Oscilloscope tricks 21 to 30

Arthur Pini - April 07, 2016

Modern digital oscilloscopes have a great many features that are not apparent to the casual user. By using these "hidden" features, you can save time and get the results you need to get the job done. This is the third installment of useful hints for extending the effectiveness of your digital oscilloscope. The first two appear at these links:

10 Tricks that extend oscilloscope usefulness

10 More tricks to extend oscilloscope usefulness

Go directly to your trick of choice or browse them all.

Using a spectrogram display to see variations in the signal spectrum

Using a spectrogram display to see variations in the signal spectrum

The spectrogram display is a component of the spectrum analyzer option in many oscilloscopes. It shows a history of spectral changes in a separate display grid. In the oscilloscope I used, up to 256 spectra are displayed in a vertically stacked display as shown in **Figure 1**. Spectrum peaks trace the sinusoidal pattern showing the variation in the FM signal's frequency over time. The vertical axis shows time with the oldest information at the top while the horizontal axis is frequency, with the same scaling as the source spectrum shown below the spectrogram. Spectral amplitude is proportional to the display intensity.

Figure 1. An example of a spectrogram display showing the frequency variation of an FM signal.

Controls in the Spectrogram field of the Spectrum Analyzer dialog box are used to turn on and configure the spectrogram display. The View box turns the display on or off. The Type entry allows selection of either a two dimensional (2D) or three dimensional (3D) display. Figure 1 is the monochrome, 2D view where the spectral amplitude is proportional to the display intensity. By unchecking the Monochrome check box the spectrogram will indicate spectral amplitude by color. The slider control in the Spectrogram field controls the mapping of both the intensity and color to the amplitude of the spectrum. **Figure 2** shows a 3D display of a swept frequency square wave with color graded amplitude encoding.

Figure 2. The color grading in this 3D spectrogram indicates amplitude.

The spectrogram display is ideal for viewing dynamic frequency changes in frequency agile communications systems such as BlueTooth. It can also be used to study harmonic structures as seen in Figure 2. Spectrograms are extremely useful for studying signal dynamics.

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Display graticules: The original measurement aid

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The display graticule, or the grid of intersecting lines, on a modern digital oscilloscopes display, contains elements dating to early oscilloscope development. It was the first tool added to the oscilloscope to enable quantification of the displayed waveform. Oscilloscopes use a graticule consisting of 10 horizontal divisions by either eight or ten vertical divisions. Each division is further divided into five minor divisions as shown in **Figure 3**.

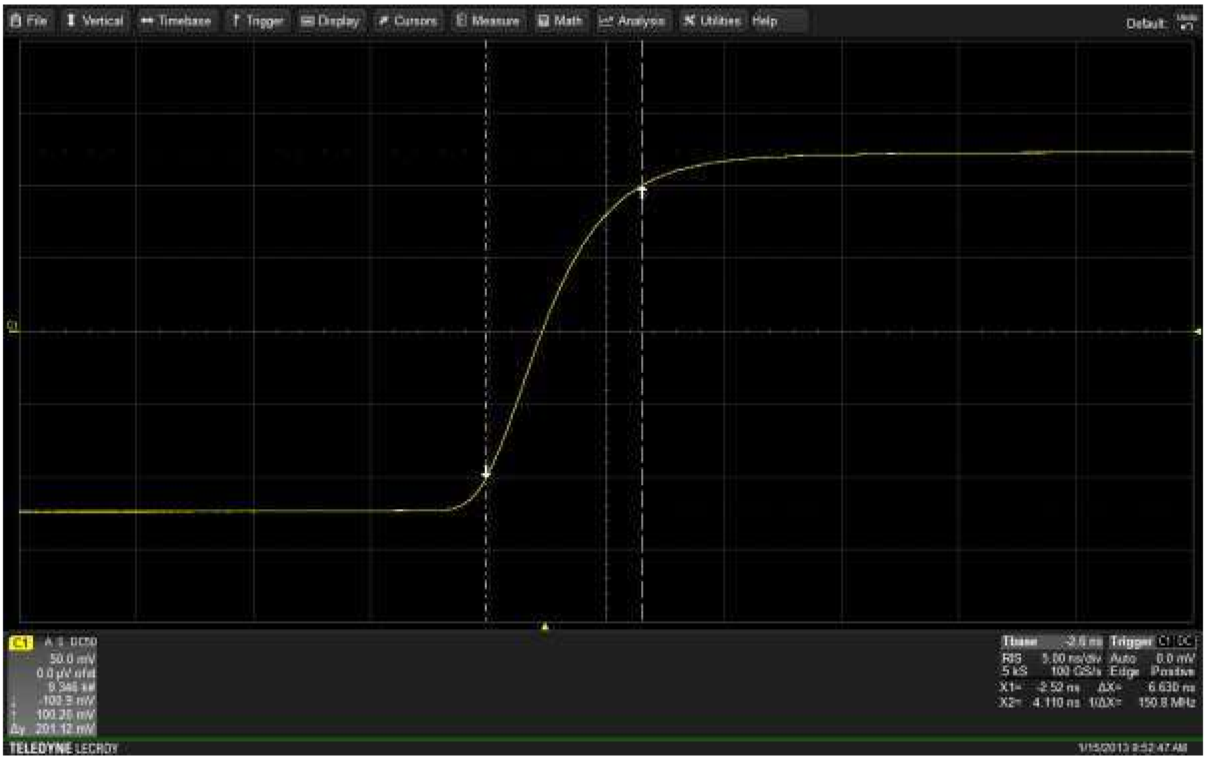

Figure 3. A waveform overlaid on the oscilloscope graticule of ten horizontal by eight vertical divisions, where each division is further sub-divided into 5 minor divisions.

The graticule's original use was to help estimate the amplitude and timing of the waveform. The step function has a vertical displacement of five divisions. Multiplying the displacement by the vertical sensitivity (50 mV/division) yields the signal amplitude of 250 mV.

Two horizontal dotted lines at ±2.5 divisions are used to estimate signal rise time, which is defined as the time it takes the signal to rise from 10% to 90% of its final value. To use these lines, adjust the signal amplitude to fit between the dotted lines using the variable vertical sensitivity control. The dotted lines are five divisions apart. The solid grid lines at ±2 divisions represent the 10% and 90%

levels. Measuring the difference of the crossing times is an estimate of the signal rise time. In Figure 3, cursors have also been employed in this example and the read the rise time as 6.63 ns. Of course, the oscilloscope also offers automatic measurement parameters which will automatically measure rise time to greater accuracy. The display graticule offers a quick "eyeball" estimate of waveform amplitude and timing.

[Return to page 1](#) **Debugging oscilloscope remote control programs**

Debugging oscilloscope remote control programs

Some oscilloscopes offer tools to help debug the programs used to control the oscilloscope remotely. For example, Teledyne LeCroy's Windows-based oscilloscopes include a feature called the RCA (Remote Control Assistant), which monitors and logs remote-control commands. Command errors, received commands that cannot be executed, are flagged as errors with descriptive text describing the nature of the error. The RCA helps you then debugging automated test programs intended to remotely control the oscilloscope. **Figure 4** shows an example of the RCA setup, log, and event detail popup.

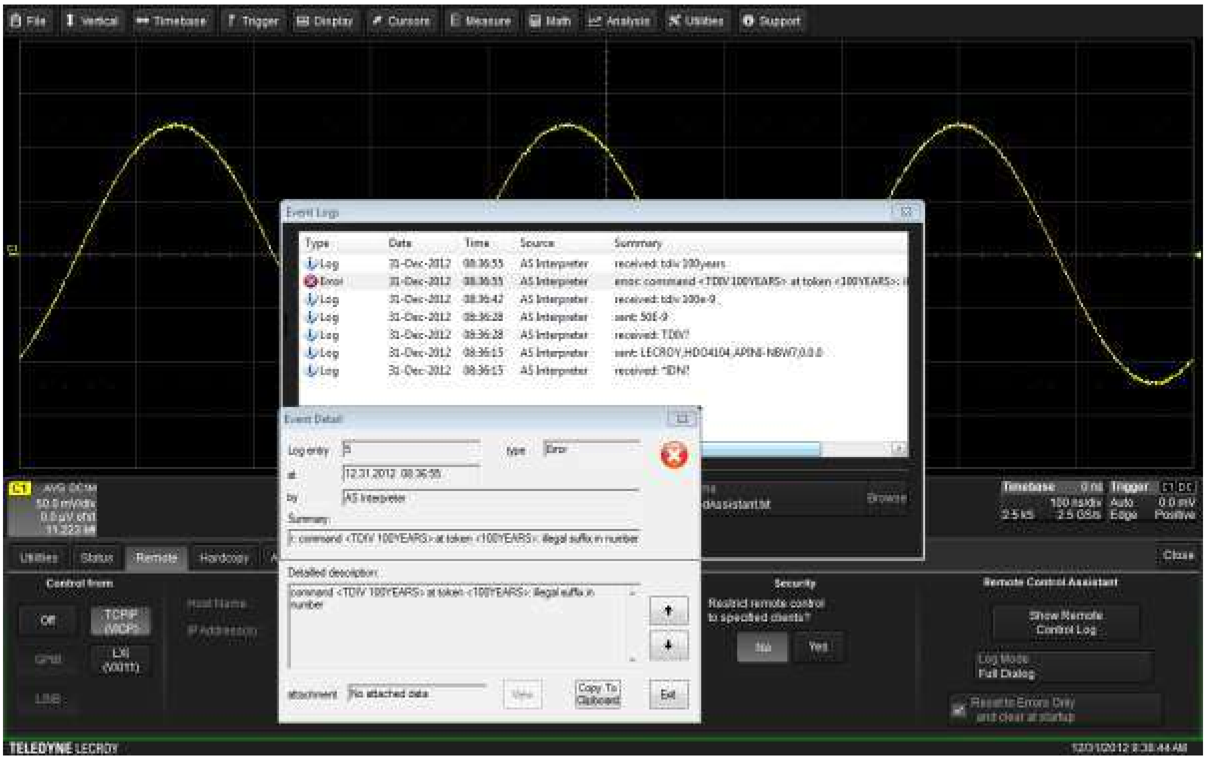

Figure 4. A screen image showing the Remote Control Assistant including the setup, remote command log and event detail popup.

The RCA is enabled using the Remote tab on the Utilities Setup dialog box. The RCA setup on the right side of the tab provides a choice of Log Mode, which includes selections of Off, Errors Only, or Full Dialog. The Show Remote Control Log pushbutton lets you view the remote control log. The event log, shown in Figure 4, has been configured to show all remote commands (Full Dialog). Note that there is an error logged. Right click on the error and select properties to get the Event Detail popup to view the details of the remote command error.

You can use RCA remotely access the COMM_HELP (or its short form: CHLP) and COMM_HELP_LOG (CHL) commands. CHLP is used to set up the logging mode, and accepts an argument that determines the mode: OFF, EO, and FD for Off, Errors Only, and Full Dialog, respectively. The remote query CHL? returns the contents of the log, in comma-delimited format. Use the command CHL? CLR to both read and clear the RCA.

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Creating safe-operating area plots

Creating safe-operating area plots

When making power measurements, you can plot the current through a power switching device like a FET (field-effect transistor) as a function of V_{DS} (drain-to-source voltage) in a switched mode power supply. The resulting plot is known as an SOA (safe operating area) plot. The safe operating area display plots device voltage as a function of current. It shows the in-circuit behavior of the device under test, revealing any transitions near peak voltage, peak current, and maximum power limits. **Figure 5** shows an example created with an oscilloscope's power analysis option.

Figure 5. In this example of a safe operating area (SOA) plot for a switch-mode power supply, the current (center left trace) and voltage (upper left trace) waveforms are cross-plotted on the X-Y display on the right. This is the SOA plot. The bottom left plot shows instantaneous power.

In Figure 5, channel 1 is the voltage waveform (horizontal or X axis) and channel 2 is the current waveform (Vertical or Y Axis). When the FET is on the drain-source voltage is close to zero and the current ramps up from zero to a maximum value. This is the conduction zone indicated by the color overlay. This forms the vertical segment on the left of the SOA plot. When the current is zero the voltage waveform plots as the horizontal segment on the bottom of the SOA plot, this is the Off state indicated by the color overlay. When the FET is changing state we get simultaneous non-zero current and voltage values which show as the curved sections joining the linear elements previously discussed. These are regions of finite power dissipation. Higher power levels are indicated by moving upward and to the right on the SOA plot.

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Constellation diagrams

Constellation diagrams

Constellation diagrams are commonly used to analyze the performance of data-communications systems using quadrature signal generation to phase encode digital data. The constellation diagram is an X-Y display that shows the data states of phase or phase-amplitude encoded data. The input is baseband data consisting of the in phase (I) and quadrature (Q) components. **Figure 6** shows a constellation diagram for a sixteen state, circular 16 QAM (quadrature amplitude modulation) signal. There are 16 data states associated with each transmitted symbol encoded using a unique magnitude and phase. These are shown on the X-Y display, with persistence turned on, while the other traces are the X-T and Y-T components.

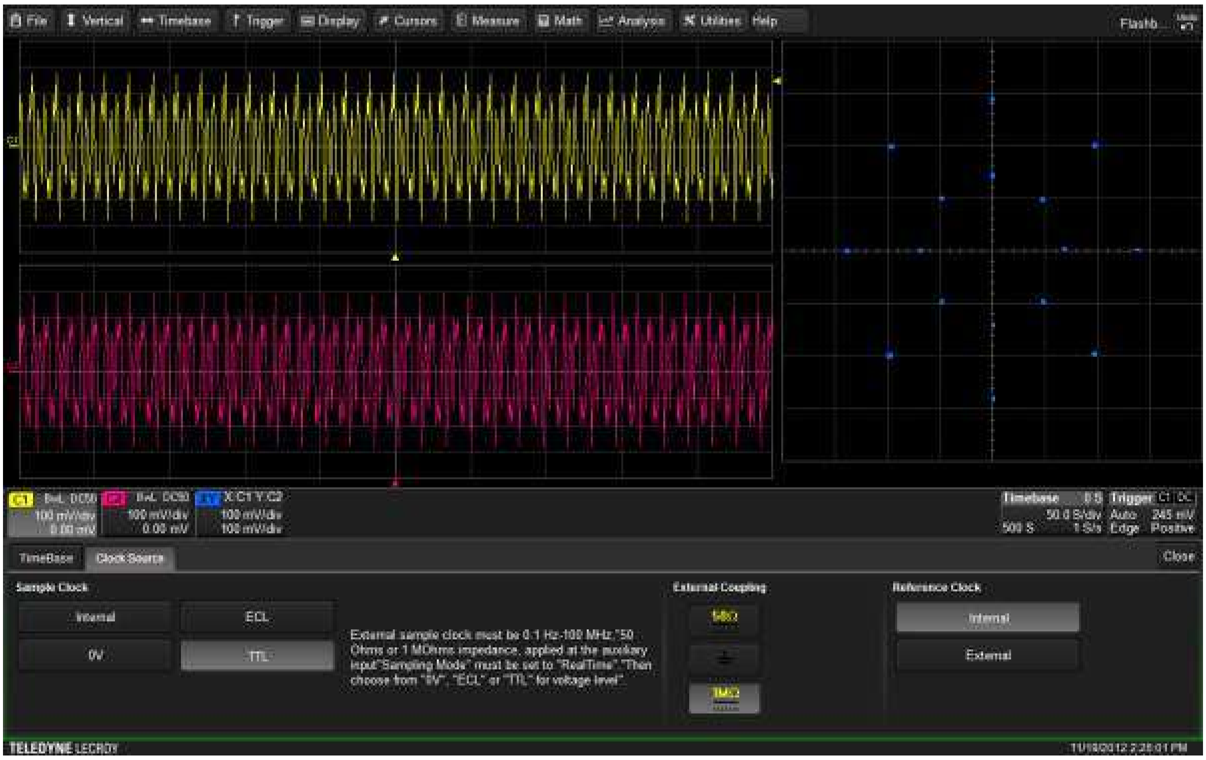

Figure 6: The creation of a constellation diagram for a circular 16 QAM signal requires the I and Q components along with the symbol clock as the external sampling input.

These data are externally clocked using the symbol clock so the oscilloscope plots the data from the data states only. We exclude the data transitions between states. External Clock is available on several Teledyne LeCroy oscilloscopes. Figure 6 shows the external clock setup. The scope will accept ECL, TTL or zero-crossing levels. The External Sampling clock is applied through the Ext input on the front panel.

Note that the delay timing of the symbol clock may need to be adjusted to assure that the signal waveforms are sampled at the correct time. This is usually accomplished outside of the oscilloscope. Use the Horizontal scale (Time/Division) knob to set the record length. Record lengths of from 50 s to 10 ms can be selected in multiples of 1, 2, or 5.

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Reading quadrature signal magnitude and phase from X-Y plots

Reading quadrature signal magnitude and phase from X-Y plots

X-Y plots in the form of state transition or constellation diagrams of quadrature modulated signals contain information on the magnitude and phase of the resultant combination of in-phase (I) and quadrature (Q) components. An oscilloscope's X-Y cursors can read these signal parameters directly using the polar coordinate readout fields as shown in **Figure 7**.

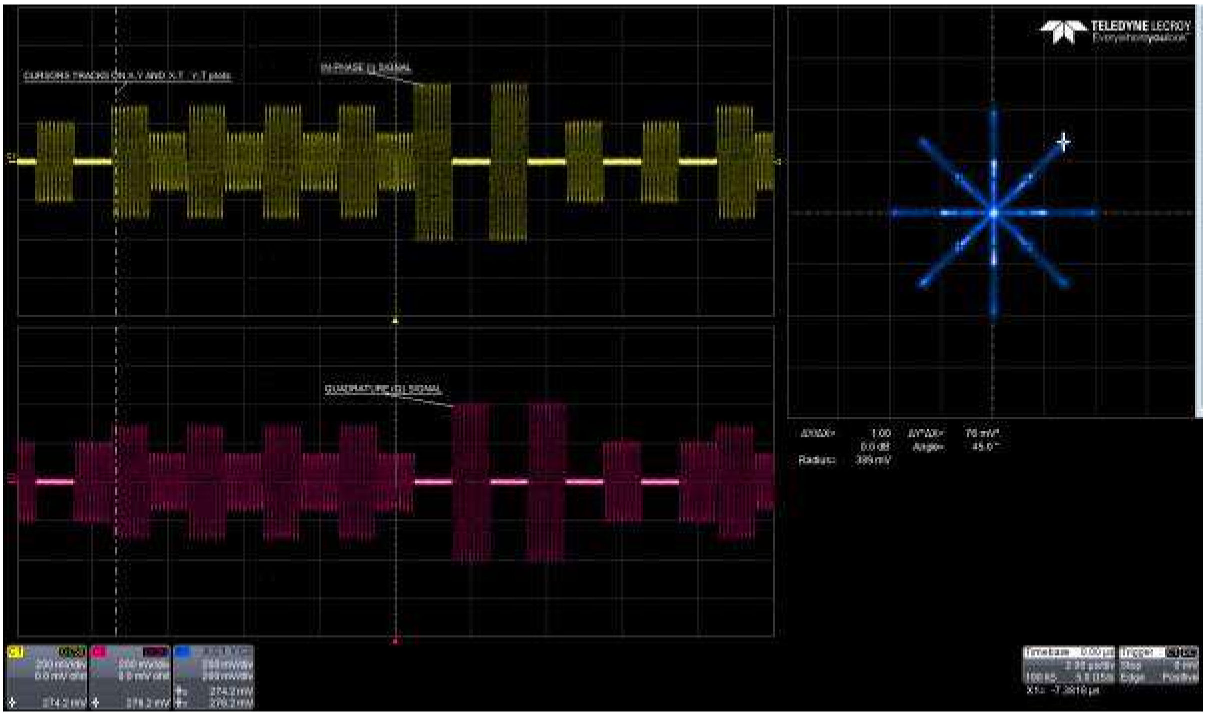

Figure 7. The horizontal absolute cursor reads both the X and Y amplitude as well as the magnitude and phase of the combined signal. Cursors track on both displays so anomalous vector states can be tracked back to the I and Q source waveforms.

The horizontal cursor, shown as a vertical dashed line on the I and Q source waveforms in channels 1 and 2, respectively, reads and displays the vertical amplitude of those signals at a specific point in time. Amplitudes appear in the channel descriptor boxes in the lower left corner of the figure. The time location appears under the time base descriptor boxes in the lower right corner.

The equivalent cursor location on the X-Y plot that's marked by a small cross icon is the vector sum of the I and Q components. This signal magnitude and phase are read in the radius and angle readout fields under the X-Y display grid. In this example the 274.2 mV X component combines with the 276.2 mV Y components to produce a vector at 389 mV with an angle of 45°.

The horizontal relative cursors, shown in **Figure 8**, are marked by two vertical dashed lines. Amplitude readouts in the channel descriptor boxes shown the absolute signal amplitudes where each cursor intersects the waveform as well as the difference in amplitude. The time readouts mark the time location of each cursors and the time difference.

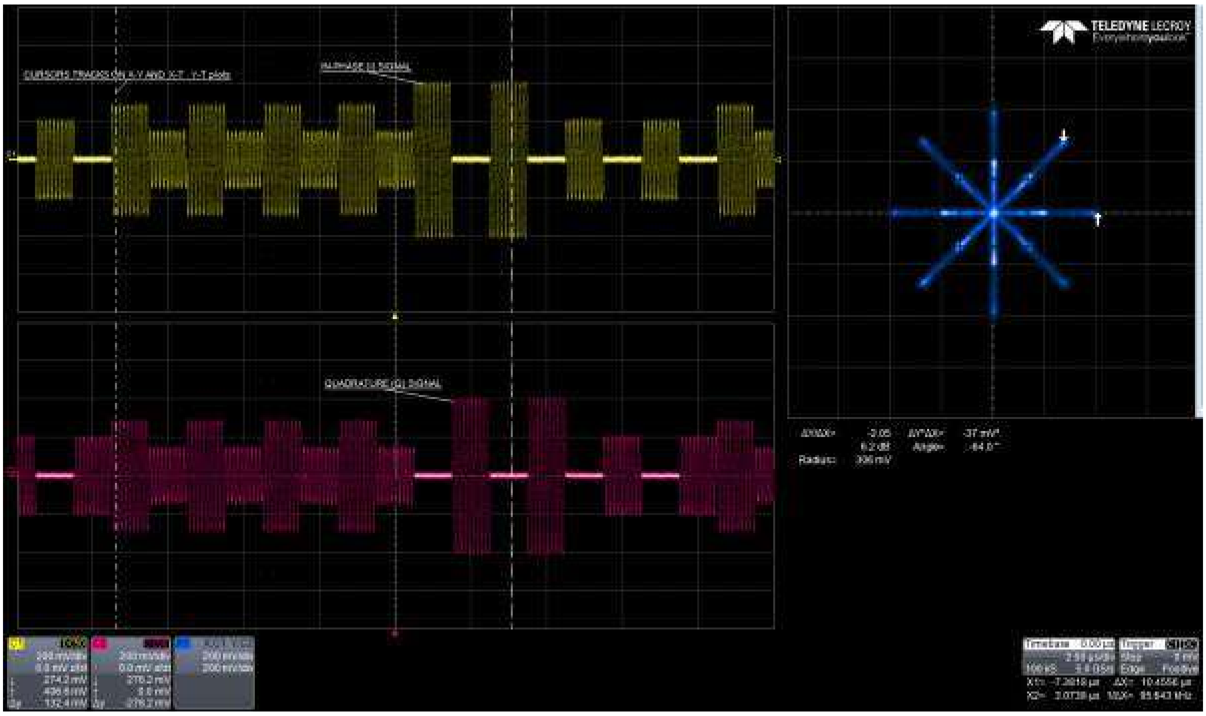

Figure 8. The horizontal relative cursors measure the vector difference between the cursor locations on the X-Y plot.

The polar readouts, under the X-Y display grid, read the vector difference between the cursor locations (marked as up and down arrows). The radius field reads the magnitude of a vector connecting the up and down arrows. Similarly, the angle field reads the phase angle of that vector. This is the vector difference between the two marked states.

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Measuring exponential time constant

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Many physical phenomena result in waveforms with exponentially rising and/or falling edges. In such cases, the exponential time constant reveals information about the underlying process.

You can find the time constant of an exponentially decaying signal by direct measurement using cursors or measurement parameters. Alternatively, you can verify that the waveshape is indeed exponential by logarithmically weighting the signal. If the result is linear, it indicates that the source waveform is exponential. Thus, you can read the slope of the signal directly. Consider the example in **Figure 9**, which shows the two suggested methods.

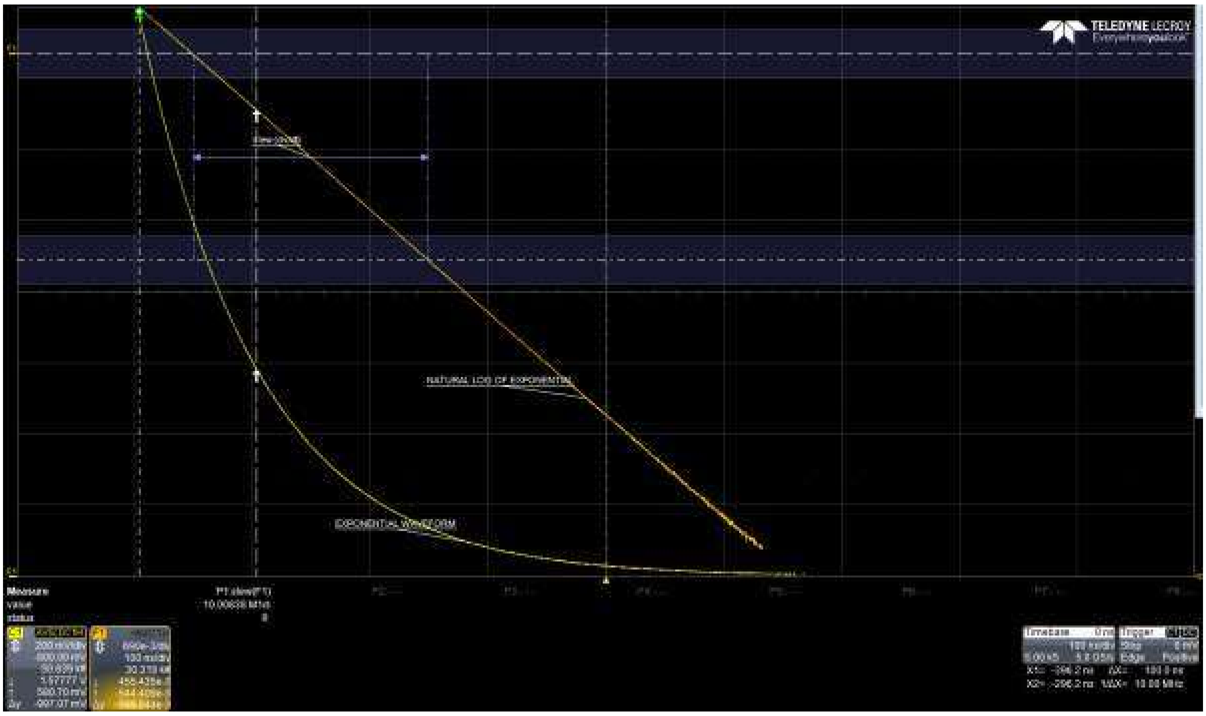

Figure 9. You can find the time constant of an exponential signal using cursor measurements on the signal itself or by measuring the slope of a logarithmically weighted version of the same signal.

Find the time constant by setting the upper (left-most) cursor to a point on the exponential waveform. Note the amplitude readout for this cursor. In this example, the upper value is 1.577 V (read using the cursor field in the trace descriptor for C1). Calculate 36.78% of that reading (580 mV) and move the lower (right-most) cursor to a horizontal location where the amplitude, as read by the right-hand cursor, is at or very near that value. The time constant is the time between cursors, ΔX, under the time base descriptor box. In Figure 9, the cursor reading is 100 ns.

The signal F1 in Figure 9 weights the exponential signal by the natural logarithm. The resultant trace is linear. The cursor readout for this linear trace shows a vertical change of 999.84 mV for the 100 ns time interval between cursors for a slope of 10 mV/s. This is the reciprocal of the time constant which is 100 ns.

The slew-rate parameter applied to the logarithmically weighted exponential reads the same value for the slope of 10 mV/s yielding the same time constant of 100 ns.

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Understanding and using decibels

Understanding and using decibels

The decibel is used for a wide variety of measurements in science and engineering. In electronics, the gains of amplifiers, attenuation of signals, and signal-to-noise ratios are often expressed in decibels. The decibel has a number of advantages, such as the ability to conveniently represent very large or small numbers, and the ability to carry out multiplication or ratios by simple addition and subtraction.

In practice, the decibel is as defined in the following equation:

$$dB = 10 log \frac{P1}{P2}$$

Where P1 and P2 are power measurements,

The logarithmic scale provides the best view of wide dynamic range measurements. As an example consider the FFT (Fast Fourier Transform) analysis of the waveform in **Figure 10**.

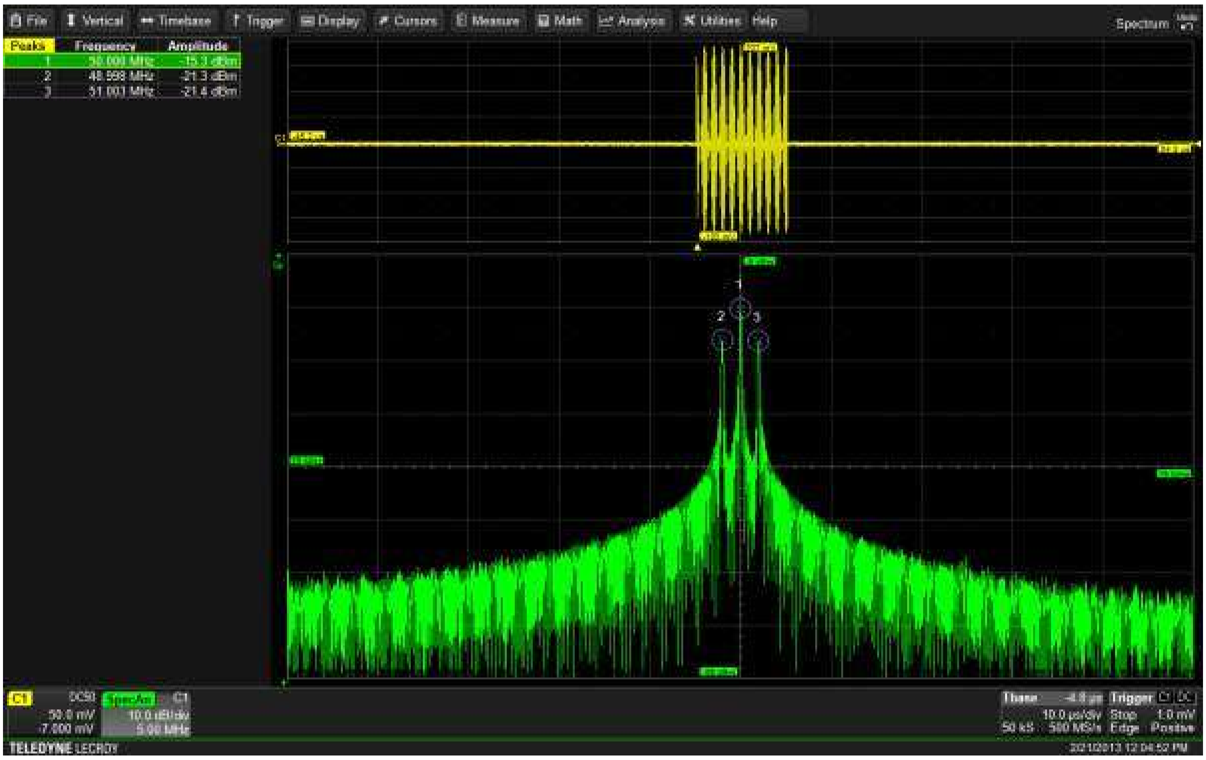

Figure 10. The lower trace from the spectrum analyzer option shows a logarithmically weighted vertical scale calibrated in decibels relative to a milliwatt (dBm). The peak table in the upper left displays the amplitudes of the 3 marked peaks. Peak 1at 50 MHz is -15.3 dBm and that at peak 2 (498.998 MHz0 is -21.3 dBm. The amplitude of peak 2 is 6 dB lower than peak 1, this is a factor of 4:1, or peak 2 is 1/4 of peak 1.

The lower trace is the Spectrum Analyzer display of the power spectrum, displayed using a logarithmic scale calibrated in units of dBm (dB relative to a milliwatt). It covers an amplitude range of 100,000,000:1 or 80 dB in power. The dB scale overlays a linear grid on the logarithmic scale. This grid makes it easy to see data separated by common multiplicative factors. For example a 2:1 steps show up as 3 dB increments, 10:1 steps are 10 dB increments.

If you're given the relative power levels in dB you can calculate the ratio using:

$$\frac{P1}{P2} = 10^{\frac{dB}{10}}$$

Many applications use specific reference levels of power. In most digital oscilloscopes and RF spectrum analyzers, the power measurements are referenced to 1 mW as explained above. In Figure 10, the peak table readings of the spectral amplitude of peak 1, reads -15.3 dBm. The absolute power can be calculated as:

$$\frac{P1}{1mW} = 10^{\frac{-15.3}{10}} = 0.0295$$

$$\text{P1} = 0.0295\ \text{mW}$$

Voltage ratios can also be expressed in dB. If you express power in the form of V^2/R with R the same for both measurements, then the definition of dB becomes:

$$dB = 10\ \log_{10}\left(\frac{V1^2/_R}{V2^2/_R}\right)$$

$$= 10\ \log_{10}\left(\frac{V1}{V2}\right)^2$$

$$\mathbf{= 20\ \log_{10}\frac{V1}{V2}}$$

Given a voltage ratio in dB you can calculate the ratio of the voltages using:

$$\frac{V1}{V2} = 10^{\frac{dB}{20}}$$

As with dB power calculations, there are a number of standard voltage reference levels used in computing dB. The unit dBV refers to dB relative to 1 V. It simply means that V2 in the voltage ratio equation is replaced by 1 V. So that 6 dBV has an absolute value of 2 V.

Relative levels in signal generators are often described in units of dBc, or decibels relative to the carrier level. For example an arbitrary waveform generator specification for non-harmonic spurious is less than -60 dBc. This means that spurious signals are 60 dB below (1/1000th) the current carrier voltage level.

Similarly dBµV is dB relative to a microvolt. Many other "specialized" reference levels are in use with the dB scales, but these are the most commonly encountered when dealing with oscilloscopes and signal generators.

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Use trigger hold-off to get a stable trigger in the presence of multiple trigger events

Use trigger hold-off to get a stable trigger in the presence of multiple trigger events

Hold-off is a trigger function used when there are multiple trigger events per acquisition. It lets you ignore extra trigger events and stabilize the display as if there was only a single trigger event per acquisition.

Figure 11 shows an example of Hold-off by Event. The waveform being acquired is a burst of 8 pulses so that there are 8 trigger events possible. A trigger event is a signal condition that would normally result in the oscilloscope triggering. Hold-off should be interpreted as a command to ignore the trigger for a specified time or event count.

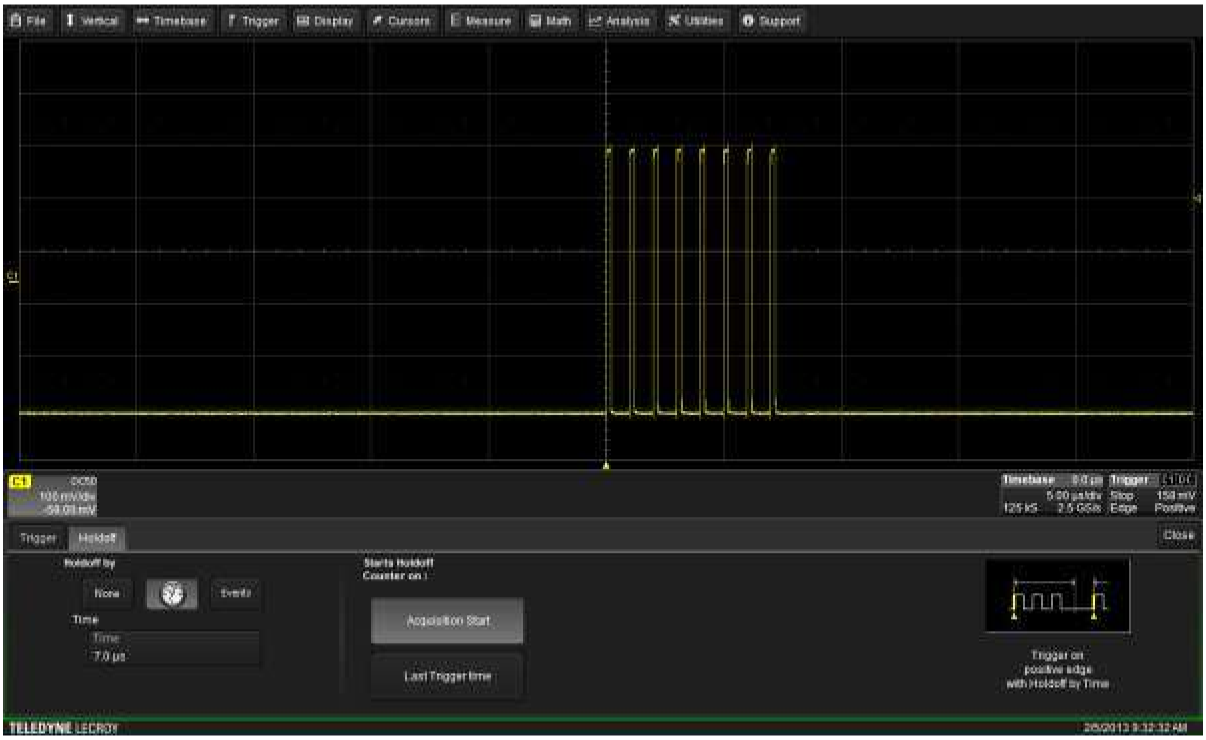

Figure 11. Using Hold-off by Time to obtain a stable trigger on a pulse burst waveform with a 7µs duration from the first to the last positive going edge.

In Figure 11, hold-off was set to ignore triggers for the 7 µs duration of the burst. When the oscilloscope trigger is enabled any trigger will be followed by a 7 µs interval where no triggers are possible. Since this is the duration of the burst the next trigger will occur at the beginning of the next burst.

You can do the same thing with Hold-off by Events. In this example, you can hold off by eight trigger events—the entire duration of the pulse burst. Again, the acquisition will synchronize itself with each pulse burst. Note that hold-off does not guarantee triggering on a specific point in the burst, just synchronizing with the burst. Synchronization will be maintained until there is an interruption of the signal and then will resynchronize, perhaps at a different point, when the connection is resumed.

The Starts Hold-off Counter determines if the hold-off counter is reset at the beginning of each acquisition (the Acquisition Start selection) or if it accumulates continuously (the Last Trigger time selection). Keep in mind that the trigger input is active at all time. If trigger pulses arrive, even if not during an acquisition, they may be counted in the hold-off condition unless the hold-off counter is restarted at the beginning of the acquisition. Similarly, if the process you are synchronizing with is continuous you can count all trigger events by selecting to start the count at the last trigger time.

Hold-off is an useful tool, but does require some experience to use it effectively.

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Characterizing Gated (Keyed) Oscillators

Characterizing Gated (Keyed) Oscillators

Many devices use on-off gating or keying of a carrier to encode data for short range transmission. Keyless automobile entry systems, wireless thermometers, and weather stations are examples. These devices use codes consisting of multiple amplitude-modulated pulses of an RF carrier to carry information. It's important that the carrier be turned on and off cleanly to minimize off-channel spurious signals. Also, the carrier frequency must be constant in the presence of the keying. Those of you with amateur radio background will know the former as "key clicks" and the later as "chirps." Digital oscilloscopes can be applied to measure the quality of on-off carrier keying.

Consider the example in **Figure 12**. The pulse modulated carrier is shown in the upper left trace of channel 1. The yellow and blue highlights show the areas which are expanded in the zoom traces at the bottom left and right traces. The modulated carrier is detected, using the scope’s demodulation math function, and appears in trace F1 (second down on the left. We can see the rectangular shape of the modulation envelope. If the modulation envelope is truly rectangular then the resulting frequency spectrum would be broadened. The spectrum would consist of a sin(x)/x shape centered at the carrier frequency. Looking at the fast Fourier transform in trace F3 (top right) we see that the spectrum is centered at the carrier frequency and fall away quickly. Looking at the leading and trailing edges of the modulated pulse and the modulation envelope in the zoom traces in the bottom left and right grids, we see that the modulation envelope and the modulated carrier have transition times on the order of a microsecond, this reduces spurious sidebands.

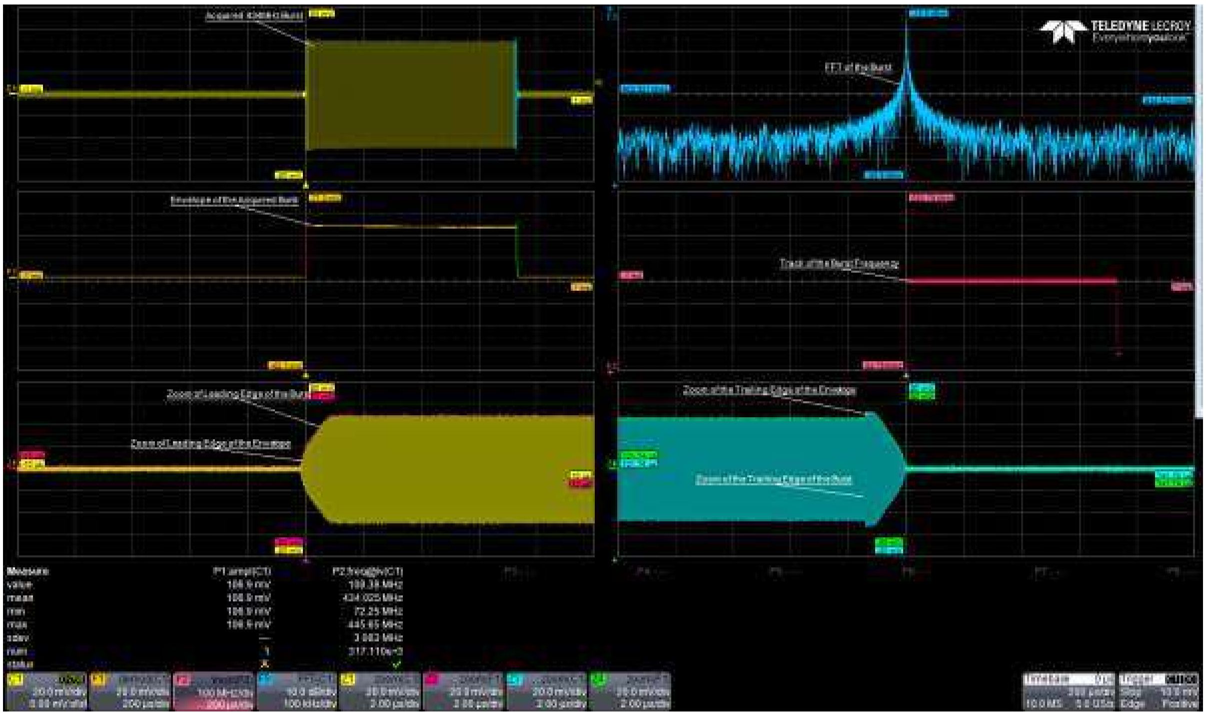

Figure 12. A pulse modulated 434 MHz weather station signal. The FFT of the signal shows a relatively clean carrier at 434 MHz. The pulse envelope is detected, when expanded horizontally we can see that the pulse enveloped is shaped to minimize spectral spreading. The track of the carrier frequency over time shows little or no frequency shift.

The frequency of the pulse modulated carrier is measured. Do to the transient nature the measurement statistics a wide variation in this measurement. The track (frequency vs. time) waveform in the center right grid, shows that during the pulse the frequency rises to 434 MHz and remains flat for the burst duration. There is no evidence that the frequency changes significantly during the modulation. So all in all the oscilloscope has all the tools to assure that this is a well-designed device.

Conclusion
Our oscilloscope trick count is now up to thirty for the article series. I hope that you have found at least one new measurement tool to help in your day-to-day work.

I encourage you to share your own measurement experience through articles, design ideas, or comments.

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Signal processing boosts digitizer performance
Limit the range of a waveform measurement
Trigger and synchronize digitizers to acquire the right data
Why are oscilloscope probe amps at the tip?
Perform pass/fail tests with an oscilloscope
Digitizers: Finer resolution is better
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10 More tricks to extend oscilloscope usefulness
Electromechanical measurements with an oscilloscope
MSOs probe analog and digital
How to select a modular waveform digitizer
Read sensors with an oscilloscope
Measure vector and area with an oscilloscope X-Y display
Product How To: Calculate power with a scope
Improve power supply reliability
How to measure instantaneous RF power
How to perform histogram analysis on your oscilloscope