APPLICATION NOTE

Enabling Breakthroughs in Terabit Research

From high-speed mobile access to cloud-based services, consumers and businesses have an increasing need for more data in more places in less time. These needs have no signs of abating.

While the communications industry is rolling out 100G and 400G technologies to address current needs, leading-edge researchers are looking at 800G and beyond. Because the marketplace continues to demand increasing data, the lifecycle of every successive high-speed standard is getting shorter.

In this accelerating environment, keeping pace depends on advanced measurement solutions that enable you to rapidly validate your research and boost your success rate with innovative technologies. Such solutions must deliver exceptional measurement quality that enables a deeper understanding and transformative new insights. For example, measurements must be significantly better than the in-channel signal-to-noise ratio (SNR). If not, you merely measure the test setup rather than the channel.

This application note explores new measurement capabilities that enable breakthroughs in terabit research. It presents an advanced measurement solution designed for optical research and other forms of wideband, high-speed networking and communications. This application note outlines four groundbreaking applications: coherent optical, 802.11ay WLAN, high-speed digital buses, and 5G MIMO.

KEYSIGHT TECHNOLOGIES

Challenges: Thinking Over the Horizon

In recent years, the time between generational technologies is accelerating — the transition from 100G to 400G took four years. If current trends continue, the jump from 400G to 800G may take less than three years — and terabit will be close behind. As a result, there is a growing sense of urgency in the chase to reach 800G and beyond, spurring the pursuit of breakthroughs in wideband, high-speed communication technologies.

Based on our ongoing conversations with leading researchers, we understand the desire to set new speed and capacity records that will transform applications such as long-haul, regional, metro, data center, and data center interconnect (DCI). However, breaking records means finding new ways to optimize a complex web of interactions and trade-offs between faster data rates, more complex modulation schemes including spatial modulation, the effects on SNR, the maximum reach of fiber links, NRZ versus PAM4, PAM4 versus coherent, and more.

When you're pushing the envelope, adequate measurement tools are not immediately available. Unfortunately, creating your own measurement system can take a tremendous amount of valuable research time. Connecting a downconverter and a digitizer to a PC is tempting, but issues with noise, spurious signals, dynamic range, and more, limit the performance of your measurements. In most cases, the results are neither accurate nor repeatable. These compromises serve only to undermine your confidence in critical performance measurements.

Solution: An Integrated and Calibrated Instrument

In your pursuit of breakthroughs no one has seen before, you need measuring instruments that reach higher, go faster, and deliver repeatable results. Keysight's Infiniium UXR Series oscilloscopes provide industry-best capabilities in five crucial areas:

- 110 GHz real-time bandwidth
- 256 GSa/s digitizing
- 10-bit resolution and excellent equivalent number of bits (ENOB) (6.8 bits at 13 GHz of bandwidth, 5.0 at 110 GHz of bandwidth)
- Lowest noise floor currently available (150 µV (rms) at 13 GHz of bandwidth, 860 µV (rms) at 110 GHz)
- Lowest jitter currently available with less than 25 fs (rms) of intrinsic jitter and less than 10 fs (rms) of inter-channel jitter

Legitimate 10-bit resolution above 8 GHz gives you the benefits of superior ENOB during characterization of increasingly complex modulation standards. Also, today's technologies operate at increasingly low amplitudes, making them difficult to distinguish from noise. Thus, an oscilloscope with better SNR performance means more of your signal is visible above the instrument's internal noise. In the UXR, a low jitter measurement floor minimizes instrument phase noise, which can interfere with I/Q measurements, making it difficult to distinguish the two signals. When configured with four full-bandwidth channels, the UXR provides reduced timing error when working with dual-polarization coherent modulation, measuring I/Q, and so on.

Unlike one-off measurement configurations, the UXR is an integrated instrument that provides calibrated results (Figure 1). Further, to maximize the availability of the UXR in your lab, it includes the ability to perform full self-calibration. For most high-performance instruments, the typical process requires that you return it to the manufacturer for calibration, taking it out of your lab, potentially for weeks at a time. That absence means lost time, lower productivity, and the potential for significant delays in your program schedule. The ability to calibrate the UXR in your lab eliminates these issues and keeps your team and your project moving forward. It also ensures the ongoing accuracy of crucial measurements.

Figure 1: The UXR-Series real-time oscilloscopes deliver performance beyond the extremes, bringing greater visibility, accuracy, and speed to leading-edge research

Breakthroughs: Taking Research Farther, Faster

To demonstrate the capabilities of the UXR, you will learn from four examples of measurement results that are opening the door to deeper understanding and transformative insights. Specifically, the areas of research are coherent optical transmission, wireless LAN (802.11ay), high-speed digital (with channel de-embedding), and 5G MIMO at millimeter frequencies.

Coherent optical: Achieving exceptional transmitter and receiver performance

As noted earlier, the accelerating lifecycles of transmission standards are driving the need for better measurement tools in areas such as coherent optical. Recently, a noted research team set new records for the fastest optical transmissions ever achieved — and a UXR-Series oscilloscope was a key contributor.

The measurement challenges start with the signals themselves. The carrier is infrared light (193 THz), and it is modulated within a 100 GHz bandwidth using quadrature phase-shift keying (QPSK) to convey two-bits of information per transmitted symbol. Also, the polarization of light is used to send two sets of information simultaneously. Thus, with this modulation scheme, everything happens in multiples of four.

In the real world, these signals travel tremendous distances through long transmission channels that introduce noise and distortion. This has crucial implications for the research team. First, every optical transmitter must produce signals with exceptional signal integrity. Then, at the other end of the optical fiber, every receiver must provide exceptional performance concerning noise and sensitivity.

Testing and validating such a system requires a measurement solution with three key attributes: exceptional noise performance, four synchronized measurement channels, and wide analysis bandwidth.

In this case, the researchers used a UXR oscilloscope to analyze the modulating signals by accessing and capturing all four polarizations simultaneously within the instrument's four channels of 110 GHz bandwidth. This enabled them to decipher the incoming signals, gain new insights, and design a full coherent receiver at the highest symbol rate ever documented.

802.11ay WLAN: Leveraging outstanding EVM results

For data-intensive applications, millimeter-wave (mmWave) frequency bands offer the potential for larger swaths of contiguous spectrum that enables faster data throughput. Operating in the 60 GHz band, IEEE 802.11ay is an emerging wireless LAN standard based on IEEE 802.11ad, which was the first specific-use Wi-Fi standard.

To achieve higher throughput, 802.11ay uses a technique called enhanced directional multi-gigabit (EDMG). This method uses two bonded 2.16 GHz channels to provide a total bandwidth of 4.32 GHz. For developers, the frequency and bandwidth requirements of 802.11ay present many challenges in design and test.

With the UXR-Series, engineers can gain invaluable insight into the true performance of 802.11ay designs by directly acquiring mmWave signals with a maximum sampling rate of 256GSa/s and a 10-bit analog-to-digital converter (ADC). This gives you measurement results that are superior to those acquired using down-conversion with a lower-bandwidth oscilloscope. Also, the UXR-Series can run Keysight 89600 VSA software, enabling post-processing demodulation and analysis of acquired signals.

Recently, Keysight introduced an 802.11ay testbed that uses an UXR-Series oscilloscope and the 89600 VSA software for signal acquisition and analysis (Figure 2). Also, the testbed uses a Keysight M8195A 65 GSa/s arbitrary waveform generator (AWG) to generate 802.11ay signals created with Keysight Signal Studio software. The testbed uses a Keysight E8257D PSG microwave signal generator as a precise local oscillator (LO) for a compact mmWave upconverter to translate those signals up to 60 GHz.

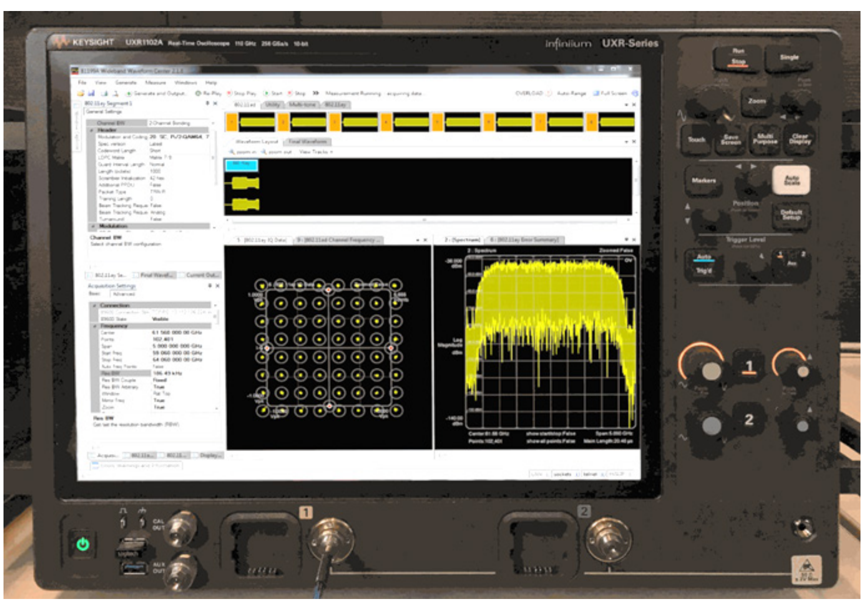

Figure 2: The UXR-Series oscilloscope directly digitizes the 802.11ay signal, and the 89600 VSA software demodulates the signal for display and analysis in a variety of formats

This configuration provides exceptionally low EVM, as evidenced by the clean 64QAM constellation diagram in the lower center portion of Figure 2. With very little dispersion and no perceivable rotation, the residual EVM noise floor of the test setup is very low. The benefit: with very low EVM in the testbed, engineers can expect to see the true performance of their 802.11ay hardware designs.

High-speed digital: De-embedding up to 40 dB of channel loss

When working with serial data buses at speeds greater than 100 Gbps, the effects of probes, cables, connectors, and fixtures make it difficult to measure the true characteristics of a digital signal accurately. Fortunately, de-embedding is a proven way to characterize the signal path and then, post-measurement, remove the effects of passive devices between the probe tip and the oscilloscope input.

However, as bus speeds climb towards terabit rates, the effects of noise within the oscilloscope will also affect measurement quality. To illustrate the benefits of a lower noise floor, we created a side-by-side comparison of measurements made with a Keysight Z-Series oscilloscope and a new UXR-Series oscilloscope. Both were equipped with Keysight InfiniiSim waveform transformation software, which enables the removal of unwanted effects caused by passive channel elements.

To create a repeatable input signal, we used a Keysight M8045A pattern generator module, which is part of the M8040A high-performance bit error ratio tester (BERT). In this configuration, one polarity of the pattern generator drove one scope channel directly, and the other drove a second channel through a long, lossy cable. In both cases the output signal amplitude was 300 mV_{pp} — it was captured at 50 mV per division (400 mV full scale) on the direct channel. However, the loss through the cable was significant, and the signal was captured at 33 mV per division.

The InfiniiSim software provides separate control of “per div” settings for acquisition and display, to enable the optimization of acquisition for “pre-embed capture” and display for “post-de-embed.” This optimization is an important detail; as loss increases, it’s possible to capture the signal with more “scope gain” (a smaller V/div setting). The higher the scope gain, the greater the benefit of a lower noise floor.

Figure 3 shows the height and width of the eye diagram for a 32 Gbps non-return-to-zero (NRZ) signal for the direct (top) and lossy (bottom) signal paths. In the lower eye, the significant closure is due to noise in the cable as well as the effects of de-embedding, which boosted the oscilloscope’s noise floor and signal by 24 dB at 40 GHz.

Figure 3: Compared to the clean eye diagram of the direct signal (top), the effects of noise are evident in the lower trace

Figure 4 shows the same measurement performed with a UXR-Series oscilloscope. In this case, both traces — clean and lossy — are more open than in Figure 3. The process of de-embedding and emulating equalization, which applies digital signal processing (DSP) to remove loss in the channel, boosts noise along with the signal. However, because the UXR has a very low noise floor, less noise is boosted, and the result is the ability to de-embed more than previously possible. The UXR achieves the de-embedding of up to 40 dB of channel loss.

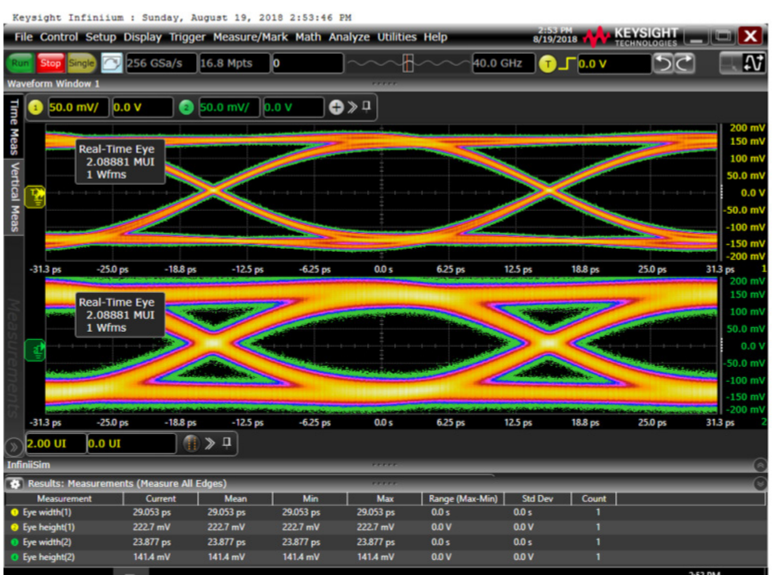

Figure 4: As the lower eye shows, the lower noise floor of the UXR-Series provides better measurement results when using de-embedding

5G MIMO: Coherence across multiple channels

The fifth-generation of wireless technology, known as 5G, promises to revolutionize the concept of mobile connectivity. In pursuit of the 5G vision, developers are embracing a variety of technologies —some evolutionary and some revolutionary.

One legacy idea made new is multiple-input/multiple-output (MIMO) transmission and reception. Beyond multiple antennas and the underlying matrix math, the key idea is to squeeze more bits per second from a limited amount of frequency spectrum. This technique is already widely used in Wi-Fi networking with 2x2 and 4x4 MIMO configurations.

In 5G, the concept of "massive MIMO" refers to larger antenna arrays, 64x64, 128x128, and 256x256, potentially operating at mmWave frequencies. Today, many researchers focus on mastering 2x2, 4x4, or 8x8 MIMO at 28, 39, 60, or 65 GHz and then scaling up to massive MIMO implementations.

However, in the characterization and troubleshooting of these designs, one limiting factor is the availability of multi-channel measuring instruments — oscilloscopes, spectrum analyzers, or signal analyzers — that maintain coherent synchronization across all measurement channels.

Measurement channel synchronization was a key design goal for the UXR Series oscilloscopes, and the outcome was a cross-channel skew of less than 35 fs (femtoseconds) inside not only a two-channel unit but also between separate units. When characterizing 5G MIMO performance, simultaneously measuring the in-phase and quadrature (I/Q) signals is essential to achieve precise cross-correlation between the measurement channels.

Thus, it's possible to synchronize a pair of two-channel UXR scopes to make precise 2x2 MIMO measurements. Moreover, if budget is no object, four two-channel units can be synchronized for 4x4 measurements. Special software available for the UXR scopes ensures synchronization across multiple units. Also, the Keysight 89600 VSA software is available to make MIMO measurements with the necessary demodulation and analysis capabilities; including EVM measurements.

Conclusion

Demand from consumers and business is driving data rates ever higher, shortening the lifecycle of each new standard and placing greater urgency on terabit research. Whether you're working with optical, wired or wireless technology, the exceptional measurement capabilities of the UXR Series real-time oscilloscopes will help you rapidly validate your research and boost your success rate with innovative technologies.

Seeing is believing. Video demos are available on our website and through the Keysight channel on YouTube. For more details, please see the related information listed below.

Related Information

- Video: Introduction of the Keysight UXR Series Oscilloscopes
- Video: The Signal Path #133, Keysight UXR Oscilloscope Teardown & Experiments
- Data Sheet: *Infiniium UXR-Series Oscilloscopes*, publication 5992-3132EN
- User's Guide: *Keysight UXR-Series Real-Time Oscilloscopes*, publication 54964-97002

www.keysight.com/find/UXR