Keysight Technologies

Component Testing Using an Oscilloscope with Integrated Waveform Generaor

Application Note

Introduction

This application note describes methods for testing components using an oscilloscope and waveform generator. We will show you how to test capacitors, inductors, diodes, bi-polar transistors, output resistance and cables. These test methods can be used to confirm a defective component or identify the value of an un-marked component.

KEYSIGHT TECHNOLOGIES

Test Configuration

The general idea behind this method of component testing is to apply a stimulus to the component using a waveform generator and measure the response using an oscilloscope. The Keysight Technologies, Inc. InfiniiVision X-Series oscilloscope has a built-in waveform generator, making it a convenient "one-box" solution for component testing. This is not a complete substitute for specialized component testers, which provide better accuracy and more comprehensive testing; however, specialized testers may not be readily available. In that case, this is a "quick and dirty" way to test components with more commonly available equipment.

Figure 1 illustrates the measurement configuration. The waveform generator output is connected to the oscilloscope input, with a "tee" off to the component, also referred to as the device under test (DUT). For better time-resolution measurements of cables, you can use the TRIGGER OUTPUT as an alternative output instead of the waveform generator output (discussed latter in this application note). For testing of surface- mount components, we recommend the Keysight 11060A (or equivalent) surface mount device probe. The waveform generator voltage, Vsrc, is applied to the DUT through the waveform generator's 50-ohm source resistance. The oscilloscope input channel measures the voltage across the DUT. The oscilloscope is triggered from the waveform generator. In Keysight's X-Series oscilloscope, this trigger connection is built-in, eliminating the need for an additional cable connection and trigger configuration steps. You simply select the built-in waveform generator as the trigger source.

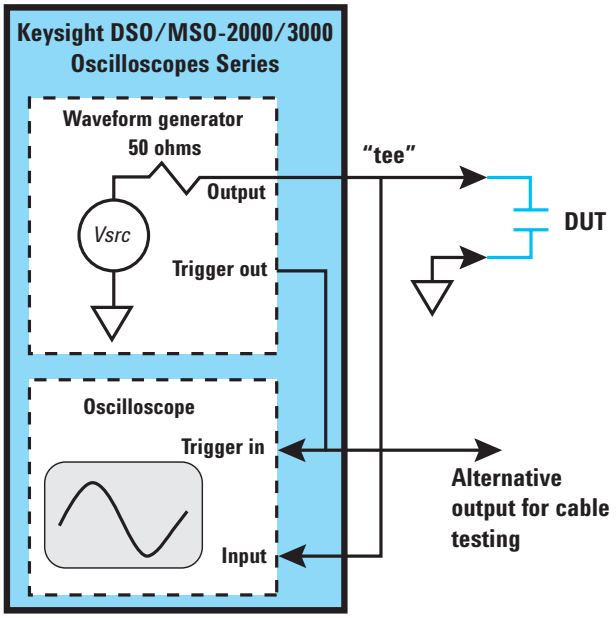

Figure 1. Test configuration

Capacitor and Inductor Testing

For testing capacitors and inductors, a 10-Hz 100-mVpp square wave is used as the stimulus. Using such a low voltage makes in-circuit testing of the DUT possible without biasing semiconductor devices that may be connected to the DUT. Also this low voltage minimizes reverse leakage current on polarized capacitors, which may degrade measurement accuracy.

Figure 2 shows the oscilloscope measurement without a DUT connected. Averaging is used to reduce noise and therefore improve accuracy. The automatic Min voltage, rise time and fall time (10%-90%) measurements are turned on, and the trigger point location is set to the left side.

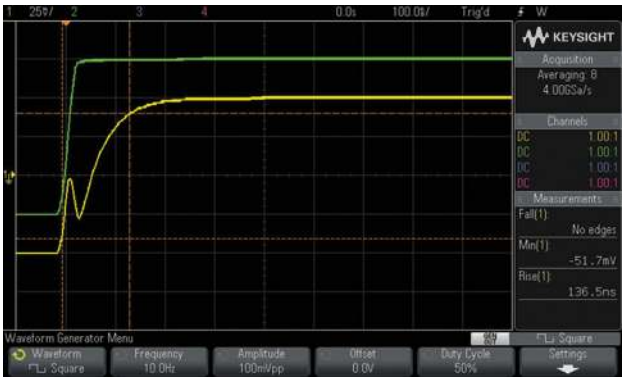

Figure 2. Capacitor and inductor measurement: without a DUT connected (green trace); with a 1 nF capacitor as the DUT (yellow trace).

Capacitor Testing

When the DUT is a capacitor, the circuit configuration is a classic R-C network, with R being the 50-ohms source impedance of the function generator. The input impedance of the oscilloscope is 1 Mohm, much greater than the waveform generator's 50-ohms source impedance, and therefore can be ignored. The DUT's capacitance value, *Cdut*, can be calculated from the rise time (10%-90%) measurement using the following formula:

$$Cdut = 0.0091 * \text{risetime} - \text{Ctest}$$

For the most accurate measurement, you should measure and account for the capacitance of the test system, *Ctest*. The method recommended to determine *Ctest* is to measure a known good, accurate 1 nF capacitor, and subtract 1 nF from the measured value to get *Ctest*. Figure 2 shows such a measurement for a 1 nF capacitor. From the rise time measurement shown in Figure 2 the calculated capacitance value is 1.24 nF. Thus *Ctest* is about 0.24 nF.

You should be careful to adjust the oscilloscope's s/div setting to display the complete transition, but not to make it so slow that there is insufficient resolution to measure the transition accurately. A good rule of thumb is to set the s/div between one-half and twice the measured rise time or fall time. For example, if the measured rise time is 175 nS, then the s/div should be set to either 100 nS/div or 200 nS/div.

Once *Ctest* is known, then you can test capacitor values larger than 1 nF. The upper limit of capacitor values that can be tested is limited to 100 uF by the waveform generator frequency. You can test larger values by decreasing the waveform generator frequency.

Note the "spike" at the beginning of the edge transition. This spike occurs during the time required for the stimulus edge to travel through the test system cable to the DUT and return. The spike is the primary reason that capacitor values less than 1 nF cannot be tested accurately. You can reduce this spike by using a very short connection (< 6") to the DUT, which would enable testing of capacitor values as low as 250 pF.

Inductor testing

When the DUT is an inductor, an R-L network is formed. In this case, you measure the fall time. In addition, you measure *Vmin* to determine the inductor's DC resistance (DCR). This DCR is added to the waveform generator's 50-ohm output resistance to determine the total R value. The formula relating inductance to fall time is derived as follows:

$$Ldut = 0.45 * \left(50 - \frac{(50 * Vmin)}{(0.05 + \mathrm{Vmin})}\right) * \mathrm{falltime}$$

The rise time of the waveform generator limits the minimum inductance value that can be tested to 10 uH. The upper limit depends on the inductor's DCR. If DCR is too high, the oscilloscope will not measure the fall time automatically. You could, however, measure the fall time manually, if necessary.

Figure 3 shows the measurement for a 1200 uH inductor. Note that there is a visible DC-voltage drop due to the inductor's DCR. The calculated inductance measurement, *Ldut*, is about 1208 uH.

Figure 3. 1200 uF inductor measurement

A defective inductor or capacitor will measure the wrong value or likely appear as an open or short. An open DUT will look like the unconnected DUT shown in Figure 2. , whereas a shorted DUT will look like a horizontal trace.

Diode and Bi-polar Transistor Testing

For testing of diodes, configure the waveform generator to a +/-2.5 V ramp signal at 100 Hz. This is a low-frequency test, so high-resolution mode should be used to reduce noise. Also the automatic Max and Min voltage measurements are turned on, and the trigger point is set to the middle. Figure 4 shows the oscilloscope measurement without a DUT connected.

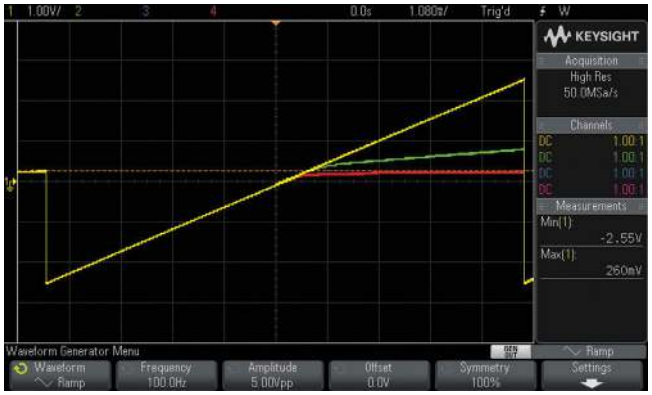

Figure 4. Diode and transistor measurement: without a DUT connected (yellow trace); with a small signal silicon diode as the DUT (green trace); with a power Schottky diode as the DUT (red trace).

This test method differs from that of a traditional curve tracer. A curve tracer plots a DUT's current versus voltage. In this test method, however, the oscilloscope's horizontal axis represents the waveform generator voltage, and the vertical axis represents the voltage across the DUT. Unlike a curve tracer, the amplitude of the waveform generator is not high enough to test reverse breakdown voltages.

This test method can apply a fair amount of current to the DUT. For example, if there is a 0.7 V drop across a diode, then that leaves a maximum of 1.8 V across the waveform generator's 50-ohm output resistance. This means the current flowing through the diode can exceed 36 mA. If the component being tested cannot tolerate this current level, then reduce the amplitude of the waveform generator.

Diode Testing

Figure 4 shows measurements for a small signal silicon diode and a power Schottky diode.

Note the small signal diode turns on at about 400 mV, as expected, and has a noticeable positive slope due to its relatively high ON resistance.

Contrast this to the power Schottky diode, which turns on at a lower voltage of 260 mV, which is expected with this type of diode.

A defective diode will likely appear as an open or short. An open diode will look like the unconnected DUT shown in Figure 2, whereas a shorted diode will look like a horizontal trace.

LEDs can also be tested using this method. The waveform generator offset can be increase to supply more voltage to the LED, if needed.

Bi-polar Transistor Testing

To test bi-polar transistors, use the same method detailed above to test diodes. First confirm that both the Emitter-Base and Collector-Base junctions behave like a diode. Finally confirm that the Collector-Emitter is not shorted, i.e., it should behave like an open circuit.

Output Load Line and Resistance

To measure the output load line of a device or circuit, start with the same technique as above for a diode and then export the measurement data to a spreadsheet to calculate the load line. The DUT's output resistance can then be calculated from the load line.

For example, Figure 5 shows the measurement of a 74ACT08 logic gate output in the high (+5 V) state. The waveform generator is configured to output 5 V to 0 V ramp signal at 100 Hz into the logic gate output.

Figure 5. Output resistance measurement: without a DUT connected (yellow trace); with a 74ACT08 DUT attached (red trace).

The current out the gate is the difference between the measured voltage and the waveform generator output voltage, divided by 50 ohms. The measured voltage can then be exported to a spreadsheet to calculate and plot the load line, as shown in Figure 6.

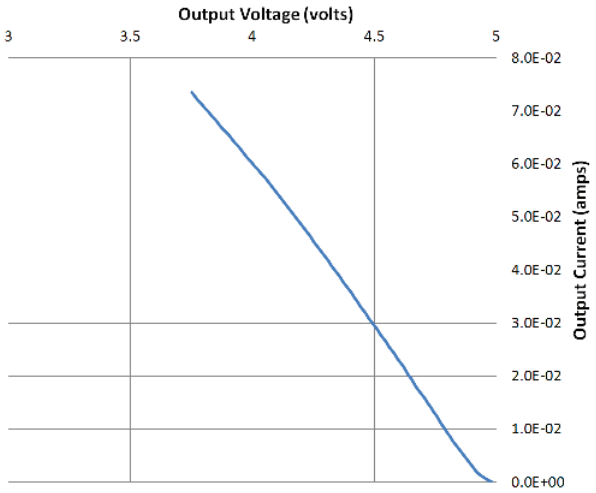

Figure 6. Measured load line for a 74ACT08 logic gat output.

Output resistance is simply the voltage drop divided by the output current. For example, at an output current of 60 mA, the voltage drop is 1 V (i.e., 5 V – 4 V), which corresponds to an output resistance of 16.7 ohms.

As with diode testing, this test method may exert current levels beyond the DUT's safe limit. If that is the case, reduce the voltage swing as appropriate.

Cable Testing

For testing cables, you can use a low-speed time-domain reflectometer (TDR) method. For accurate impedance measurements, the signal-source amplitude must be accurate. But for higher resolution time measurements, the rise time of the stimulus step must be fast. The waveform generator output provides accurate amplitude with an 18 nS rise time. If better time resolution is needed, the waveform generator can be configured to provide a much faster rise-time step (~3 nS) on the TRIGGER OUTPUT with approximate 5 V of amplitude. In this case, the TRIGGER OUTPUT would be used instead of the Waveform Generator Output as the stimulus. For purposes of the following discussion, the waveform generator output is used.

The waveform generator is configured to output a 100 Hz, 0 V to 1 V square wave, as shown in Figure 7. Averaging is used to reduce noise, and the trigger position is set to left side. Cursors are used for manual measurement of waveform parameters.

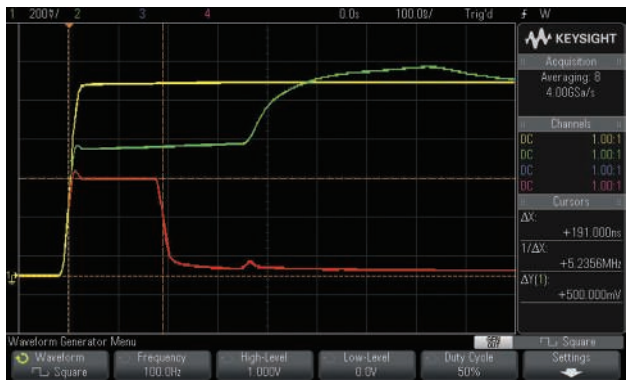

Figure 7. Cable test measurement: without a DUT connected (yellow trace); with twisted wire as the DUT (green trace); with shorted RG-58 as the DUT.

Figure 7 shows the measurement for an unknown length of twisted line wire. The impedance of the twisted wire, Zcbl, can be calculated using the following equation:

$$Z_{cbl} = \frac{50 * \Delta Y}{1 - \Delta Y}$$

ΔY is the voltage at the first step (the step at the trigger point), measured manually using the oscilloscope's cursors. In this case, *ΔY* is 660 mV (not shown in Figure 7). Thus *Zcbl* is calculated to be about 97 ohms, a typical value for twisted wire. The far end of the twisted wire is an open circuit, indicated where the voltage level suddenly increases.

Also shown in Figure 7 is a measurement of an unknown length of RG-58 cable. From the *ΔY* measurement, the impedance can be calculated to be 51 ohms. This is the expected value for RG-58. The measurement also indicates, however, that the cable is shorted down line, where the voltage returns to zero. If the *propagation_delay* of the cable is known, then the *distance* to the short can be calculated using the following formula:

$$\text{distance} = \frac{0.5 * \Delta X}{\text{propagation_delay}}$$

The *propagation_delay* for RG-58 is 1.54 nS/ft. *ΔX* is measured manually with the cursors to be 191 nS. Thus the *distance* to the short is calculated to be 62 feet.

Conclusion

We have shown how to perform basic testing of a range of components using two commonly available pieces of equipment: an oscilloscope and a waveform generator. The Keysight Technologies InfiniiVision 2000 and 3000 X-Series oscilloscopes, with built-in waveform generator and integrated triggering, are ideally suited for making these measurements.

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