

Hands-On Learning

Scope Probes: Compensation and Loading

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Using the Oscilloscope Probe

For much work with the oscilloscope, one can make a direct, wired connection into the BNC connectors - using an alligator-clip to BNC test lead, or a Binding-Post BNC adaptor. However, when you are observing high frequencies or your signal has abrupt transitions - like a square wave - then you should use the oscilloscope probe on the $\times 10$ setting.

Connecting the oscilloscope to a circuit inevitably adds load resistance and capacitance to the circuit under measurement. The input circuitry of the oscilloscope is typically $1M\Omega$ in resistance, and about 20 picofarads in capacitance. In some measurement applications, this resistance and capacitance can have a dramatic effect on the operation of the circuit¹.

The probes supplied as an accessory for the this oscilloscope have a two position switch: $\times 1$ and $\times 10$. In the $\times 10$ position, the probe has much less of an effect on the measurement than in the $\times 1$ position and by direct connection. The resistance increases by a factor of 10 to $20M\Omega$. The capacitance decreases to about 2 picofarads. In exchange, the signal is reduced by a factor of 10 when the probe is in the $\times 10$ position.

On the CGR-101 oscilloscope, you can automatically adjust the oscilloscope vertical setting for the effect of the $\times 10$ probe. Click on the $\times 10$ button for Channel A or Channel B, and the oscilloscope will read out directly in the signal voltage. The graticule magnitude and the cursor readouts automatically change to the correct value with a $\times 10$ probe. (Without this feature, you need to mentally multiply oscilloscope magnitude readings by a factor of 10).

The first time you are using a $\times 10$ probe with an oscilloscope, you need to adjust the *compensation*. This changes a small capacitance inside the probe, so that the probe has the same frequency response at all frequencies – or what is the same effect in the time domain – adjusts the square wave response so that there is no overshoot or undershoot.

Exercise: Compensating a $\times 10$ Oscilloscope Probe

1. Refer to figure 1. Connect the oscilloscope probe to Channel A of the oscilloscope. Rotate the part of the probe near the BNC connector so that a small hole is visible from the top.
2. Install a BNC-Binding Post adaptor on the BNC connector for the output of the signal generator.
3. Connect a short piece of bare wire to the red binding post of the generator connector. Clip the scope probe to that bare wire.
4. Connect the ground clip for the scope probe to the black binding post of the generator connector.
5. Ensure that the $\times 1$ - $\times 10$ switch on the oscilloscope probe is set to the $\times 10$ position.

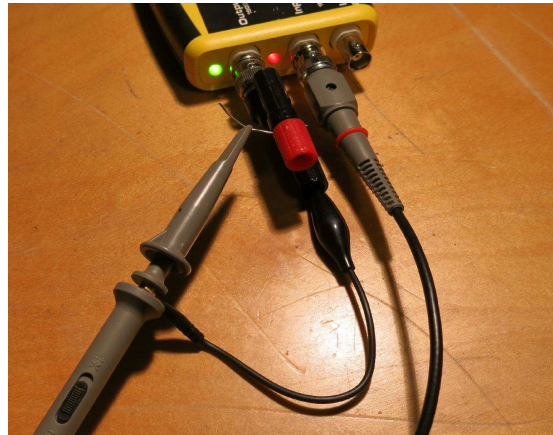


Figure 1: $\times 10$ Probe Compensation Adjustment

¹In one particularly frustrating case, the circuit started to work correctly when the oscilloscope was connected, so it was impossible to see the signal when the circuit was malfunctioning.

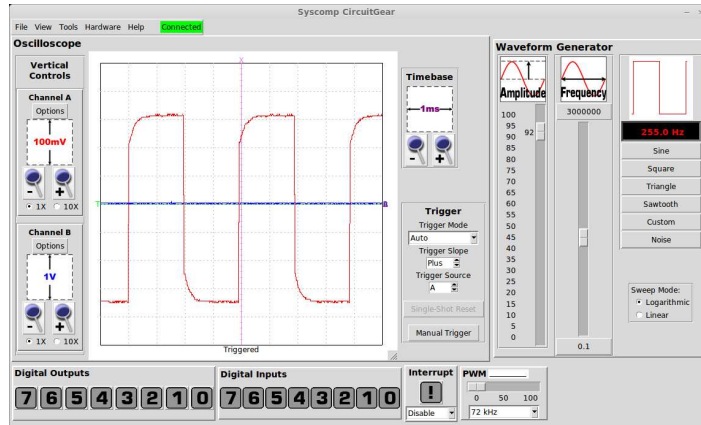


Figure 2: Undercompensated

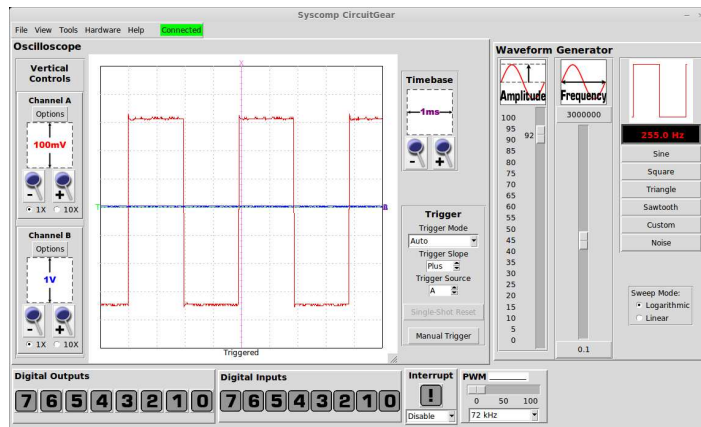


Figure 3: Correctly Compensated

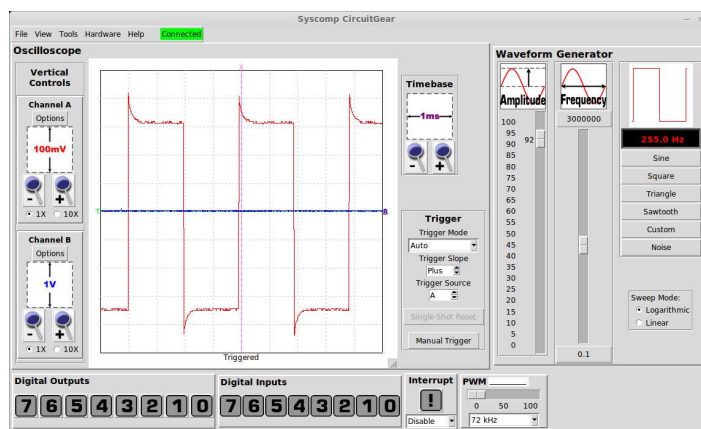


Figure 4: Overcompensated

6. Now refer to figure 2 on page 2. Set the generator and oscilloscope controls as shown in that screenshot:
 - generator frequency 255 Hz, amplitude 90, square waveform.
 - oscilloscope $\times 1$ - $\times 10$ buttons set to $\times 10$.
 - oscilloscope vertical: 1 volt per division.
 - oscilloscope timebase: 1mSec per division.

You should see an oscilloscope display that resembles one of the screenshots of figure 2, 3 or figure 4.

7. Insert the blade of a small screwdriver into the hole of the base of the probe. Rotate the screwdriver and you will see the scope trace change from undercompensated (figure 2) through to overcompensated (figure 4). Adjust the trace until it appears as properly compensated, figure 3.

The probe is now correctly adjusted.

Oscilloscope Probe Loading Effect

In this section, we explore the effect of oscilloscope probe *loading* on a measurement circuit.

If you haven't done so already, go through the procedure to compensate the oscilloscope probe.

Set up the circuit shown in figure 5. This is similar to the circuit used for probe compensation, but with a $1\text{M}\Omega$ resistor attached to the output of the signal generator. The internal resistance of the generator is 150Ω , which is small enough to be ignored in this exercise. Then the $1\text{M}\Omega$ resistor represents the *source resistance* of the circuit being measured. When the probe is connected to the right end of the resistor, at the generator output, the source resistance is 150Ω , which we'll treat as zero. When the probe is connected to the left end of the resistor, the source resistance is $1\text{M}\Omega$.



Figure 5: $\times 10$ Probe Loading Circuit

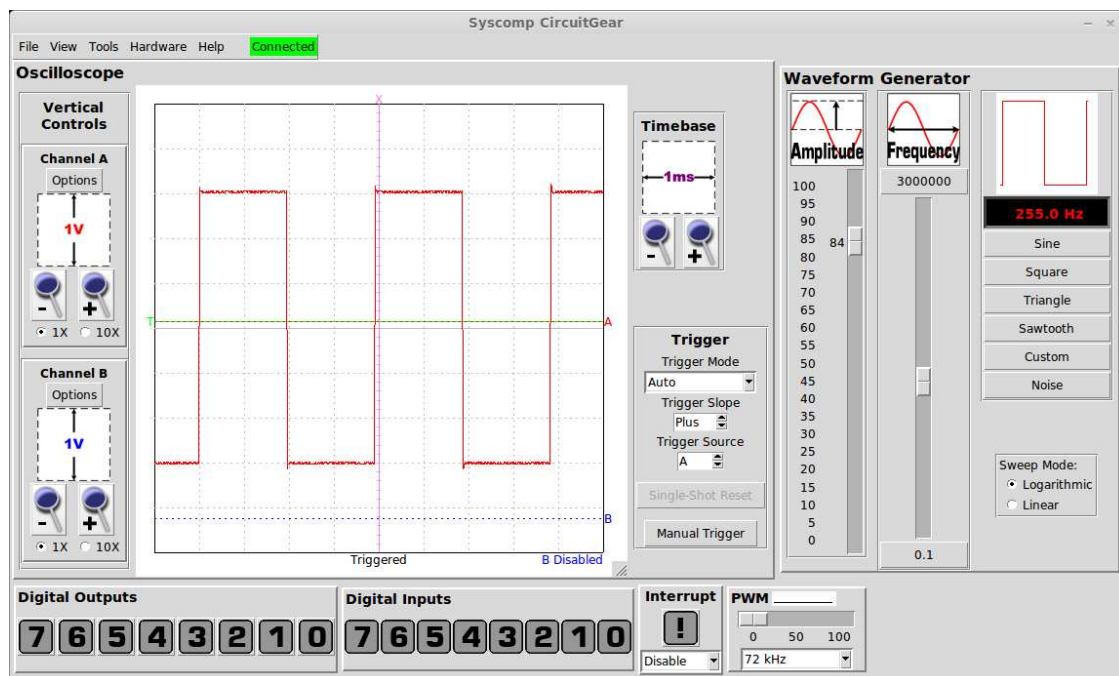


Figure 6: Loading Exercise Start Screen

Loading effect of $\times 1$ Probe

1. Connect the scope probe to the output of the generator, as shown in figure 5. Set the scope probe to the $\times 1$ position.
2. Select the `Square` waveform. Adjust the amplitude of the generator so that the oscilloscope waveform is 6 volts peak-peak.
3. Disable Channel B and drag the Channel A trace so that it is symmetrical around zero volts. You should see a display something like figure 6.
4. Now move the oscilloscope probe to the other side of the $1M\Omega$ resistor.

What two effects have occurred on the waveform display? Is the waveform display still accurate?

Explain:

Optional: Using the oscilloscope results, determine the effective resistance and capacitance of the oscilloscope probe in the $\times 1$ position.

Results:

Loading effect of $\times 10$ Probe

1. Connect the scope probe to the output of the generator, as shown in figure 5. Set the scope probe to the $\times 10$ position. On the oscilloscope, under Channel A, select the $\times 10$ position and adjust the vertical scale factor on Channel A back to 1 volt per division. Again, the oscilloscope trace should appear as in figure 6.
2. Move the oscilloscope probe to the other side of the $1M\Omega$ resistor, so that the measurement source resistance is now $1M\Omega$.

What is the effect on the waveform magnitude and rise time?

Results:

What is the effect of the $\times 10$ probe?

Results:

Optional: Using the oscilloscope results, determine the effective resistance and capacitance of the oscilloscope probe in the $\times 1$ position. To determine the capacitance, you'll need to speed up the timebase significantly.

Results:

Measuring Probe Parameters

Here's an example calculation:

When the probe is set to x1 or x10, the output voltage directly from the generator is 6 volts peak-peak. Call this E_{oc} , the open circuit voltage.

x1 Probe Setting, Resistance Measurement: With a $1M\Omega$ source resistance R_s , the measured pulse amplitude is 3.0 volts peak-peak. Consequently, the $1M\Omega$ source resistance and the probe load resistance R_l are acting as a voltage divider. Since the probe voltage is half the open circuit value under this condition, the load resistor is equal to the source resistance, ie, $1M\Omega$.

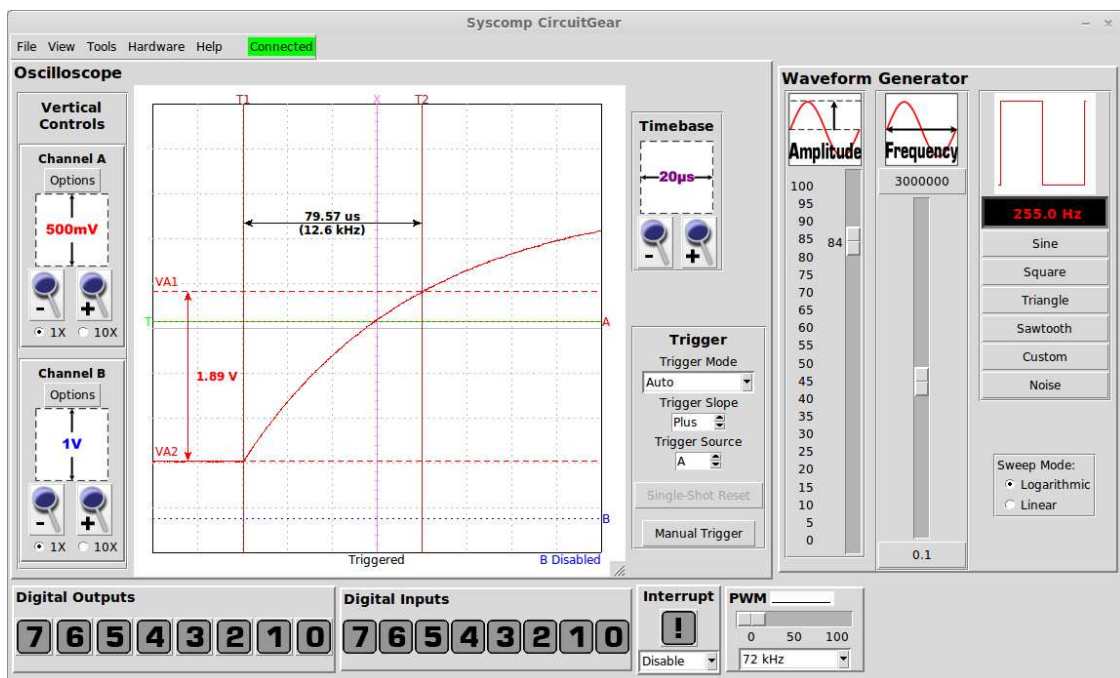


Figure 7: Measuring Time Constant

x1 Probe Setting, Capacitance Measurement The step waveform reaches 63.2% of its final value in one time constant RC where R is the effective source resistance and C the probe capacitance. Set the amplitude cursors to indicate 63.2% of the final value: 1.89 volts. Then set the time cursors to measure from the start of the rise to a voltage of 1.89 volts. The result is $79.6\mu\text{Sec}$. (See figure 7).

The effective value of the resistance R is the Thevenin equivalent of the source resistance R_s ($1M\Omega$) and the load resistance R_l (also $1M\Omega$), which is $500k\Omega$.

Now some math:

$$RC = 75 \times 10^{-6} R = 500 \times 10^3$$

Solve for the capacitance:

$$C = \frac{79.4 \times 10^{-6}}{500 \times 10^3} = 158 \times 10^{-12}$$

In words, in the $\times 1$ position the probe appears as a $1M\Omega$ resistor in parallel with a 150 picoFarads capacitor.

In the $\times 10$ position, the resistance should increase to $1M\Omega$ and the capacitance decrease to 15 picoFarads. Let's see if that's the case.

$\times 10$ Probe Setting, Resistance Measurement: The pulse amplitude is 5.46 volts. Then apply the voltage divider equation:

$$E_{oc} \times \frac{R_l}{R_s + R_l} = 5.46 \text{ volts}$$

Substitute $E_{oc} = 6$ and $R_s = 1M\Omega$, and solve for R_l :

$$6R_l - 5.46R_l = 5.46M\Omega R_l = 10.1M\Omega$$

This calculation is very sensitive to measurement errors, so take the results carefully.

$\times 10$ Probe Setting, Capacitance Measurement

Using the same technique as previously, the measured value of time constant is 19.13μ sec.

The Thevenin source resistance R is:

$$R_s \parallel R_l = 1 \times 10^6 \parallel 10 \times 10^6 = 0.909M\Omega$$

Solving for the capacitance:

$$C = \frac{19.13 \times 10^{-6}}{0.909 \times 10^6} = 20.9 \times 10^{-12}$$

The the $\times 10$ probe appears as a $10M\Omega$ resistor in parallel with a 20 picoFarad capacitor.