10 More tricks to extend oscilloscope usefulness

Arthur Pini - November 21, 2014

An earlier article introduced ten ideas for extending the basic functions of mid-range digital storage oscilloscopes (DSO’s). Here are ten more ideas that will help save you some time and may make you the company DSO expert. You can follow the links below to the individual items.

Page 1: Demodulating PWM Signals (below)
Page 2: Creating hysteresis plots for evaluating magnetic devices
Page 3: Create a bandpass filter
Page 5: Find signal anomalies
Page 7: Three-phase power measurements
Page 9: RMS and Standard Deviation

Demodulating PWM Signals

PWM (Pulse width modulation) is used extensively in switched-mode power supplies and motor controllers. Analyzing control-loop dynamics requires visualization of the variation of pulse width with time. If your oscilloscope has a power analysis option package, then you have this capability. If, however, your oscilloscope isn’t so equipped you can demodulate the PWM control signals using the oscilloscope’s track (time track in some oscilloscopes).

First, make sure your oscilloscope includes all instance measurements. That means if you measure the width of a waveform, the oscilloscope will measure every cycle of the waveform that appears on the screen. It should also include a track function that generates a waveform based on a measured parameter. The track of the width or “width@level” parameters will show pulse width changes on a cycle-by-cycle basis versus time, synchronous with the source trace. This makes the track of width the ideal tool for demodulating a PWM signal. The track function can be accessed from the parameter or math setup.

**Figure 1** shows the track Trace F1, (bottom trace) of the width at level parameter versus time, of the PWM controller output (trace C1, top trace) in response to a step change in load current (Trace C2, third from the top). The zoom trace Z1 (second from the top) is a horizontally expanded view of the controller output about the load change showing the variation in pulse width.
Figure 1. Using the track of the width@level parameter, the instantaneous width of each cycle of the PWM waveform is plotted vs. time in math trace F1 (bottom trace) for a step change in load current shown in trace C2 (third trace from the top).

Parameters can be applied to the track function as in Figure 1 where parameters P2 through P4 read the maximum, minimum, mean, and last pulse width from the track waveform.

Creating hysteresis plots for evaluating magnetic devices

Creating hysteresis plots for evaluating magnetic devices
A common power measurement is the hysteresis, or B/H curve, for an electromagnetic component such as an inductor or transformer. Magnetic materials are characterized by plotting magnetic flux density (B) as a function of magnetic field intensity (H). This feature is sometimes provided in an oscilloscope's power analysis option. It can easily be created on any oscilloscope with an X-Y display. Figure 2 shows how an inductor and a signal generator are connected to generate a B/H curve.
Figure 2. Connect the voltage waveform, $v(t)$ to the vertical or Y channel of the oscilloscope’s X-Y display. The current waveform $i(t)$ is connected to the horizontal or X channel.

\[ B = \frac{1}{nA} \int v(t) \, dt \]

\[ H = \frac{n}{l} i(t) \]

$H$ is Magnetic Field Intensity in Amperes/meter  
$B$ is Flux Density in Tesla  
$A$ is Cross sectional area in meter$^2$  
$n$ is Number of turns  
$l$ is Mean path length in meters  
$v(t)$ is Voltage across inductor in Volts  
i(t) is Current through the inductor in Amperes

Note that the voltage waveform has to be integrated in order to determine the magnetic flux density.

If desired, you can apply scaling to magnetic field intensity and flux density using the rescale math function. This requires a knowledge of the physical characteristics of the device being tested as specified in the equations above.

**Figure 3** shows a screen image of such a B/H curve in terms of the integrated voltage and current on an oscilloscope. The applied voltage from the device under test has been integrated in math trace F1 and rescaled in math trace F2 to read flux density in Teslas on the vertical axis of the X-Y display. The current waveform was rescaled in math trace F3 and applied to the horizontal axis.
Rescaling waveform data to applicable units

In the previous section, we had to convert the integral of the voltage waveform into magnetic flux density. This required dividing the waveform by a constant (the product of the number of turns and the cross sectional area). Additionally, the proper unit should be Tesla. These operations can be carried out using the oscilloscopes rescale math function. Rescale allows the user to multiply a waveform by a constant and then add a constant. It also has provision to override the native units (V-s in this case) with user selected units. The oscilloscope used in this example offers 48 standard electrical units, including Tesla.

**Figure 4** shows the rescale setup in math trace F2. We need to divide the integral of the voltage waveform by $20 \times 10^{-6}$, but because the rescale function only offers multiplication by a constant we use the reciprocal or $50 \times 10^{3}$. The Override Units check box, when checked, provides a units entry field into which we have entered T for Tesla. This will rescale the output of the integral (math trace F1) by multiplying each point in the waveform by the desired constant. The vertical scale for the F2 math trace will now read in Teslas. Similarly, math trace F3 is used to rescale the measured current to magnetic field intensity.

**Create a bandpass filter**
Create a bandpass filter

Have you ever needed to apply a band-pass filter to isolate a desired signal from adjacent channel interference? Most midrange oscilloscopes include a low pass filter in the form of the ERES (Enhanced Resolution) math function but they lack a band-pass filter unless you have the digital filter option. You can use a little trick to convert the ERES low pass filters into a band pass filter. **Figure 5** shows the trick.

![Figure 5](image)

**Figure 5.** You can apply a band-pass filter to an oscilloscope's input by subtracting the low-passed input from the input channel and then applying a low-pass filter to the result.

The upper left trace, C1, is the input signal, a narrow pulse. Math function F1 has been set up to apply a low-pass filter to the input, channel 1. In this case, the ERES filter is a 16 MHz low-pass filter. The effect of the filter on the time-domain signal is shown in trace F1 (left center). In math function F2, the output of the low-pass filter in F1 is subtracted from the input, which removes the low-frequency content, resulting in a high-pass response. The second math operation in F2 is another ERES low-pass filter with a cutoff of 58 MHz. The result: The band-pass response in trace F2 (lower left).

Trace F3 (upper right) shows the input FFT (fast Fourier Transform) frequency spectrum. F4 (right center) is the spectrum of the low-pass filtered input. Trace F5 (lower right) is the spectrum of the band-pass filter operation. Control of these filters is limited by the filter selections on the ERES function. The digital filter option package, available in the oscilloscope, offers much greater flexibility but this little trick is readily available with a standard oscilloscope configuration.

Capturing serial data patterns

Oscilloscopes include several tools to capture serial data patterns. The optional serial trigger and
decode functions operate on data from specific serial standards. An alternative serial pattern capture technique uses the oscilloscope’s search function, called WaveScan, in the oscilloscope used here. This data search engine is included in all this supplier’s mid-range oscilloscopes, other manufacturers offer similar functionality. Figure 6 shows an example of a serial pattern captured using WaveScan.

**Figure 6.** Using the WaveScan search engine in Serial Pattern search mode to capture an 18bit serial pattern. Patterns of from 2 bits to 64 bits may be used as the search criteria. Bit rate, slope and logic level also need to be entered under the "NRZ-to-Digital" tab.

The serial pattern search mode will search for patterns of from 2 to 64 bits in length entered in binary or hex. In addition to the serial pattern the user has to input the serial bit rate. This is included in the physical parameter setup for serial pattern recognition in the "NRZ to Digital" tab, setting up the data bit rate, slope, and logic threshold of the data.

When a selected pattern is detected any of WaveScan’s seven actions is triggered. The example in Figure 6 has stopped the acquisition.

**Find signal anomalies**

**Find signal anomalies**
All Instance measurement is the ability of an oscilloscope to make timing measurements on every cycle of an acquired waveform. If you measure every cycle, you can display a track plot that shows the variation of the measured parameter with time in perfect sync with the acquired signal input. Figure 7 contains an example of this capability.
Figure 7. Use the rise time track parameter to find a single waveform cycle with a slow rise time.

The acquired signal has 781 cycles of a 4-MHz sine wave. From the rise-time parameter (P1) statistics, we can see that a measurement was made on every cycle because there are 781 values. The mean value of the rise time is 2.88 ns. The minimum value is close to the mean at 2.8 ns but the maximum value is 27 ns. Turning on the track of rise time, math trace F1, we see a peak near the center of the trace. The track is a plot of every measured value of period versus time. It's time synchronous with the waveform acquired in trace C1. The maximum value of the track of rise time is 27 ns. Its location is time synchronous with the cycle with the slow rise time.

Using zoom traces Z1 and Z2 as zooms of C1 and F1, respectively, and engaging the multi-zoom feature to have them track horizontally, we can expand both zooms to find the single cycle corresponding to the maximum period value.

This is the advantage of All Instance measurements. You can see the timing changes in a waveform on a cycle-by-cycle basis. This technique is an alternative to using the WaveScan search function to find this pulse with the slow rise time.

Noise measurement tools

Random processes are difficult to characterize because no individual measurement provides any information about the previous or next measurement. It is only by looking at cumulative measurements that you can learn about the process you are investigating. Figure 8 shows the basic tools for measuring random processes like noise. The upper left trace is an amplitude time plot of the input on channel 1. The lower left trace is a power-spectral-density plot showing the frequency distribution of noise power. The right hand trace is a histogram of the individual noise voltage measurements. The histogram shows the distribution of the amplitude values of the individual
measurements. These analysis functions, combined with measurement parameters, offer a complete tool set for noise measurements.

You can gain some insight into the characteristics of the random noise signal by using measurement parameters. The most meaningful parameters for noise measurements are the mean value of the waveform (P1), the standard deviation (P2), and the peak-to-peak value (P3). Of these measurements, the standard deviation, which can also be described as the AC RMS value, is probably the most useful as it describes the effective value of the waveform.

The most common noise measurement in the frequency domain is PSD (power spectral density). PSD is usually measured in units of \( V^2/Hz \) and represents the power-per-unit bandwidth. Because noise is generally spectrally spread, the noise power in a band or range of frequencies can be determined by integrating the PSD over that range of frequencies.

The histogram provides the user with an estimate of the probability density function of the process being measured. This data can be interpreted by using histogram parameters. Figure 8 shows three histogram parameters, histogram mean (hmean in P5), histogram standard deviation (hsdev in P6), and range (P7). These are the mean, standard deviation, and range of the histogram distribution. These three views can quickly characterize noise.

![Figure 8](image)

**Figure 8.** Time, frequency, and statistical domain tools for noise analysis have related parameter measurements.

**Three-phase power measurements**

The two-wattmeter method for measuring power in three-phase circuits can be implemented using a four-channel oscilloscope. The power dissipated in a three-wire, three-phase load can be determined using a four-channel oscilloscope by measuring two phase currents and two line voltages. For
example, looking at the schematic in Figure 9, the total power drawn by a three-phase motor can be determined by measuring $V_{ac}$, $V_{bc}$, $I_a$ and $I_b$:

$$P_T(t) = V_{ac}(t) \times I_a(t) + V_{bc}(t) \times I_b(t)$$

**Figure 9.** The power dissipation of a three-wire, three-phase load (motor) can be measured using two phase currents and two line voltages.

The line voltages, $V_{ac}(t)$ and $V_{bc}(t)$, are measured using high voltage differential probes. The phase currents, $I_a$ and $I_b$, are measured using current probes. The power measurement requires an oscilloscope with four input channels. **Figure 10** illustrates the technique.
Figure 10. Measuring the power drawn by a three-phase motor using two line-voltage and two phase-current measurements.

The two components of the real power are 425.6 W and 425.8 W, respectively. The sum of these—or 851.4 W (computed using parameter math in P3)—is the total real power drawn by the motor.

Waveform trace smoothing

Digital oscilloscopes are sampled data instruments. They make use of sampling theory, which states that a waveform, if sampled at a rate greater than two times the highest frequency contained, can be reconstructed without loss of information. The result of this sampling process is that waveform traces in a digital oscilloscope consist of a number of data points as shown in Figure 11.
Figure 11. Examples of three techniques that can be used to smooth a waveform. They include sin(x)/x interpolation, Random Interleaved Sampling (RIS), and persistence trace mean.

This is a perfectly correct waveform, but it is a little hard to interpret. The simplest way to view these waveforms with some form of continuity is to connect the dots with lines. This is called linear interpolation and an example is shown in the top trace in the figure. When there are very few samples on the screen, this example has only 50 samples) linear interpolation often appears discontinuous. One solution is to increase the number of sample points. If the data has been sampled in conformance with the sampling theorem, an interpolator function such as sin(x)/x can be applied to increase the number of sample points. The second trace from the top shows the application of a sin(x)/x interpolator with ten times more samples than the raw acquisition.

The one down side of sin(x)/x interpolation is that if the waveform has fast edges, as may happen with pulse waveforms, it may exceed the Nyquist limit and have frequency components greater than one half of the sampling frequency. In that case, the sin(x)/x interpolator will fail and the waveform will be distorted. Pulse edges will exhibit overshoot and undershoot that does not actually exist in the waveform, these are called "Gibbs ears."

If the waveform is repetitive, Random Interleaved Sampling, a form of equivalent time sampling, can be used to increase the effective sampling rate and bring the sample points closer together. This is demonstrated in the third trace from the top in Figure 11. If the waveform is repetitive, turning on display persistence will produce a smooth waveform based solely on the sample values. This is shown in the bottom trace in Figure 11 where an advanced math tool called persistence trace mean provides the ability to capture the mean value of each point on a persistence display.

RMS and Standard Deviation

RMS and Standard Deviation
Root mean square (rms) and standard deviation (sdev) are closely related measurements. Rms is
The mean value of the waveform is read in parameter P1. This is the nominal DC output independent of the ripple and noise. The rms value, P2, includes both the mean and the ripple and noise. The
standard deviation (sdev in parameter P3) reads jst the AC components (noise and ripple) of the power supply output. The mean value is subtracted from each measurement point. So standard deviation is the “AC” rms value.

The rms value is now higher because the offset has been included. Knowing the mean and rms value you can calculate the sdev value.

\[ sdev = \sqrt{rms^2 - mean^2} \]

To compute the rms value of just the noise and ripple on a power supply output you can select Standard Deviation or AC rms.

**Conclusion**

Now you have ten more application for oscilloscope features that allow you to extend the usefulness of this versatile instrument. Hopefully, you will find some of them useful in your work.

See EDN collection: [Oscilloscope articles by Arthur Pini](#)

[Return to page 1](#)