# Measuring pH and fF with a TDR using a cursor measurement

The TDR is an instrument that is often used to measure printed circuit board (PCB) test coupons and cable impedance. The TDR is also quite useful for measuring the inductance and capacitance of vias and component pads, probe tip capacitance and inductance and even the parasitic inductance transceiver coupling capacitor. It is also a simple way to validate your Hyperlynx simulations or to extract your own model. High-end dedicated TDR's often include this capability, but even using a simple real-time oscilloscope-based can produce these results, using a simple cursor measurement.

You can download my setup file for the Picotest J2151A and Tektronix MSO 5/6 oscilloscope.

## Theory and Simulated Result

The fundamental TDR measurement is the reflection coefficient, Γ, and this data trace is provided by nearly every TDR, including the J2151A using the setup file referenced above. The TDR determines the impedance of the transmission line (cable or PCB trace) using a transform from Γ and the TDR impedance, typically 50Ω.

$$Z_{TL} = Zo\frac{1+\Gamma}{1-\Gamma} \quad (1)$$

This impedance transform is also included in the above referenced setup file. For a transmission line with uniform Γ (or impedance) the displayed TDR trace is a flat line, requiring little interpretation. Gated cursors are used to display the mean impedance value between the cursors.

When the transmission line is not uniform or a component is attached, the displayed TDR trace is not flat, and this is where interpretation is required.

Positive "blips" in the reflection coefficient, Γ, represent series inductance while negative going "blips" in the reflection coefficient, Γ, represent shunt capacitance.

The series inductance and shunt capacitance can be obtained from the reflection coefficient as:

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$$L = 2 \cdot R_{ref} \cdot \int_0^{\infty} reflection \qquad (2)$$

$$C = \frac{2}{R_{ref}} \cdot \int_0^{\infty} reflection \qquad (3)$$

A simple simulation can be used as an example. The example, shown in Figure 1, includes both a series inductance and a shunt capacitance.

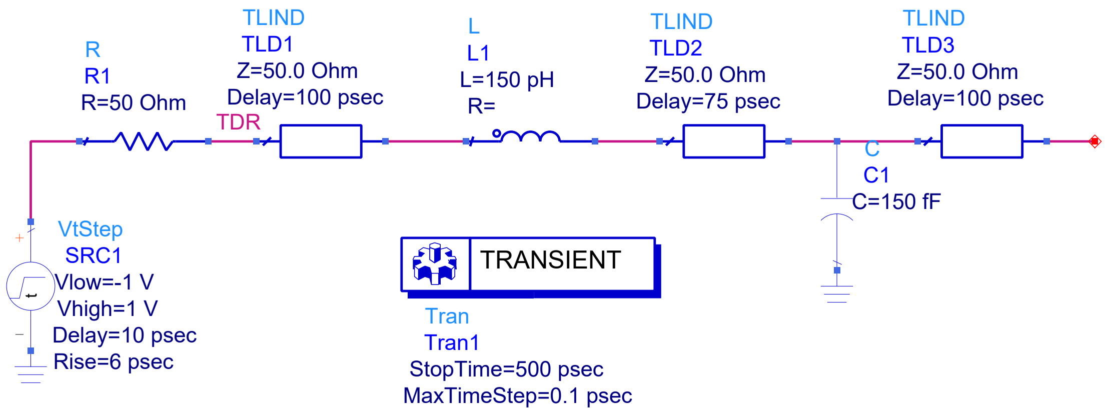


*Figure 1 Simulation example used to simulate the reflection coefficient for a 150pH and 150fF capacitor, placed between short 50 Ohm traces*

The simulation result is shown in Figure 2.

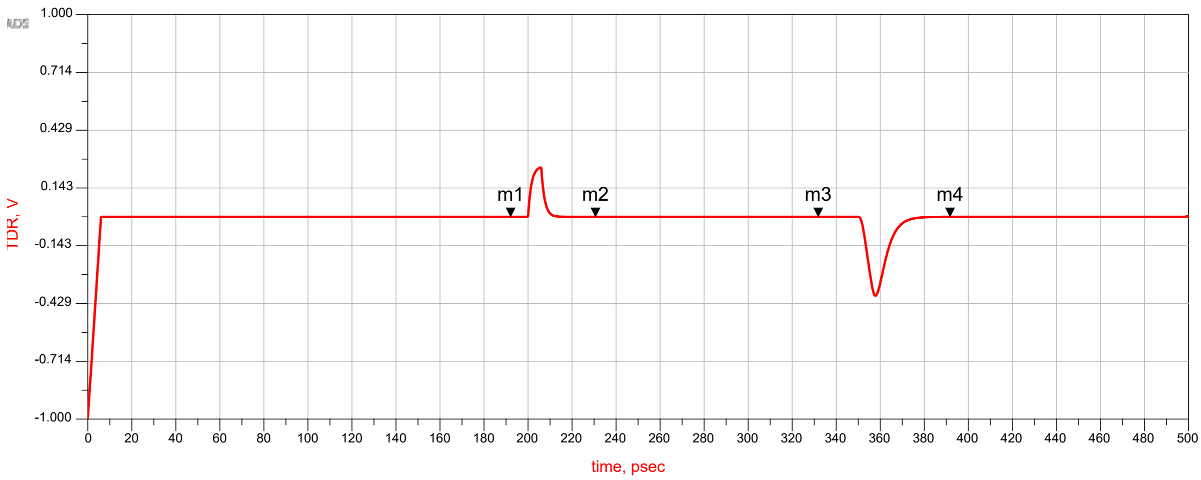


*Figure 2 The inductor generates a positive "blip" and the capacitor generates a negative "blip". Using equation 2 and equation 3, the inductance and capacitance are accurately computed.*

The first "blip" in this simulation result is the series inductor, which is located at the end of a 100ps transmission line. The TDR sees the round-trip path, so correctly displays 200ps.

The shunt capacitance is placed 75ps after the series inductor, and again the TDR correctly sees the round-trip path as 2*(100ps+75ps) or 350ps.


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Markers, placed before and after each "blip", are used as the integration time. The placement of the markers is not critical since flat regions before and after the blip contribute little to the integration result.

## Experimental Result

A 500fF chip capacitor is soldered to one coplanar demo PCB. The center trace of a second coplanar demo board is cut, and a 10nF series capacitor is soldered across the cut. This will allow measuring the ESL of the capacitor.


*Figure 3 Two coplanar demo boards are used for the experimental measurements. A 500fF chip capacitor is soldered in shunt at the center of one demo board and a 10nF chip capacitor is soldered in series at the center of the second demo board.*


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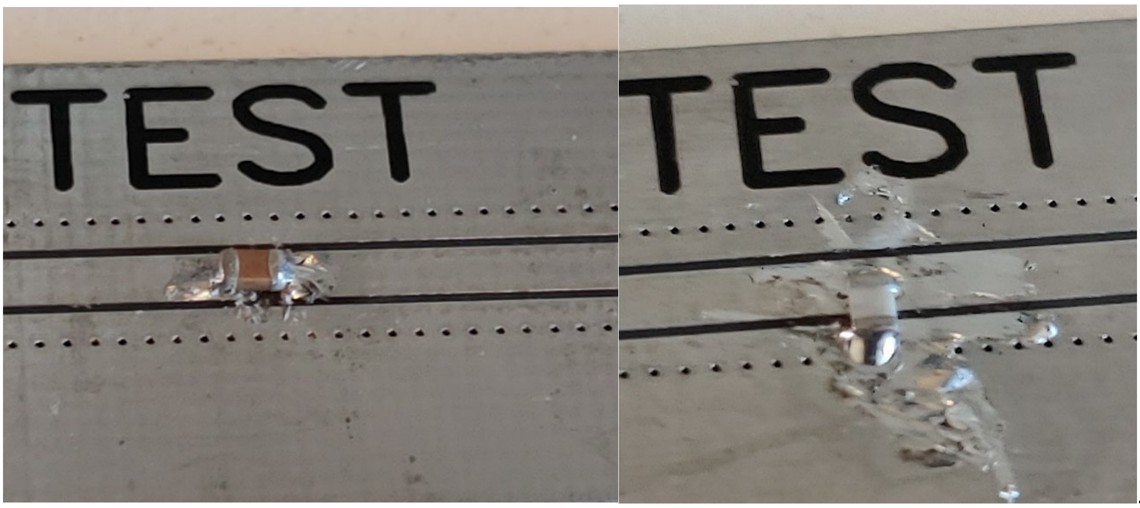


*Figure 4 Closeup view of the mounted capacitors. The center trace is cut on the left demo board and the series capacitor is soldered across the cut. A 500fF capacitor is soldered between the center conductor and the ground on the right demo board.*

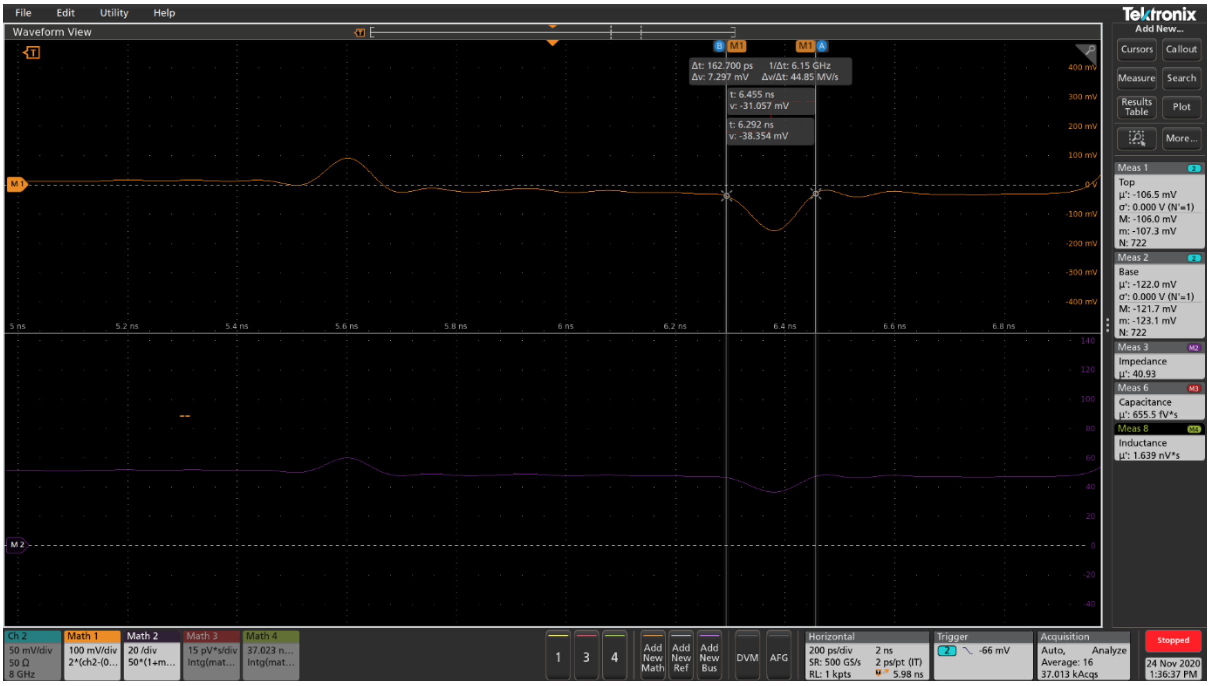


*Figure 5 The capacitance equation is entered into Math 3 in the oscilloscope and measurement function M3 displays the equation result, evaluated between the cursors. The negative "blip" indicates a capacitor, and the M3 measurement function displays 655fF, within the* ± *200fF tolerance of the capacitor.*


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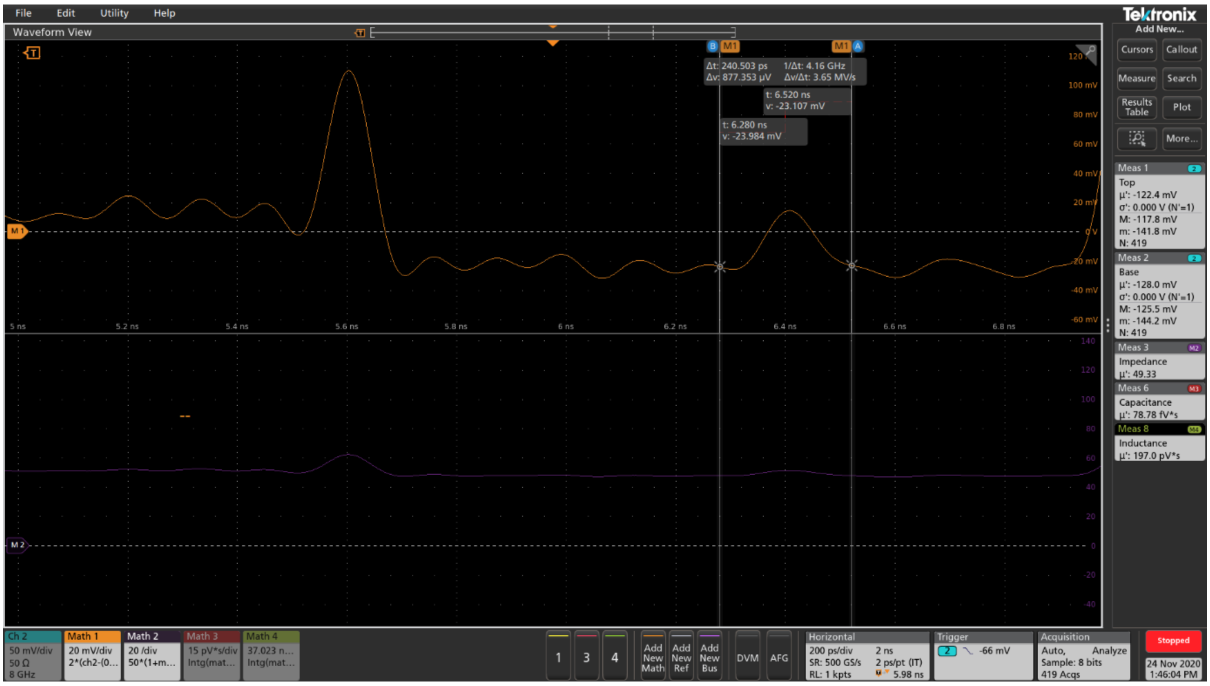


*Figure 6 The inductance equation is entered into Math 4 in the oscilloscope and measurement function M4 displays the equation result, evaluated between the cursors. The positive "blip" indicates an inductor and the M4 measurement function displays 197pH. The larger "blip" to the left is the inductance of the P2104A, 100mil pitch TDR probe.*

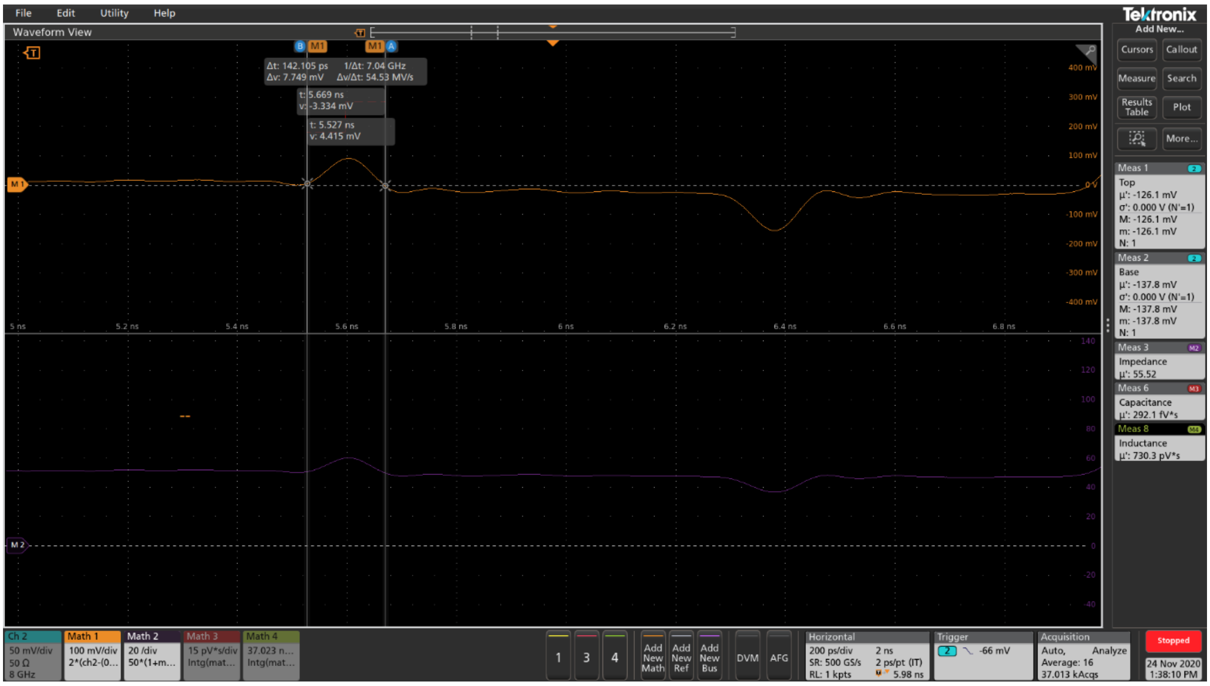


*Figure 7 Using a P2104A 60mil pitch TDR probe, the cursors are placed at either side of the positive "blip" created at the probe tip. Using the M4 measurement function, the probe tip inductance is displayed as 730pH*



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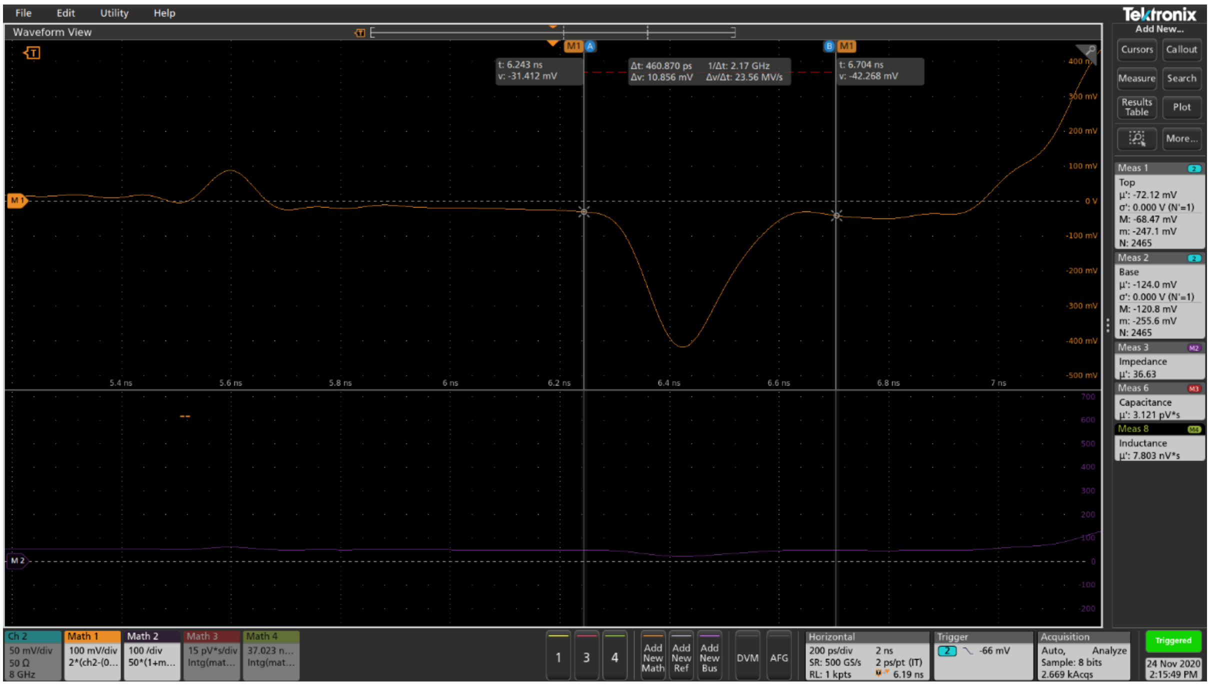


*Figure 8 The 550fF chip capacitor is replaced with a 3.3pF chip capacitor. Using a P2104A 60mil pitch TDR probe, the cursors are placed at either side of the negative "blip" created at the capacitor. Using the M3 measurement function, the capacitance is displayed as 3.12pF, within the 10% tolerance of the capacitor.*

## Conclusion

The TDR provided accurate measurements of a 500fF capacitor and a 280pH inductor. In both cases the signal to noise ratio was good and the traces were clear. This suggests that it is possible to measure even smaller values of inductance and capacitance.

## Tips for Better Measurement

- A single measurement trace is used, which is the TDR trace connected to CH2. Maximize the signal to noise ratio of this channel by making the waveform fill the window as much as possible and include trace averaging.
- The setup file includes the pulse voltage, reflection coefficient, the impedance and the capacitor and inductor calculations. Disabling unused traces will provide better viewing of the desired waveform. Be sure to turn off the display, do not delete the math functions. Maximize the SNR BEFORE turning off the channel display.
- The capacitors were soldered at the middle fo the demo board, allowing clean lead-in and lead-out traces to minimize reflections near the measurement.
- Smaller pitch probes provide higher bandwidth, which allows a sharper measurement.


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## References

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