Oscilloscope probes are handy tools for making measurements, but they have limitations. For example, they have rather limited bandwidth and that ground clip can create a loop that can pick up noise. You might think of using a coax cable. You can, but make sure impedance mismatches don't ruin your day.

Recently, I used a shielded coaxial cable to measure power supply ripple and the results were even noisier than using an oscilloscope probe. How can that happen? Doesn’t the shielding reduce noise? I even measured my setup using a signal generator and it all looks ok. So what was wrong?

On the surface, it seems like a great idea to use a shielded cable to measure noise. In reality, it is a great idea to use a coaxial cable to measure ripple and noise and you can gain the benefit of the shield. Another benefit is the optimization of the measurement's SNR (signal-to-noise ratio), which is obtained from using a unity-gain probe. Yet another benefit is that the resulting measurement can generally support a wider bandwidth than most probes and at a much lower cost. The measurement execution, however, requires some care.

**The nature of coaxial cables**
The coaxial cable is a transmission line, designed to have a specific impedance, usually 50Ω, though there are other standard impedances, such as 75Ω. This cable should connect to an identical impedance. In most test instruments, the signal outputs present a 50-Ω output impedance while the instrument inputs present a 50-Ω input impedance. This well-matched system results in a very wide bandwidth, flat response measurement. When this system isn't well matched, things tend to go astray.

I made five oscilloscope measurements with a 50-Ω signal generator (Picotest G5100A) connected to an oscilloscope input through a 1-m long RG174 (50Ω) coaxial cable. The signal generator produces a voltage pulse that can be measured on an oscilloscope. The signal amplitude is normalized at the oscilloscope by adjusting the signal generator's amplitude. The measurement setup is shown in **Figure 1** and the measurements are shown in Figures 2-7. **Table 1** shows the values used in the test setup.
The test setup includes a signal generator, shunt resistor, DC blocker, an oscilloscope.

Table 1. Summary of test setups.

<table>
<thead>
<tr>
<th>Setup</th>
<th>Signal Z</th>
<th>Scope Z</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50Ω</td>
<td>1 MΩ</td>
<td>The cable and generator are matched</td>
</tr>
<tr>
<td>2</td>
<td>50Ω</td>
<td>50 Ω</td>
<td>The cable, scope and generator are all matched</td>
</tr>
<tr>
<td>3</td>
<td>1Ω</td>
<td>50 Ω</td>
<td>The cable and scope are matched</td>
</tr>
<tr>
<td>4</td>
<td>1Ω</td>
<td>1M Ω</td>
<td>The cable, scope and generator are all unmaached</td>
</tr>
<tr>
<td>5</td>
<td>1Ω</td>
<td>50 Ω/2130A</td>
<td>The cable and scope are matched for AC conditions</td>
</tr>
</tbody>
</table>

The step response using Setup 1 has a slightly reduced bandwidth, evidenced by the slow rise time (Figure 2), but the measurement appears well behaved with no overshoot or ringing. In the case of measuring power-supply ripple, the signal source is the power supply and the signal impedance is generally much lower than 1Ω, but this is most closely represented using Setup 4.
Figure 2. A 50-O signal generator and 500 cable are matched and the 1-MO oscilloscope is unmatched. The waveform is well behaved and with reasonable fidelity.

**Oscilloscope at 50 ohms**

Figure 3 shows the measurement with the oscilloscope input set to 50 Ω. The signal amplitude is halved due to the 50-Ω signal generator impedance and the 50-Ω oscilloscope input forming a voltage divider. This amplitude change is not seen here because of normalizing the display amplitudes.

Figure 3. The cable, scope and generator are all matched - This is the ideal setup for minimum noise, which is why most high performance instruments have both 50Ω (or 75Ω) input and output impedance.
In **Figure 4**, you can see that while there’s a small amount of overshoot, it should be well within limits for most measurements.

![Figure 4](image1)

**Figure 4.** The 50-Ω cable and 50-Ω oscilloscope are matched while the 1-Ω signal generator is unmatched. The waveform is well behaved and maintains reasonable fidelity.

**All different impedances**

**Figure 5** shows what happens when the signal source, transmission medium, and oscilloscope inputs are all different impedances.

![Figure 5](image2)

**Figure 5.** The 50-Ω cable, 1-MΩ scope and 1-Ω signal generator are all unmatched. The waveform does not provide reasonable fidelity with severe ringing.
Suppose you see some ringing but don’t know what’s causing. Is the ringing frequency or damping time constant of any significance?

Unfortunately, unless you how the "system" is mismatched you can’t tell much. If you know what the terminations are on both sides and you know the dielectric constant of the coaxial cable, you can figure out the length of the cable. This is how the cable TV companies find damage to an underground cable. They know the impedances at both ends of the cable and the dielectric constant of the cable so they can tell where the damage is by how long a signal takes to reach it. How do they know that? They send a TDR (time-domain reflectometer) pulse and see how long it takes for the reflection to arrive at the instrument.

To maintain good signal fidelity, make sure that at least one side of the measurement setup matches the cable characteristic impedance. This means that a 50Ω series resistor can be inserted between the power supply and coaxial cable or the oscilloscope can be terminated into 50Ω (my personal preference). Inserting a low frequency DC blocker, such as the Picotest J2130A, between the coaxial cable and the 50Ω oscilloscope input removes the DC power supply voltage from the measurement. This improves the SNR by allowing you use more sensitive oscilloscope vertical scales. It also eliminates any extra power-supply load current resulting from the 50Ω termination. This recommended solution, using a DC blocker and a 50Ω scope termination, is verified in Figure 6.

![Figure 6](image)

**Figure 6.** The measurement of Figure 5 is repeated with the DC Bias Injector inserted between the coaxial cable and the oscilloscope input. The waveform is well behaved and reasonable fidelity is maintained.

**High-fidelity voltage measurements**

The technique achieves high-fidelity voltage measurements as seen in this step load. **Figure 7** shows the ripple and dynamic response of a switching regulator using the recommended technique. Note how clean the ripple signal is and also that the remaining ringing does actually exist at the output of the switching regulator.
Figure 7. Semtech SC221 1.8V 20 MHz POL with a 32 nH interconnect to the J2112A High Current (1A) Injector achieves a rise time of 10.8 nS for a 460 mA peak pulse consistent with the 11.4 nS expected for a 500 mA pulse. (Output voltage 200 mV/div top, step load current bottom, 500 ns/div).

To maintain a wide bandwidth, flat-response measurement, the coaxial cable impedance must match at least the power supply impedance or the oscilloscope input impedance. Because the power supply impedance is generally much lower than 50 &Omega, I recommend setting the oscilloscope input to 50 Ω and to insert a low-frequency DC block between the coaxial cable and the oscilloscope input.

Tips:

- It is always a good idea to measure the response, as shown here, for each new setup in order to assure the wide bandwidth, flat response measurement and also to verify the scaling.
- If an RF VNA or RF signal generator is available, the frequency response of the measurement can be evaluated using the oscilloscope's spectrum view. Use the max-hold setting (Figure 8).
Figure 8. The upper waveform is a swept sine wave from a signal generator, while the lower waveform shows the same measurement in spectrum view with max hold. The 3 dB frequency of 4.5 GHz is 10% above the rated 4 GHz oscilloscope bandwidth.