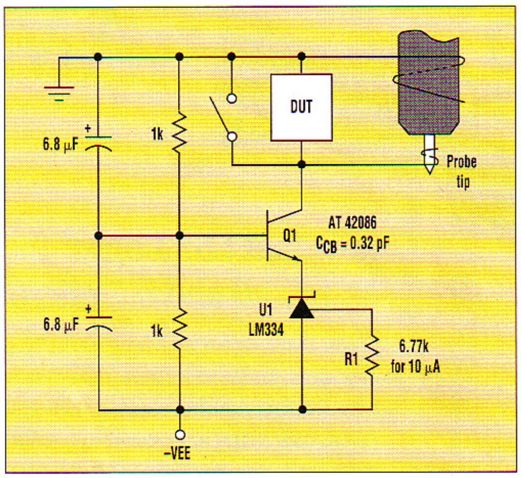
Simple Circuit Measures Voltage-Dependent Capacitance

There are many techniques for measuring capacitance. Some of these techniques require a function generator to provide either a sinusoidal or step-function voltage source. The design idea presented here has the advantage of requiring no special excitation source. Instead it relies on a simple test circuit, along with the single-shot capture and measurement capabilities inherent in digital oscilloscopes (DSOs).

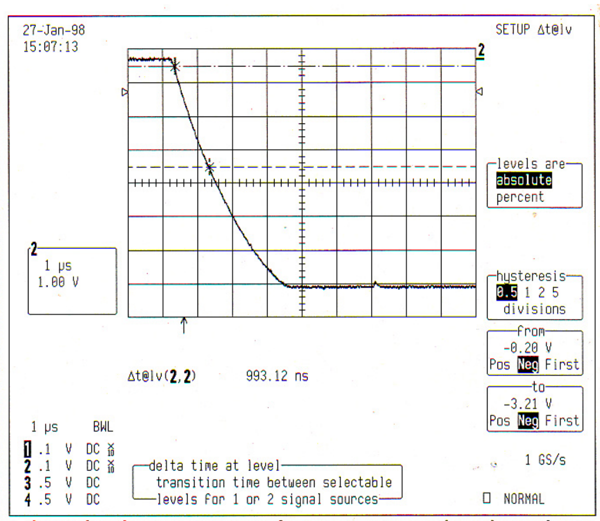


1. This circuit, combined with DSO capture features, accurately measures very small capacitances without requiring a special excitation sources.

The circuit can accurately measure very small capacitances, and also is able to accurately measure capacitances that change as a function of applied voltage. An example of devices which feature voltage-dependent capacitance is a reversed-biased p-n junction, such as the collector-base junction of a bipolar transistor. Another example is a TVS (transient voltage suppressor diode) device.

The test circuit consists of a single npn transistor (Q1) configured in a common-base connection *(Fig. 1)*. U1 is a constant-current source (LM334) in the emitter leg of the transistor. The transistor exhibits very low collector-base capacitance (C_{CB} = 0.32 pF typical). This specification is critical to the design, as the actual voltage swing across the DUT will occur between the collector of the transistor and ground. The base of the transistor is biased with a constant dc voltage equal to ½ of the supply voltage ($-V_{EE}$). Maximum V_{CE} for the transistor used in this circuit is 12 V, therefore $-V_{EE}$ should be limited to about -22 V maximum.

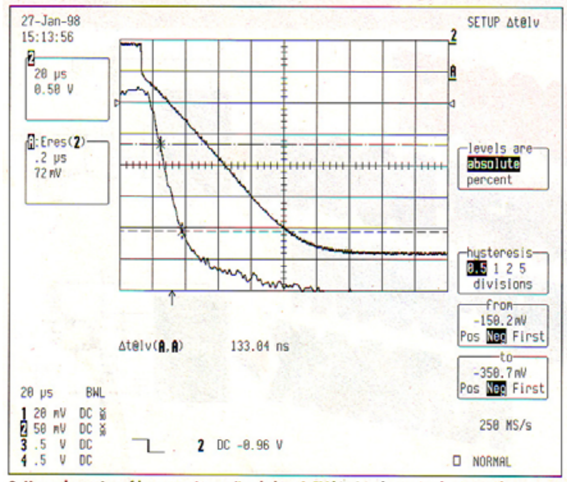
The circuit works as follows. The LM324 constant-current source (U1) is programmed for a cathode current of 10 µA by the selection of R1 (67mV/R1 = $I_{CATHODE}$). The capacitance to be measured is connected between circuit ground and the collector of Q1. A low capacitance switch is used to short the collector of Q1 to ground. Please note-I used the sharp edge of a simple clip-lead to manually contact the ground node, making a very low capacitance connection.



2. The waveform shown is a measurement of test circuit capacitance without a device under test.

A very low capacitance scope probe (FET type) is attached to the circuit as illustrated in Figure 1. A digital oscilloscope is used in single-shot capture mode to capture the falling edge of the voltage waveform, which appears across the DUT after the short is released. The unknown capacitance is charged by the constant current source through Q1. With proper triggering, the entire voltage waveform can be captured.

The programmed current of the constant-current source can be changed, depending on the range of capacitance value to be measured, and is not critical. The selected value of charging current determines the slope of be displayed waveform. The voltage response (slope) can be made arbitrarily slow so that inductances inherent in the circuit won't affect the measurement.

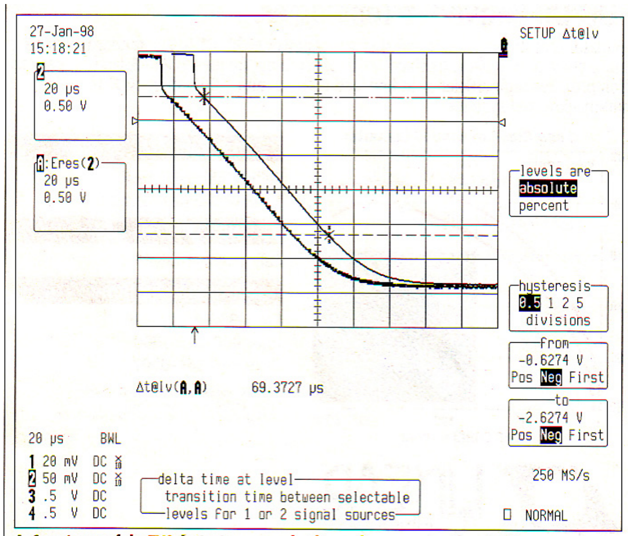


3. Here, the region of low capacitance (i.e. below 0.5V bias) is determined using a "low-capacitance" transient-voltage-suppressor (TVS) device as the DUT.

The displayed results can be analyzed as follows. Because the DUT has been charged with a constant-current, the capacitance of the device is simply :

$$C = I/(dV/dT)$$

Both the time and voltage parameters (slope of the captured voltage waveform) can be measured directly from the displayed waveform. Devices with a fixed capacitance will display a linear slope characteristic (up to the saturation voltage of Q1). Devices with capacitance that is voltage-dependent will show a varying slope characteristic. Capacitance can be directly measured at any bias voltage for devices with a voltage-dependent capacitance.



4. Capacitance of the TVS device is measured at bias voltages greater than 0.5 V.

Certain features of typical modern DSOs make these type of measurements particularly convenient. LeCroy oscilloscopes have a measurement feature called "delta-time-between-levels," which allows a direct measurement and readout of the delta-time between two cursor-selected voltages on any displayed waveform (s. 2,3, and 4).

The waveform displayed in Figure 2 is captured with the measurement circuit alone, without any DUT. Therefore, this is a baseline measurement of the capacitance of the test circuit. This consists of the capacitance (C_{CB}) of Q1, the scope probe, and the parasitic capacitances of the physical test circuit. The measured value (3.3 pF) will be subtracted from subsequent measurements.

Figure 3 displays a waveform obtained when the DUT is a TVS device. Such a device is termed a "low-capacitance-type" TVS. The manufacturer achieves a low capacitance by inserting a high-speed rectifier (with low capacitance) in series with the TVS diode. It can be seen in the displayed result that the capacitance of the device is indeed very low (3.4 pF) when the device is biased with up to 0.5 Volts. However, above this bias voltage, the internal rectifier diode is conducting, and the capacitance of the TVS device now dominates.

Figure 4 displays two waveforms. Trace 2 is the entire captured waveform showing TVS characteristics from 0 V on up to its breakdown voltage with a bias current of 10 µA (this is a 3-V TVS device). The expanded trace (A) is an expansion of the region from 0 V to approximately-0.5 V (the region of low capacitance). Measurement on this expanded trace yields the capacitance value of 3.4 pF.

This is a convenient technique which uses a simple, small, and portable circuit to measure voltage-dependent capacitance characteristics. This circuit also has been used to measure the parasitic capacitances at input connectors and other areas of pc boards, which could not easily be driven by sinusoidal voltage sources or connected to test instruments for direct measurement.