BY ED CARYL*

Making Voltage Measurements with a DSO

BECAUSE THE OSCILLOSCOPE ALLOWS YOU TO ACTUALLY "SEE" WHAT YOU ARE MEASURING, IT IS AN INVALUABLE MEASUREMENT AID AND HAS LONG BEEN A MAINSTAY IN THE ENGINEERING TOOLBOX. TODAY, the digital storage oscilloscope (DSO) will help you make voltage measurements with a higher degree of accuracy and ease than ever before.

Types of voltage measurements

Voltage can be defined as the electric potential between two points in a circuit. Typically, one of those points is earth ground, that is, zero volts. Two types of voltage measurements—absolute and amplitude—comprise the majority of voltage measurements you will be making with your DSO.

A DC voltage measurement between ground and a second point in the circuit is called an *absolute voltage measurement*. An *amplitude measurement*, conversely, is a peak-to-peak AC voltage measurement on a signal found at the second test point. Both absolute voltage and voltage amplitude measurements use the vertical axis on your oscilloscope display. The instrument's vertical scale control sets the range for voltage measurements.

Voltage amplitude includes both amplitude and peak-to-peak (often abbreviated as "Pk-Pk" or P-P) measurements. Both of these are taken from the waveform top to its bottom. Peak-to-peak measurements include any noise, spikes, or overshoot on the waveform. A scope can be set to ignore those factors if it has a Histogram High-Low setup function. The reference is always the low point on the waveform.

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Voltage measurement applications

You are making *amplitude* measurements if you measure the peak-to-peak ripple on a power supply or the peak-to-peak voltage on an AC motor. If you need to determine the total peak-to-peak voltage at a test point in a logic circuit, or the peak-to-peak voltage developed by a pressure transducer, you also will be making amplitude measurements.

Absolute voltage measurements include the maximum (Max), minimum (Min), mean, high, and low measurement of a voltage. Max is

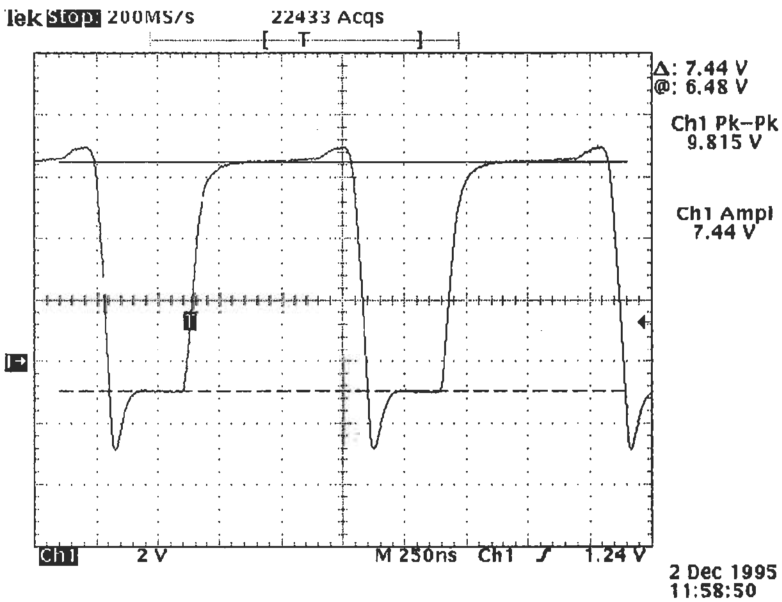

Fig. 1—THREE AMPLITUDE AND TWO ABSOLUTE voltage measurements are shown above. The oscilloscope's measurement system has made both a peak-to-peak and an amplitude measurement. For the absolute measurements, the active (@) cursor is making one absolute measurement at the waveform top. Secondly, the peak absolute value can be read from the graticule at about 7 volts (3.5 divisions at 2 volts/division). Earth ground is one division below graticule center, as marked by the 1→ symbol.

the positive peak voltage, while Min is the negative peak voltage. These measurements are referenced to earth ground.

You would make absolute voltage measurements if you needed to determine, for example, the mean value for a power supply output or the peak start-up current required by an AC motor. You would also use absolute voltage measurements to verify battery voltage or the logic levels in digital logic circuits.

Three ways to make voltage measurements

There are three ways to measure voltage. First, most DSOs have menu-selectable, *automatic measurement functions* that will make the measurements for you (Figure 1). These measurements are derived directly from waveform data and are the most accurate voltage measurements you can make—if the oscilloscope is set up properly.

To ensure proper setup, you must configure the oscilloscope to provide the highest vertical resolution possible. Select the highest sensitivity, spreading the waveform over the greatest vertical amplitude. The tradeoff, however, is that you lose the ability to know exactly where your measurement is derived from on the waveform.

Voltage cursors provide the second measurement method (Figure 1). These measurements are derived from wavefrom data, but are subject to operator error. To achieve accuracy, you must align the cursors with the exact waveform points intended. If your DSO has a zoom function, you can magnify the waveform features to make it easier to place the cursors correctly. Voltage cursors provide the benefit of indicating where your measurement is being made on the waveform.

The third measurement method is aligning the waveform with the displayed graticule markings, then counting divisions, and multiplying the answer by the vertical readout sensitivity. This is the casual *eyeball method* you probably are accustomed to using (Figure 1) when you operate an oscilloscope.

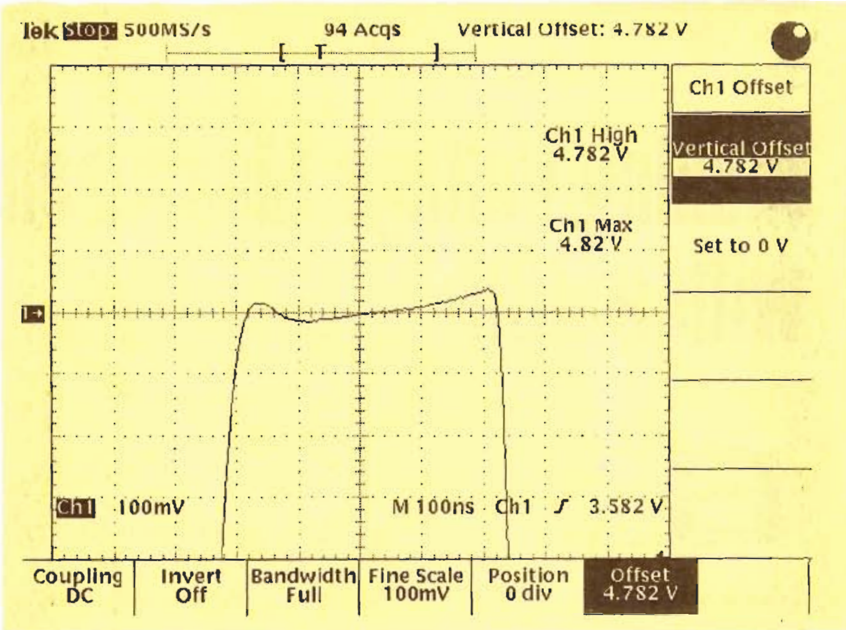

FIG. 2— AN ABSOLUTE VOLTAGE MEASUREMENT USING OFFSET is shown above. The offset voltage is the vertical difference between earth ground and graticule center. This has been set to coincide with the High value measured by the oscilloscope measurement system. The Max measurement is reading the peak value. The instrument has a ±2% AC gain error, but using offset, the error specification on these measurements is reduced to ±1.23%.

Specifications that affect measurement accuracy

There are four oscilloscope specifications that impact voltage measurement accuracy: vertical-gain accuracy, DC-balance accuracy, offset-voltage accuracy, and vertical resolution.

Vertical-gain accuracy is typically measured using DC voltages, and thus is usually called "DC-gain accuracy." This is confusing because gain accuracy most affects AC, peak-to-peak, and amplitude measurements. Vertical-gain errors typically come from vertical attenuators, amplifiers, and, in DSOs, from analog-to-digital converters (ADCs).

There are two ways to specify DC gain accuracy: as a full-scale display amplitude percentage, or as a measured value percentage. Most amplitude measurements are made at less than full scale, usually from four to six divisions. If full scale is eight divisions, two percent of full scale equals four percent of four divisions. If the gain accuracy is a measurement error percentage — in other words, a percent of reading— then two percent remains two percent for all measurements.

DC-balance accuracy is a factor in all push-pull amplifiers such as those used in oscilloscopes. A push-pull amplifier amplifies a signal that moves both above and below ground or zero potential. DC-balance accuracy is the difference between earth ground and the level that the instrument interprets as earth ground. This specification affects all measurements where ground is the reference, e.g., absolute voltage measurements.

DC balance is quite dependent on temperature, but all oscilloscopes have some way to adjust it. In Tektronix DSOs, for example, DC balance is performed during Signal Path Compensation (SPC). This routine is found in the Utility menu, under Cal (Calibration). It will typically restore DC balance to less than one-tenth division error. If necessary, the remaining error can be quantified by simply grounding the input and examining where the baseline trace falls. If you are routinely making high precision DC measurements, you should run SPC at least once a week.

Offset is a precision internal voltage source used to offset a signal level. It can be used to position a small DC signal (such as ripple signals found on power supplies) on-screen to enable amplification and a more accurate measurement of the signal. Offset also can be used as a nulling voltmeter by placing the measured level at the center horizontal graticule line.

Vertical resolution is set by the ADC and the acquisition mode. Eight-bit ADCs are the most common. This means there are two-to-eighth-power (2^8) voltage levels in the vertical resolution, 256 levels available to represent signal amplitudes. These levels are distributed over either 8 or 10.24 vertical divisions, the total vertical "dynamic range." If signal averaging, HiRes (high resolution), or other signal processing features are used, the vertical memory is extended to 16 bits. The practical limit using these higher resolution techniques is 12 to 13 bits, as set by internal instrument noise.

Measurement type vs. specification

Some DSO manufacturers lump all of the previously mentioned accuracy components into one specification, usually called "DC accuracy." This practice makes it difficult to design the method of your measurements in order to improve accuracy with special techniques or to determine the real errors.

Vertical gain error and resolution are the only error factors to consider when making amplitude or peak-to-peak measurements. You need not consider offset and DC balance accuracy. If the waveform is repetitive (a requirement of peak-to-peak measurements), use signal averaging to reduce noise. Or, if noise is to be included in the measurement, use peak detect acquisition mode (if available) to detect the noise. If signal averaging is used, only the vertical gain error affects your measurements.

When the signal is single-shot, or if you employ Peak Detect, add the gain error and resolution. The resolution will be plus or minus one digitizing level (DL). An instrument with an eight-bit ADC and 8 divisions dynamic range has 32 DLs per division. The 10.24 divisions of dynamic range in Tektronix DSOs result in 25 DLs per division. The display resolution in Tektronix DSOs is 50 levels-per-division, or 9 bits. Signal-averaged or HiRes waveforms will be displayed at this 9-bit resolution. If your oscilloscope has a zoom feature, you can employ it to see up to 13-bit resolution.

Resolution is the key to precise amplitude measurements. Use all of the DSO's dynamic range possible without clipping the waveform. Then use signal averaging or HiRes mode if your instrument provides this capability.

Absolute voltage measurement accuracy is a combination of gain, DC balance, and offset accuracy. On many DSOs, the accuracy calculation is complex if the measured voltage level is not located at center screen. The accuracy calculation is much simpler if you use the offset control voltage to bring the measured level to the center horizontal graticule line. At this point, only DC balance and offset accuracy are important. The offset control voltage is very precise—plus or minus 0.2 or 0.4 percent in Tektronix instruments. Don't be afraid to overdrive the oscilloscope by running the unmeasured waveform parts off screen (Figure 2).

Summary

The oscilloscope has more than earned its reputation as an essential tool in the electronics toolbox. As we've seen, the DSO in particular brings many advantages to making voltage measurements, including zoom and automatic measurements. Just remember, for the most accurate amplitude voltage measurements, be sure to use the maximum resolution your DSO provides. Also, take advantage of your oscilloscope's full dynamic range, and, when noise is present, employ the signal averaging or HiRes mode. For absolute voltage measurements, the offset feature will help ensure a higher degree of accuracy. Finally, whenever possible, let the oscilloscope make the measurement with the automatic measurements capability that most DSOs now provide.

Readers can contact Tektronix by calling 1-800-479-4490, Action Code 300. Additionally, Tektronix maintains a home page at:

http://www.tek.com/Measurement. EN