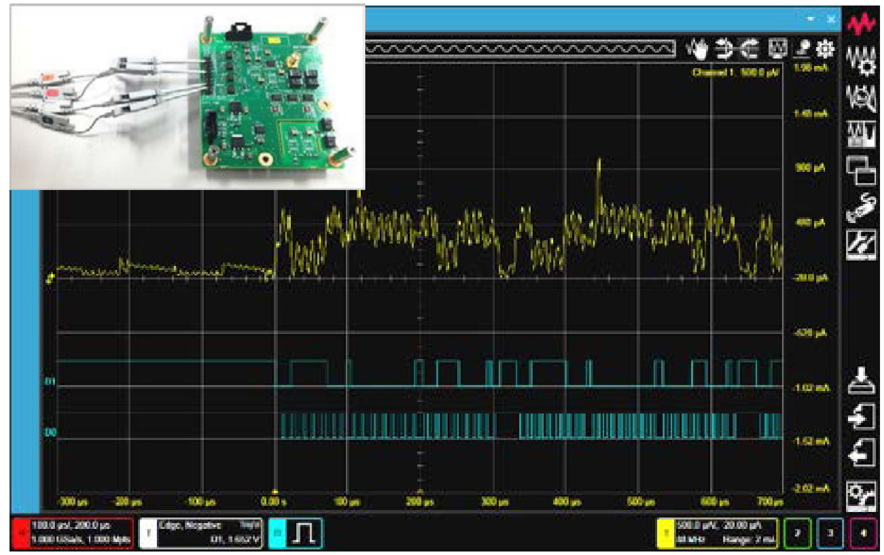


Figure 4.2. The CX3300 device current waveform analyzer has both analog and digital inputs, and the ability to align their analysis. Data bus status can be correlated with current consumption and can be used to trigger other measurements such as those of an RF signal analyzer.

Want to Learn More?

- **App Note:** *Transmitter Test: Overcoming Five Fundamental Challenges*
- **App Note:** *7 Hints for Precise Current Measurements*
- **App Note:** *Precise Current Measurements of MCU Power-Saving Mode Transition*

Progress Never Stops

The trend lines remain pointed up and to the right — more users demanding more data — but the available spectrum remains fixed. Correspondingly, wireless technology is pushing to higher frequency, wider bandwidth and more complex modulation. Techniques for using available spectrum creatively will continue to develop, such as making use of non-contiguous chunks of spectrum with techniques such as carrier aggregation. And test tools will continue to track these developments to help you make it all possible.

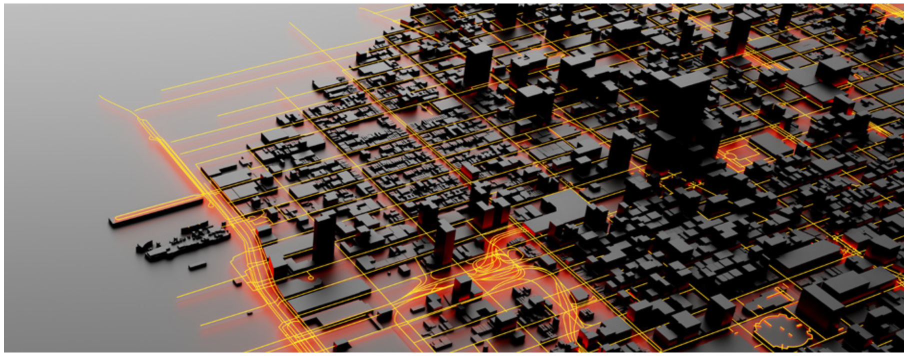
Modulation schemes, by themselves, can't solve everything. Ultimately, you still need to make more efficient use of the available spectrum. Multi-channel schemes (such as MIMO) come into play here. Fortunately, there are multi-channel signal analyzer and signal generator solutions available, and they use the same algorithms as single channel solutions so you can carry on with confidence and consistency.

Improvements in technology, including processors, signal processing and battery technology will be essential parts of the advances. And making those work for you is part of the task.

RF engineers will continue to be at the front of these curves, looking for ways to keep the magic happening.

Follow Keysight

To stay up to date with the most recent tutorials, techniques, and best practices check out the Keysight Labs YouTube channel, follow the Keysight RF Test and Measurement Facebook Page, and subscribe to our blog.



KEYSIGHT

Keysight enables innovators to push the boundaries of engineering by quickly solving design, emulation, and test challenges to create the best product experiences. Start your innovation journey at www.keysight.com.