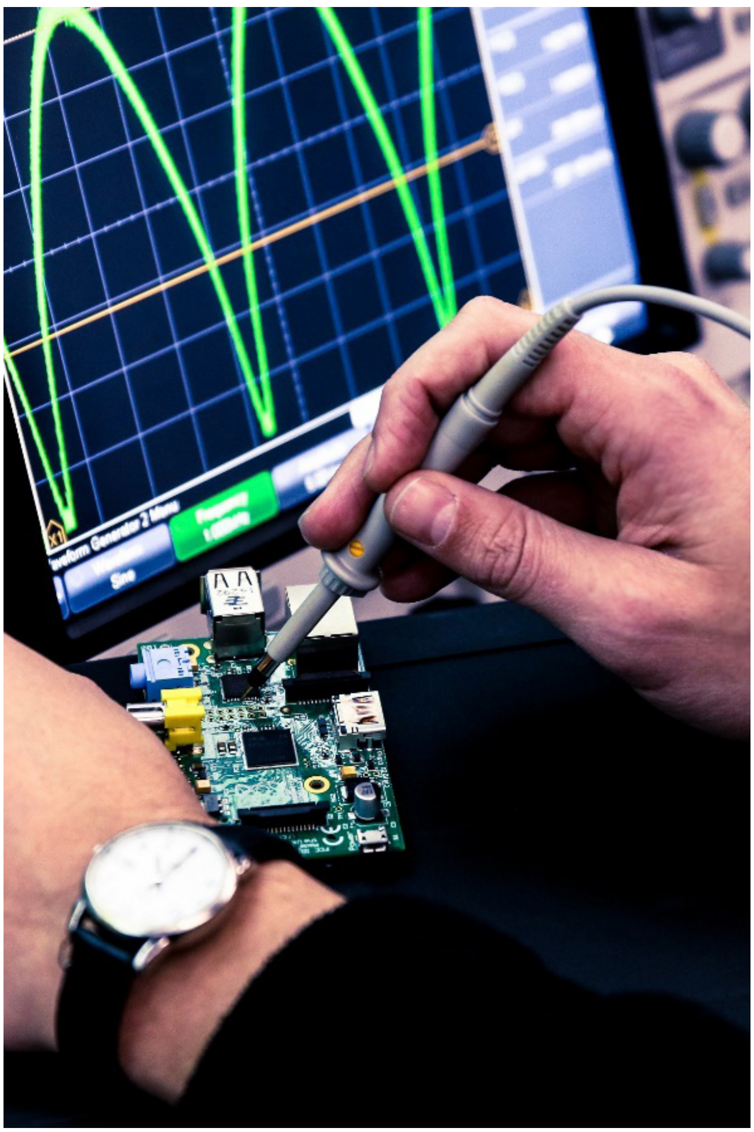
Keysight Technologies

7 Things All Advanced Oscilloscope Users Need to Know

Application Note



KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights

Advanced oscilloscope users know that making oscilloscope measurements can be tricky. It's often not enough to know only the basics, and there are other factors that come into play to do efficient, accurate testing. Take your testing to the next level by learning seven concepts that advanced oscilloscope users should know to help save time and improve the quality of their test results.

1. Qualitative vs. Quantitative Measurements
2. System Bandwidth vs. Scope Bandwidth
3. Advanced Triggering
4. Acquisition Modes
5. Reference Waveforms
6. Remote Interfaces
7. Advanced SCPI Commands

1. Qualitative vs. Quantitative Measurements

All oscilloscope testing will fall into one of two categories: qualitative testing or quantitative testing. Knowing which of these two types of testing you are doing will inform how you spend your time in the lab.

Qualitative testing – think "qualify"

Qualitative testing is the off-the-cuff testing you typically do when you're debugging a design or poking around your board with probes to make sure everything's working. Think of "qualify" as "functional or not." You don't care so much about getting a great connection to your device or if your clock signal's rise time is 10 ns or 12 ns – you just want to make sure that the clock is actually functioning.

Quantitative testing – think "quantify"

If you're doing quantitative testing, you care more about the stats. Think of "quantify" as "stats/numbers." You do care about the difference between a 10 ns and 12 ns rise time because you need to hit the crucial "set up and hold" requirements of your receiver. Or, you care about the difference between a 5 Vpp signal and a 5.5 Vpp signal because your amplifiers might saturate.

Now what?

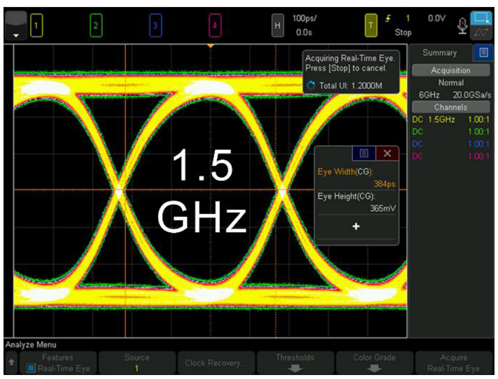
Once you know which of these categories your work falls into, you can evaluate the following considerations for yourself and decide how much they actually matter for the task at hand.

1. Qualitative vs. Quantitative Measurements (Continued)

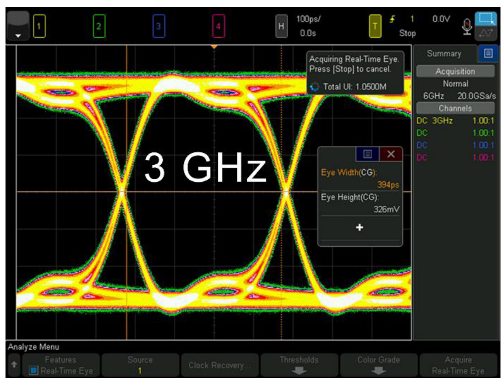
What should you always do? – Startup considerations.

The first and most important step as you begin to test is to know the capability of your test system and the current configuration it is in. Starting your test measurements from a known state can save time regardless of how casual or crucial your intent of test is. Using the oscilloscope's "default setup" button or recalling a loaded custom setup will ensure you are always starting with the same, familiar configuration.

It is also important to review the oscilloscope, probe and combined "system" bandwidth to ensure the configuration can manage the signals you intend to measure. A general rule of thumb for the system bandwidth (calculation includes scope and probe bandwidths) is 5x the fastest digital signal and/or 3x the fastest analog signal bandwidth to ensure accurate measurements. This is especially true for quantitative measurements. They need ample system bandwidth, or you could get misleading time-dependent measurements. System bandwidth is discussed more in the *System bandwidth vs scope bandwidth* section of this document.



1.2 GHz signal on an oscilloscope with a 1.5 GHz bandwidth.



The same 1.2 GHz signal on 3 GHz bandwidth.

The probes used in the system are also very important. A standard passive probe and a higher-end active probe will produce very different measurement results. For qualitative testing at lower frequencies, standard passive probes (typically provided with the oscilloscope) should work fine. For quantitative testing at higher frequencies, you may want to consider active probes with lower capacitive loading or device connectivity. There is helpful information on different probes and their specifications in this article: **http://electronicdesign.com/test-measurement/how-pick-right-oscilloscope-probe**.

1. Qualitative vs. Quantitative Measurements (Continued)

What should you sometimes do? – Calibration and test setup considerations.

Periodic calibration of your oscilloscope gives you assurance that your measurements are within the specified tolerance. For general use or debugging (qualitative test), an oscilloscope that is not up to date on calibration will usually be good enough. However, for highly sensitive conformance or manufacturing test (quantitative test), an appropriately calibrated oscilloscope should be used.

In addition to your test system, the environment you are working in should be considered, and you will want to take steps to manage any unnecessary signal interference. Lights, fans and other equipment in the work area can inject noise into your test system. For qualitative testing, this isn’t a huge consideration. However, you may spend a lot of unnecessary time debugging for quantitative testing.

What should you rarely need to do? – Verification and diagnostics considerations.

Occasionally, deep understanding of a circuit performance is required (for example, with performing product verification and diagnostics; tracking progress on a noise reduction assignment; or application specific compliance testing). Taking advantage of an oscilloscope’s on-board measurements offers an easy (and sometimes automated) method to attain even more insight into the performance of your device under test. Take the time to review and use the on-board measurements of your oscilloscope.

These time-saving recommendations are just a few of the ways you can take advantage of the powerful measurement capabilities oscilloscopes have to offer. Distinguishing between when you are doing a cursory view (qualitative) or a deep dive view (quantitative) into a circuit or device’s operation can help save you time when using an oscilloscope.

2. System Bandwidth vs. Scope Bandwidth

System bandwidth is the combined effective bandwidth of the oscilloscope and probe you use when making a measurement. Both the oscilloscope and probe have individual bandwidth specifications. When you use an oscilloscope and probe together, the combined or "system bandwidth" may not be what you expect.

To determine the system bandwidth for your oscilloscope measurement, you will first need to know the oscilloscope's front end filter response. For scopes below 1 GHz, the filter is typically a Gaussian type. For 1 GHz or higher oscilloscopes, the filter type may be a "Brickwall". The system bandwidth calculations for each type of front end filter is different, so it is important to know which type of front end filter your scope includes. Sources for determining the front end filter would be the data sheet or contacting the scope support line to ask. An alternative quick test method to determine whether the oscilloscope's front end filter is Gaussian is to apply the following formula: 0.35/scopes calculated rise time = oscilloscope's bandwidth.

For example, a 200 MHz bandwidth has a calculate rise time of 1.75 ns resulting in the formula 0.35/1.75 ns = 200 MHz. If the resulting formula were not true, and a value larger than 0.35 is required to make it true, the oscilloscope front end filter response is closer to a Brickwall filter.

After establishing the scope's front end filter, the system bandwidth can be determined by applying this formula:

Gaussian

$$\text{System bandwidth} = \frac{1}{\sqrt{\frac{1}{\text{scope bandwidth}^2} + \frac{1}{\text{probe bandwidth}^2}}}$$

or

Brickwall

$$\text{System bandwidth} = \min\{\text{scope bandwidth, probe bandwidth}\}$$

Figure 1.

This information helps you to determine the combined oscilloscope and probe "system bandwidth" for your signal measurements. Knowing the system bandwidth is important to ensure the test configuration is capable of making the measurements you want and will not cause signal roll-off at higher frequencies.

3. Advanced Triggering

Using basic triggering makes sense for some signal measurements, but when you need a deeper dive into the debug and analysis of a complex signal or physical layer glitch, it is good to be familiar with advanced triggers and the powerful analysis capability they can provide. Learning to use a few advanced oscilloscope triggers will give you the ability to isolate a problem signal for a closer look so you can troubleshoot faster. Here are some examples of advanced triggers:

Pulse width trigger

A pulse width trigger can be used to capture a signal that rises and falls across a voltage threshold within a define time. You specify the pulse width and pulse polarity (positive or negative) that the oscilloscope uses to determine a pulse width trigger. Below in Figures 2 and 3 you can see two scope displays. The first includes two signals acquired using an edge trigger. Applying a pulse width trigger, in this case with a pulse width of 150 ns, enables capture of just the targeted signal, as shown in Figure 3, for analysis or troubleshooting more closely.

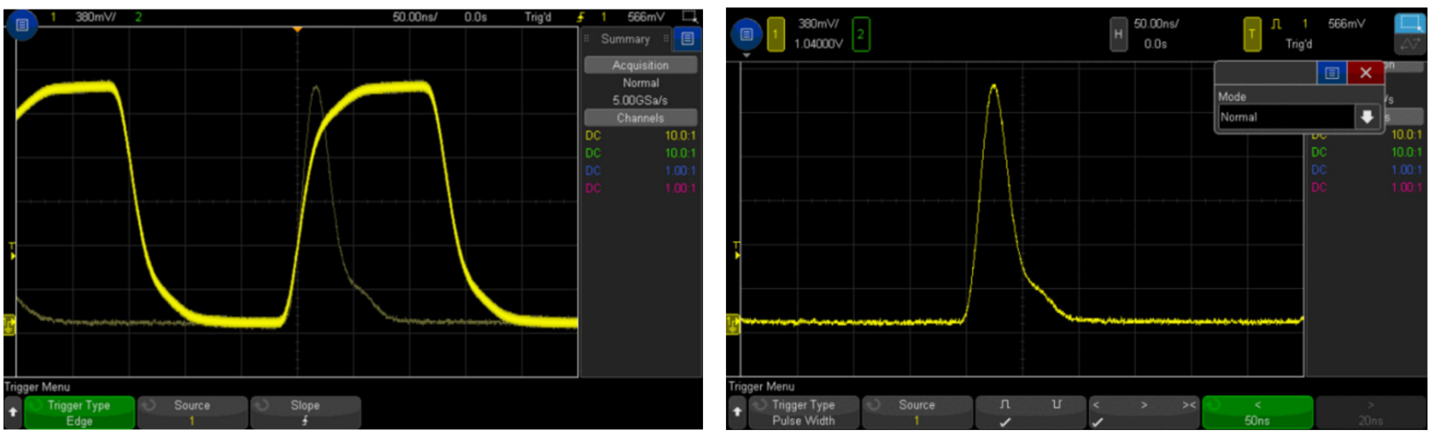


Figure 2 and 3. Applying a pulse width trigger to an acquired signal.

Edge then edge trigger

For the ‘edge then edge’ trigger mode, the oscilloscope triggers when an Nth edge occurs after an arming edge and delay period.

Pattern trigger

A pattern trigger is based on a logical combination of channel states. It identifies a trigger condition by looking for a specified pattern. Each channel could have a value of 1 (high), 0 (low) or X (don’t care). A set voltage level is used as a reference to determine whether signals are high (greater than the voltage level) or low (less than the voltage level). Channels that are ‘X’ (don’t care) are not used as a part of the pattern criteria.

Now that you are more familiar with these examples of advanced trigger capabilities, you can apply them when needed to do deep signal analysis. Using advanced triggers helps to more effectively isolate a problem signal for analysis during the debug process to fix problems faster. Learn more about advanced triggers with the blog article **“Advanced Oscilloscope Triggering and Signal Isolation”**.

4. Acquisition Modes

It's important for advanced users and beginners alike to know the different acquisition modes. Understanding how to apply an oscilloscope's acquisition mode, like normal, averaging, high resolution, or peak detect mode, can provide an optimal view of your acquired signals. The finely-tuned sampling algorithms that make up acquisition modes can selectively plot or combine sampled points to help you view different signal characteristics. The following information describes the best times to apply the different acquisition modes available.

Normal mode

Normal acquisition mode is the default mode for oscilloscopes. The ADC samples, and the scope decimates down to the desired number of points and plots the waveform. It's best to use normal acquisition mode for day-to-day debugging tasks because it gives a good general representation of your signal. It's a safe mode to use and has no significant caveats.

Averaging mode

Averaging mode takes multiple waveform captures and averages them together. The main benefit of averaging acquisition mode is that it averages out the random noise on your signal; this allows you to see just the underlying signal. Averaging acquisition mode should be used only with periodic signals and with a stable oscilloscope trigger. Averaging mode is great for viewing or characterizing very stable periodic waveforms.

High-resolution mode

High-resolution mode is another form of averaging. However, instead of waveform-to-waveform averaging, it is point-to-point averaging. Essentially, the ADC oversamples the signal and averages neighboring points together. This mode uses a real-time boxcar averaging algorithm that helps reduce random noise. It also can yield a higher number of bits of resolution.

High-resolution mode isn't as effective at reducing random noise as the averaging mode discussed earlier, but it has some distinct advantages. Because high-resolution mode doesn't depend on multiple captures, it can be used with aperiodic signals and unstable triggers. This makes high-resolution mode much better than averaging mode for general-purpose debugging.

Peak detect mode

Peak-detect acquisition mode functions similar to high-resolution mode. The ADC oversamples the signal and selectively chooses which points to display. But instead of averaging these points together, peak-detect mode chooses the highest and the lowest points and plots them both. This is useful because it can provide insight into any unusually high or low points that might be otherwise hidden. Peak-detect mode is best used for detecting glitches or viewing very narrow pulses.

5. Reference Waveforms

To save time when probing multiple devices of the same type, try using a reference waveform. A reference waveform is created by capturing a waveform on the oscilloscope and then storing the single-shot image. The reference waveform can be recalled to the display and compared to another device's live updating waveform either side-by-side or overlaid to quickly see differences in waveshape characteristics between the device waveforms.

Below you can see an example comparison of NFC poller modulation measurements from two different mobile phones. The reference waveform (orange trace) was initially captured using channel 1 and then saved into a reference waveform memory (R1). Channel-1 (yellow trace) is showing what is supposed to be a same NFC signal from a different mobile phone. Using the vertical offset to adjust the waveforms makes it easy to compare the two signals and quickly see the differences in amplitudes, widths of modulation and transition times. Measurements, such as the automatic Vpp shown here, can also be performed on both waveforms for comparison.

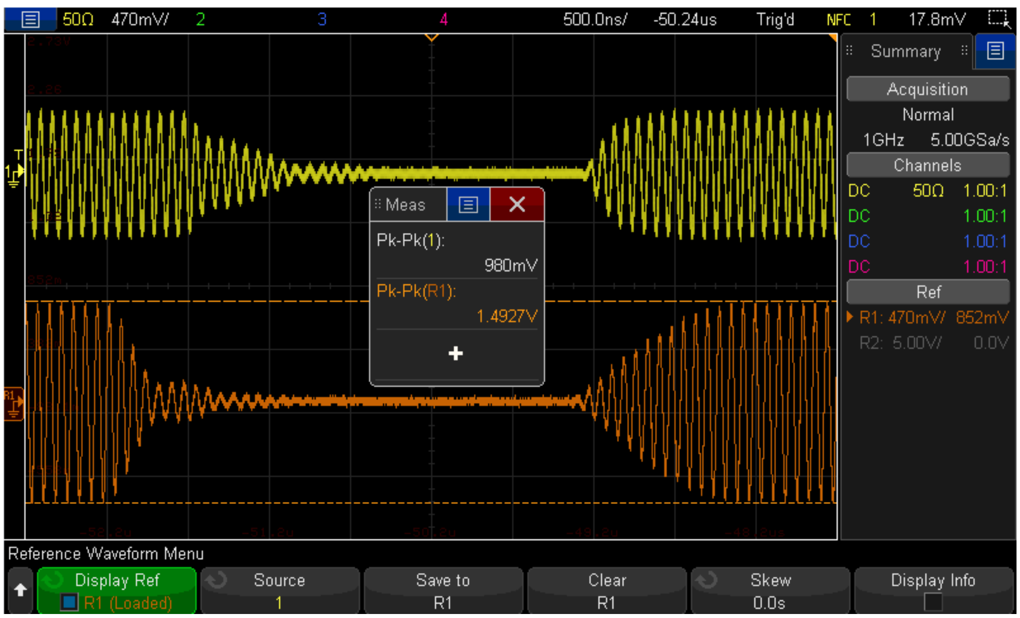


Figure 4. Comparison of cell phone signals using a reference waveform.

Using a reference waveform is easy and can help you quickly see differences in device waveforms.

6. Remote Interfaces

A majority of test engineers automate their test systems, including oscilloscopes, by connecting to a PC through remote interfaces such as LAN, USB or GPIB. Today, connecting to instruments through a remote interface to a PC is nearly as easy as connecting a mouse or keyboard. The ease of connecting instruments to a PC for control has made test automation more widely used than ever before. Test automation not only saves time but also provides consistency between tests and generates directly comparable results for different devices. The benefits of automating tests are recognized by engineers during design, development and manufacturing of various devices.

Design engineers take advantage of automated test to track differences in iterations of device design. Using an automated test with key measurements during each step of design modification helps engineers to see effects of the changes more quickly. They are able to test and capture or document results in support of the modifications. Design validation engineers can also use repeatable automated tests to capture the changing performance of a device in different temperature or humidity environments. Manufacturing environments value automated tests that require minimal human interface and enable fast and efficient cycles of repetitive tests that may run for multiple builds or data sets. The use of automated tests for every stage of a product's life cycle from design through manufacturing helps to save time, improve accuracy and provides repeatable tests.

The ability to create automated tests for a device's every test need can be a big challenge. Historically, expert programmers have been needed to integrate instruments and develop test systems. Today, there are tools available to help engineers program automated test systems whether they are non-programmers, occasional programmers or skilled programmers.

Keysight's BenchVue is a good example of an easy-to-use software tool for non-programmers. They can use a drag-and-drop interface for instrument controls and measurement rather than software commands, so there is no need to write code. BenchVue is able to send instrument commands or run external.exe files when needed, but it basically enables program loops, sweeps and delays as well as controls for a selection of instruments. The test flow environment, shown in Figure 5, is designed for non-programmers and occasional programmers, enabling them to create a test sequence and get measurement results quickly.

6. Remote Interfaces (Continued)

Figure 5. BenchVue software enables test automation for occasional or non-programmers.

Experienced programmers can take advantage of the flexibility that graphical and text-based program languages have to offer, such as communications with nearly any instrument and support of any data type. When custom code is necessary to address more complex test requirements, experienced programmers are essential for getting the job done. Automating a test with custom code (even for skilled programmers) takes a dedication of time for the initial program development and verification as well as modifications and maintenance over time.

Regardless of your programming ability or the programming environment your test program resides in, using LAN, USB or GPIB remote interfaces to connect to and control the instruments in your test system helps to save time and ensure repeatable tests.

7. Advanced SCPI Commands

Controlling instruments from an external computer using LAN, USB or GPIB interfaces can also be accomplished using the standard commands for programmable instruments (SCPI) programming language. SCPI is an ASCII language used to create instrument configuration and query commands that are common to all SCPI-based instruments and are organized in a hierarchical order based on functions.

SCPI commands are usually similar between instruments with the same functional capability. For each measurement function, such as frequency or voltage, a specific command set is available. The advantage of the functional command sets is that two SCPI compliant instruments (though made by different manufacturers) can be controlled using the same voltage measurement commands. You can see in Figure 6 the hierarchical structure for the "Measure" command. To create a command to measure DC voltage using the command structure, the result will be "MEASure:VOLTage:DC?" Or "MEAS:VOLT:DC?". For more complex commands, such as configuration of parameters for a specific instrument, a selection of parameters is made available.

```
:MEASure
    :VOLTage
         :DC?
         :AC?
    :CURRent
         :DC?
         :AC?
           ...
```

Figure 6. Example of SCPI command hierarchy.

Using the organized structure and applying the simplified commands makes it possible to construct a frequency measurement for a SCPI counter or an oscilloscope using the same commands. SCPI commands are easy to learn, self-explanatory and are used by both experienced and beginner programmers. Once you are familiar with the organization and structure of SCPI, efficient program development is possible, regardless of the control program language you are working in. Because of the ease of using SCPI commands to configure and control instruments, more than 50% of all test system programs use direct SCPI programming in automated test systems.

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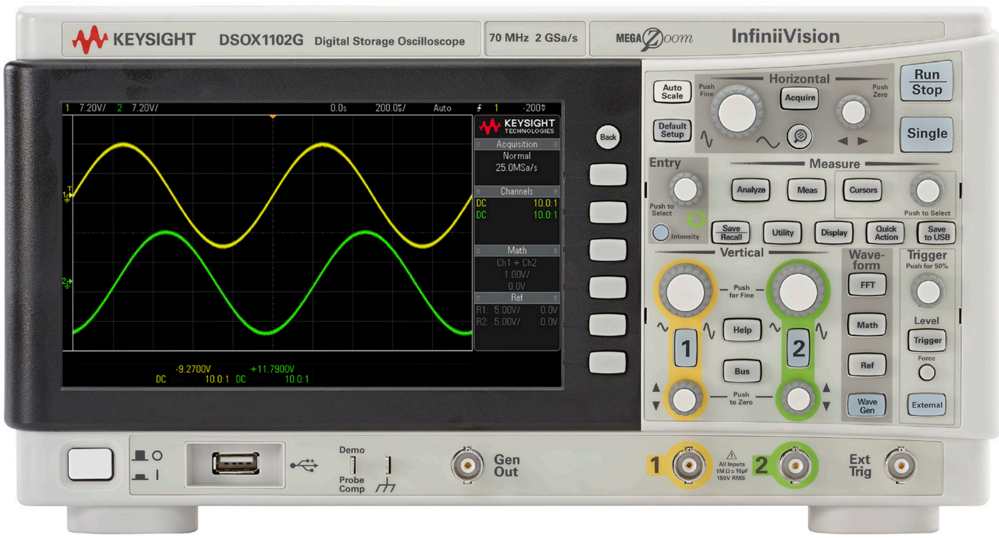

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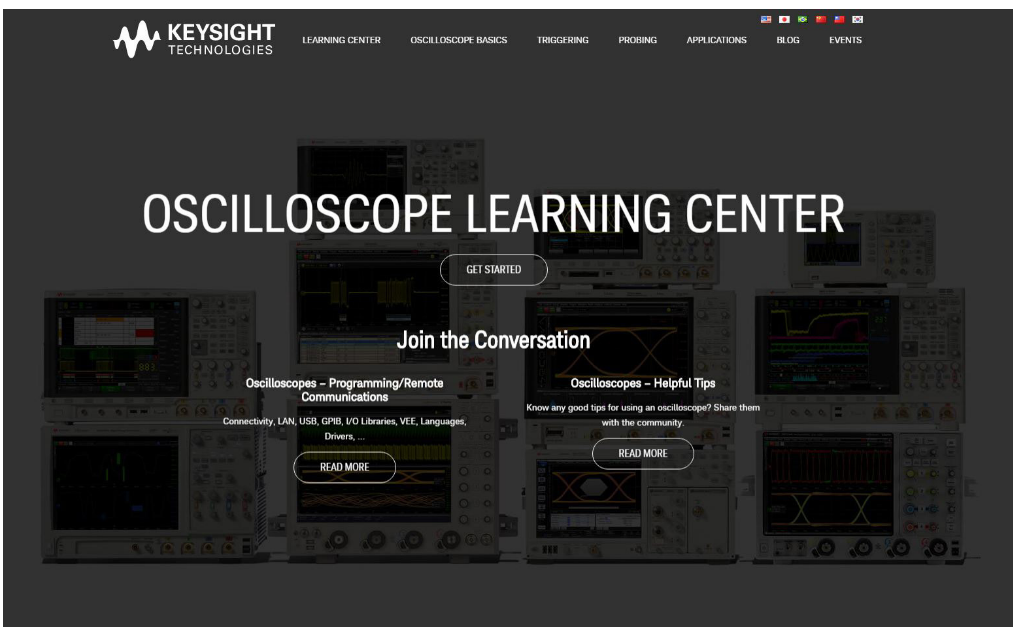
Visit the oscilloscope learning center

Check out Keysight's oscilloscope learning center for more oscilloscope resources. From oscilloscope basics to advanced measurement tips and access to Keysight experts, the learning center has all the resources you need.



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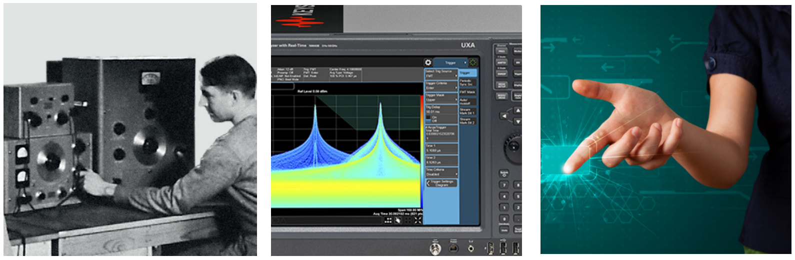

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