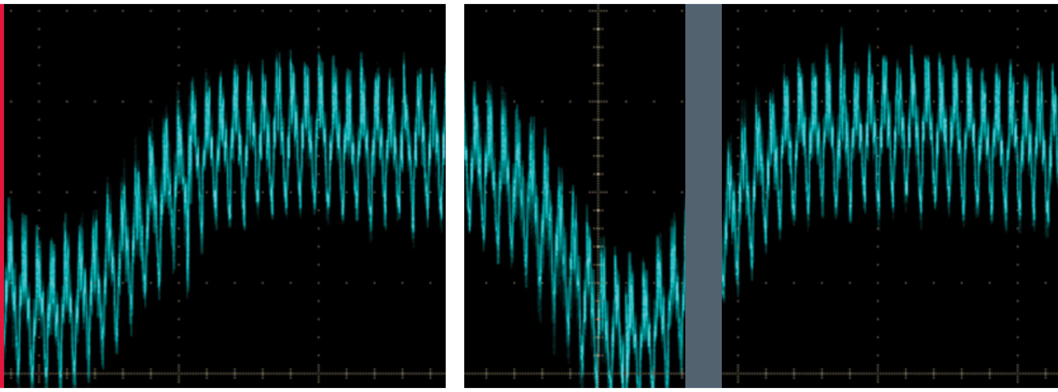

Probe Considerations for Low Voltage Measurements such as Ripple

Application Note

This application note describes considerations for making low voltage measurements using an oscilloscope and an oscilloscope probe. Ripple measurements will be described as an example of a low voltage application.

Tektronix®

Figure 1. 2X Probe (CH1) and 10X Probe (CH2) Lowest System Vertical Sensitivity.

The probes that ship with an oscilloscope may not be the right choice for low voltage measurements

Nearly all oscilloscopes ship with 10X attenuation passive probes because this type of probe is the best choice for making measurements across a broad range of applications. To cover the widest range of applications, a general purpose probe is usually rated from DC to 500 MHz and is generally capable of measuring up to a few hundred volts. Users making low voltage measurements will often fall into the trap of using the 10X probe that came with their oscilloscope and they end up with inaccurate results because a 10X passive probe is not capable of making accurate measurements in the low millivolt range.

Probe Considerations when making Low Voltage Measurements

When making low voltage measurements, it is important to consider oscilloscope sensitivity, probe attenuation, system noise, probe grounding, probe input impedance, AC coupling, probe offset, and probe bandwidth.

1. Use probes with a low attenuation factor to maximize the oscilloscope's vertical sensitivity

Vertical sensitivity indicates how much the oscilloscope's vertical amplifier can amplify a signal. On most Tektronix oscilloscopes, the most sensitive vertical setting is 1 mV/division when no probe is attached. As shown in Figure 1, the measurement system's smallest vertical scale factor will be 2 mV/division when a 2X probe is attached (Channel 1) is, and the smallest vertical scale factor is 10 mV/division when a 10X probe is attached (Channel 2).

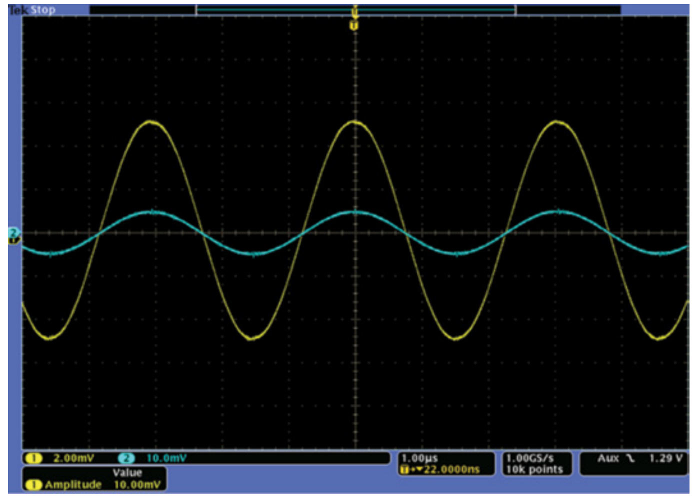

Figure 2. Probe (CH1) and 10X Probe (CH2) 10 mV Measurement.

Many Tektronix oscilloscopes have 10 vertical divisions. Using a 10X probe with the system in the 10 mV/division setting, a 100 mV signal would completely fill the screen (10 mV/division times 10 divisions). If 10 mV is again used as an example of a low voltage measurement, this signal would only span 1 vertical division on the screen using a 10X attenuation probe with the oscilloscope channel adjusted to its smallest vertical scale of 10 mV/division. This example is shown as the blue trace on Channel 2 in Figure 2. However, this same 10 mV signal measured with a 2X probe will span 5 vertical divisions since the vertical sensitivity of this channel can be adjusted to 2 mV/division. The 10 mV measurement with a 2X attenuation probe is also shown in Figure 2 as the yellow trace on Channel 1.

The user should always set the volts/division so that the signal nearly fills the screen. If not, the signal cannot be viewed with greater detail and the scope's digitizer is not fully utilized. In the 10 mV measurement example above, only 1/10th of the scope's digitizer is being used when a 10X attenuation probe is attached since the signal only spanned 1 vertical division on the screen. When the 2X attenuation probe is attached, the signal is able to span 5 vertical divisions and half of the digitizer is now being used. When more of the digitizer is used, signals are captured with greater resolution.

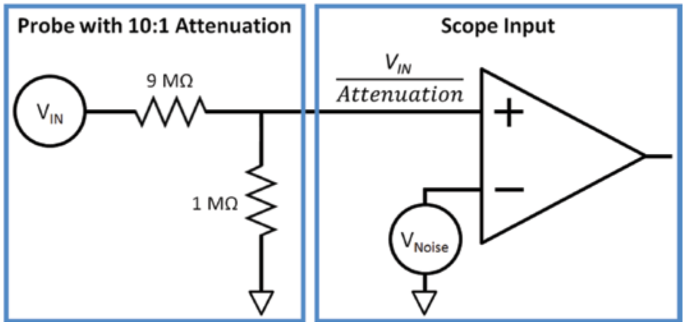

Figure 3. Input signal, probe attenuation, and random noise.

2. Use probes with a low attenuation factor to improve the measurement system's signal-to-noise ratio

A probe's attenuation factor (i.e. 1X, 10X, 100X) is the amount by which the probe reduces the amplitude of the oscilloscope's input signal. A 1X probe doesn't reduce or attenuate the input signal while a 10X probe reduces the input signal to 1/10th of the signal's amplitude at the scope input. As shown in Figure 3, the input voltage arrives at the scope input divided by the probe's attenuation factor, shown as V_{IN} divided by Attenuation.

Probe attenuation extends the measurement range of an oscilloscope, allowing signals of greater amplitude to be measured. However, when measuring low voltage signals, the probe attenuates the signal and then the oscilloscope amplifies it which causes a decrease in signal-to-noise ratio. The equation for signal-to-noise ratio (SNR) is:

$$SRN = \frac{V_{IN}}{(Attenuation)\ (V_{Noise})}$$

V_{Noise} is typically specified as *Random Noise* in oscilloscope data sheets

Equation 1. Calculation for Signal-to-Noise Ratio.

In order to use Equation 1, VIN and VNoise have to be determined. If V_{IN} is assigned a value of 10 mV as an example of a low voltage measurement, the oscilloscope would be in the 1 mV/division setting regardless of probe attenuation. An example of an oscilloscope specification for Random Noise is 150 uV + 8% of the volts/division setting, and in the 1 mV/division setting, V_{Noise} is 230 uV. SNR calculations for a 10X probe and 2X probe using these values for V_{IN}, V_{Noise} and probe attenuation are:

SNR calculation using a 10X probe

$$SRN = \frac{10\ mV}{(10)\ (230\ uV)} = 4.3{:}1$$

SNR calculation using a 2X Probe

$$SRN = \frac{10\ mV}{(2)\ (230\ uV)} = 21.7{:}1$$

Equation 2. SNR Calculations on a 10 mV Measurement using 10X and 2X Attenuation Probes.

A 2X probe has a 21.7:1 signal-to-noise ratio for a 10 mV measurement while a 10X probe has a 4.3:1 SNR. Clearly, a lower attenuation probe increases the measurement system's ratio of signal-to-noise, which makes this probe a better choice for low voltage measurements.

3. Be careful using long ground leads, especially near the transformer and switching elements

A long ground lead is convenient because the user can make one ground connection and probe many test points within the range of the ground lead. However, any piece of wire has distributed inductance, and the distributed inductance reacts to AC signals by increasingly impeding AC current flow as signal frequency increases. The ground lead's inductance interacts with the probe input capacitance to cause ringing at a certain frequency. The ring frequency is described by the following formula:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Where:
V = the ring frequency
L = the inductance caused by the probe's grounding solution
C = the probe's input capacitance

Equation 3. Ring Frequency Calculation.

This ringing is unavoidable, and may be seen as a sinusoid of decaying amplitude. As the length of the ground lead increases, the inductance increases and the measured signal will ring at a lower frequency. The effects of ringing can be reduced by limiting the length of the probe's grounding or by choosing a probe with lower input capacitance.

One simple solution to improve the ring frequency is to use a shorter piece of grounding wire such as a short ground spring. A picture of a probe with a short ground spring is shown on the left side of Figure 4. With a short ground spring, the inductance is reduced, decreasing the LC value and pushing the inductive ringing out past the frequency range of interest.

Figure 4. Chassis mount test jack.

A grounding solution with the least amount of inductance while obtaining a secure ground connection is a probe tip chassis mount test jack (Tektronix part number 131-4210-00) shown on the right side of Figure 4. The jack can be inserted into the user's test board and reduces the ground lead length to almost zero.

The grounding wire can also act as an antenna or a loop, causing capacitive and magnetic coupling effects. An added benefit of reducing the ground lead length is reduced exposure to radiated emissions near the transformer and switching devices. If a longer ground lead is required, the user should be careful not to place the grounding wire near a transformer or switching device.

4. Use probes with high input impedance

When a probe is inserted into a circuit, the probe will have some effect on the circuit under test. A probe has resistive, inductive and capacitive elements and one can imagine that if a resistor, capacitor, or inductor was inserted at the measurement point, it would change the behavior of the circuit. Users should be aware of a probe's input impedance specifications to minimize the effects of probe loading.

The interaction of resistive, inductive and capacitive elements produces total probe impedance that varies with signal frequency. To minimize probe loading, the user should use the shortest ground leads possible to minimize the inductance and use a probe with low input capacitance. An active or differential probe will offer the lowest input capacitance. Another option may be a low input capacitance passive probe such as the TPP0502, which is the only low attenuation, high bandwidth, and high impedance passive probe in the industry that is suited to make low voltage measurements on signals with high frequency content. Again, this relationship is shown in the ring frequency formula shown above in Equation 2 as a relationship between frequency, inductance, and probe input capacitance.

5. Use the oscilloscope's AC coupling feature or adjust the probe's offset

One measurement challenge is measuring a low voltage AC signal riding on top of a DC signal. There are a couple of options to help users focus in on the AC portion of the signal. When using an active probe, users should use the probe's offset control. Probe offset can be used to subtract out the DC component of the signal in the probe amplifier. With the DC portion of the signal removed, the user may now accurately evaluate and measure the AC portion of the signal. On select differential probes, Tektronix offers a feature called DC Reject. DC Reject automatically generates an internal offset that cancels the DC component of the signal.

When using a low attenuation passive probe to look at these kinds of AC signals, users should use the AC coupling feature on the oscilloscope to block the DC component and show only the AC signal. For example, with AC coupling enabled on the signal path of the oscilloscope and using the TPP0502, engineers can evaluate the AC portion of the signal down to 2 mV of resolution. This method allows the user to separate out the AC portion of the signal without having to add in the DC offset. In some cases, this kind of measurement may not be possible with an active probe due to the measurement system's limited offset range or the inability of the probe's amplifier to tolerate the large DC input.

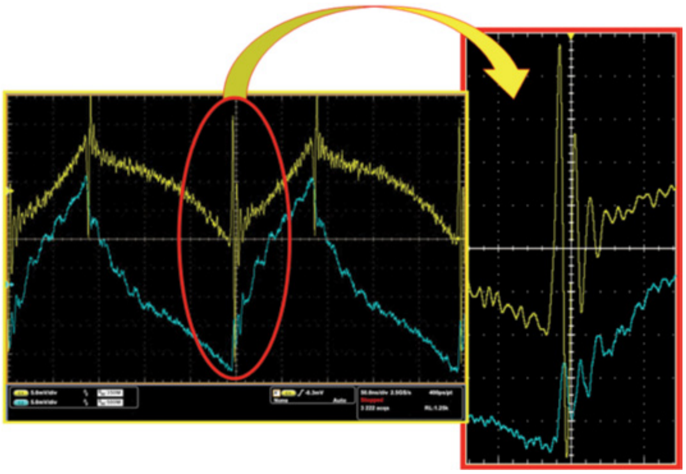

Figure 5. Low and High Bandwidth Passive Probes Capturing a Signal with Fast Edge Speeds.

6. Use a probe with sufficient bandwidth

The rule-of-thumb for selecting a probe with sufficient bandwidth is the probe should have five times the bandwidth of the signal being measured. Bandwidth is a valid specification when evaluating simple signals such as a sine wave and characterizing what is occurring in the frequency domain. However, most signals are complex and contain many spectral components which may have frequency values orders of magnitude higher than the fundamental frequency. For signals that change quickly over time and have a fast slew rate (dv/dt), the measurement system must be capable of capturing these events over time and must be able to accurately characterize what is occurring in the time domain. The specification that determines how effective the measurement system is over time is the rise time specification. Rise time is an important specification when considering the measurement system's capability of evaluating rising and falling edges and for capturing higher order harmonics. Many times, users conclude that since their signal is "not that fast", they select a probe with insufficient bandwidth or better stated, they select a probe with insufficient rise time capability.

Consider the ripple measurements shown in Figure 5. The blue trace shown on Channel 2 was captured using a P2220 probe in the 1X attenuation setting. In the 1X attenuation setting, the P2220 has 6 MHz bandwidth and has a rise time specification of < 50 ns. Many users making "Power" measurements would consider 6 MHz to be fast enough since 6 MHz is more than enough bandwidth to make a measurement on a design with switching frequencies below 1 MHz. Using the P2220 probe as part of the measurement system, the ripple characterized in Figure 5 appears very well behaved. However, the measurement on Channel 1 using a low attenuation, high bandwidth probe (TPP0502) yields a very different result. The low bandwidth of the P2220 masks high frequency signal content. The yellow trace in the highlighted area shows 50 mV of ringing. By contrast, the signal captured with the P2220 only shows ~5 mV of ringing.

What are the right probes for making low voltage measurements?

The best probes for making low voltage measurements are active or differential probes. One example is the Tektronix TDP1500 differential probe which has selectable 1X and 10X attenuation ranges. In the 1X setting, this probe doesn't reduce or attenuate the signal and will produce a measurement with greater SNR and greater resolution. One of the features that make a differential probe the best choice for a low voltage measurement such as ripple is its common mode rejection capability. Common mode rejection allows the probe to reject signals common to both probe inputs such as the coupling that can occur from a transformer or switching nodes. Active and differential probes also typically have higher bandwidth and lower probe loading effects.

A lower cost alternative with good performance is the Tektronix TPP0502. The TPP0502 shares the advantages of both passive and active probes, offering ruggedness, performance, and lower cost. Along with its low, 2X attenuation range, the TPP0502 offers high bandwidth (500 MHz), large dynamic range (300 V CAT II), and high input impedance at the probe tip with banner specifications of 2 MΩ and 12.7 pF. With its 500 MHz bandwidth, the TPP0502 offers significantly better performance than other low attenuation passive probes in the industry which offer a maximum of 25MHz of bandwidth. When a probe has limited bandwidth, it can cause the user to miss frequency content which may be affecting in the signal under test.

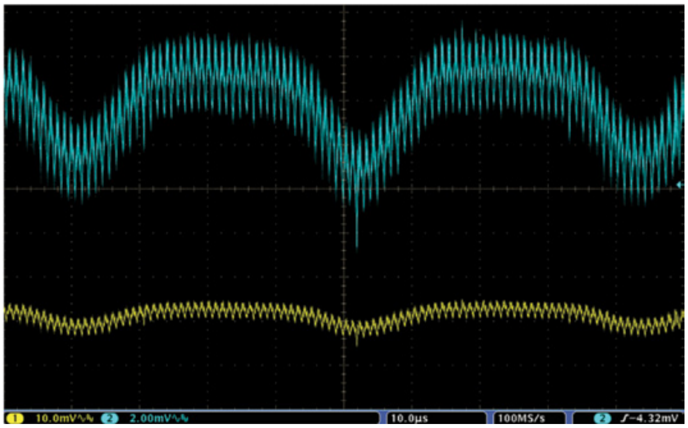

Figure 6. 3.3 V supply measured with a 2X Probe (blue) and a 10x probe (yellow).

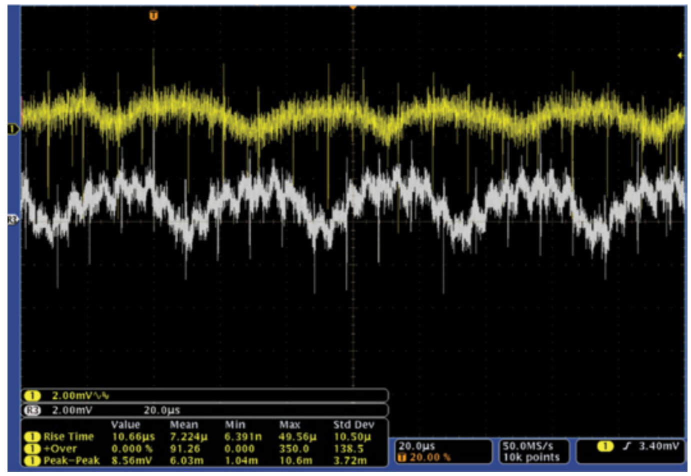

Figure 7. Probing a 3.3 V Power Supply with a 2X Attenuation Passive Probe.

Ripple Measurement Case Study

A design engineer was struggling with power supply noise. He needed to probe a 3.3 V supply, but the 10X probe he was using didn't provide him with enough sensitivity to see the small ripple voltage and he couldn't trigger on the periodic noise present in the waveform. Separating noise from ripple voltage can be a significant problem, and this kind of measurement requires a probe with low attenuation. Consider the waveforms in Figure 6. The yellow trace is a 10X probe adjusted to the lowest vertical setting of 10 mV per division and a 2X probe (TPP0502) is the blue waveform. The 2X probe can be adjusted down to its lowest vertical setting of 2 mV per division. The output of the power supply produces a signal with 3 mV of ripple, and it is clear why a probe with 10X attenuation is not effective for making low voltage measurements.

The design engineer understood the benefits of low attenuation probes for making low voltage measurements. The engineer made this comment regarding the usability of the TPP0502 - "It was a very simple matter to AC couple the signal and find the 25kHz ripple that was getting through the front end. The ease of use of this probe is fantastic- it's really just point and shoot. Doing the same measurement with an active probe means having to figure out the offset you need and dial it in. Also, thanks to the 300V CAT II rating, I didn't have to worry about accidentally touching one of the adjacent high voltage lines in the power supply. Since it has plenty of bandwidth, I was also able to see some of the other spikes in the power supply that I could be doing a better job of filtering out!" Figure 7 is a plot of the TPP0502 probing a 3.3V power supply node with the scope's vertical sensitivity set to 2mV/div, the input channel set to AC coupling, and the scope's acquisition mode set to single shot. The white reference trace is the power supply that has the noise leaking into the vertical channel, and the yellow trace is the same signal that is better behaved.

Conclusion

When making low voltage measurements, it is very important to evaluate probes by looking at their attenuation and input impedance specifications. While active or differential probes like the TAP1500 and TDP1500 are the most effective choices for measuring low voltages, the TPP0502 from Tektronix is an economical, general purpose low attenuation passive probe that is also very capable of providing accurate low voltage measurements.

Contact Tektronix:

ASEAN / Australasia (65) 6356 3900
Austria* 00800 2255 4835
Balkans, Israel, South Africa and other ISE Countries +41 52 675 3777
Belgium* 00800 2255 4835
Brazil +55 (11) 3759 7627
Canada 1 (800) 833-9200
Central East Europe and the Baltics +41 52 675 3777
Central Europe & Greece +41 52 675 3777
Denmark +45 80 88 1401
Finland +41 52 675 3777
France* 00800 2255 4835
Germany* 00800 2255 4835
Hong Kong 400-820-5835
India 000-800-650-1835
Italy* 00800 2255 4835
Japan 81 (3) 6714-3010
Luxembourg +41 52 675 3777
Mexico, Central/South America & Caribbean 52 (55) 56 04 50 90
Middle East, Asia and North Africa +41 52 675 3777
The Netherlands* 00800 2255 4835
Norway 800 16098
People's Republic of China 400-820-5835
Poland +41 52 675 3777
Portugal 80 08 12370
Republic of Korea 001-800-8255-2835
Russia & CIS +7 (495) 7484900
South Africa +27 11 206 8360
Spain* 00800 2255 4835
Sweden* 00800 2255 4835
Switzerland* 00800 2255 4835
Taiwan 886 (2) 2722-9622
United Kingdom & Ireland* 00800 2255 4835
USA 1 (800) 833-9200

*** If the European phone number above is not accessible, please call +41 52 675 3777**

Contact List Updated 10 February 2011

For Further Information
Tektronix maintains a comprehensive, constantly expanding collection of application notes, technical briefs and other resources to help engineers working on the cutting edge of technology. Please visit **www.tektronix.com**

02/12 EA/FCA-POD 51W-27668-0